REMOTE SENSING APPLICATIONS IN VEGETATION MAPPING WITH SPECIAL REFERENCE TO THE LANGEBAAN AREA, SOUTH AFRICA

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ABSTRACT

Interpretation of remote sensing products as a procedure used during the process of vegetation mapping has developed from a purely visual process of image identification to one which can utilize computerised methods to aid consistent identification of vast quantities of digitally stored/recorded spectral information.

A description of the Landsat satellite system which is currently providing imagery to potential South African users in the form of digitally stored data and photographic products is given and sources of digital spectral data at other than satellite scales of resolution are described. A brief description of some image processing systems already operational in South Africa and being utilized for land cover mapping is also included.

An introduction to the concept of computer analysis of numerical spectral data is given. The difference in approach between workers interpreting geological or other surface features as opposed to those wishing to simplify an image into categories is emphasized. This explains the local effort being expended on development of computer 'classification' routines as opposed to other methods of computer based image processing in vegetation mapping.

The first paper presents a review of current use of remote sensing products in vegetation mapping in South Africa and the potential of more recently available products and processes in this field. The relative merits of different film types is discussed, as is the problem of scale of survey, scale of remote sensing product and scale of final mapping. The position that computer analysis of spectral data occupies in a scheme designed to show the relationships between different scales of survey is described.

The second paper describes an example of the application of computer classification techniques to Landsat data in mapping vegetation in the Langebaan area, South Africa, at a semi-detailed scale of operation. The results of this exercise are illustrated together with a map produced using visual air photo interpretation techniques, backed by field checking.

More detail of the specific relationships between plant community structure, canopy cover, scale of survey and reflectance values in the map classes produced is then given in the third paper. Computer classification matches well with major structural

divisions; finer structural sub-division descriptions of sample plots correlate well with floristic divisions. A combination of digital analysis of remote sensing products and field checking based on structural schemes is recommended as a rapid mapping process.

A report compiled on the full range of investigations carried out up to the end of 1980 into the usefulness of various remote sensing products for studying and mapping the Fynbos Biome is included. The overall mapping objective of this investigation was to determine the extent of the Fynbos Biome and of the major landuse types within it. It was decided that the 'reconnaissance' level of operation at 1:250 000 final mapping scale is best suited to meet the overall mapping objective.

General conclusions are drawn as to the current status of remote sensing applications in vegetation/land cover mapping in South Africa and elsewhere. Developments and refinements in techniques subsequent to the carrying out of the investigations reported in this account are briefly discussed.

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PREAMBLE

South Africa was involved in the ERTS-A programme (Landsat initially called ERTS) in 1972-1973, in the form of a project entitled "To assess the value of satellite imagery in resource evaluation on a national scale" (Malan 1973). Investigators then worked with poor quality third and fourth generation 70mm positives and negatives, and used visual interpretation of features on these products. Subsequently the emphasis has moved internationally from purely visual or image oriented interpretation of spectral imagery to numerical or computer assisted analysis techniques.

The Fynbos Biome Project, initiated in 1977, is one of several programmes within the National Programme for Environmental Sciences, administered by the CSIR. The project has base-line objectives which include "the definition of the geographical distribution and extent of the major vegetation types of the biome" (Kruger 1978). The work reported on here was initiated in an attempt to meet this objective; particularly as it coincided with the development of an Image Processing System at the University of Cape Town (CATNIPS). It represents a small portion of the early work done and formed part of the early experimentation into the application of computer classification techniques to Landsat 1 imagery for vegetation mapping purposes.

These experiments in the south west Cape were carried out at a 'semi-detailed' mapping scale (Edwards and Jarman 1972). The capabilities of the local image processing system had not been extended to cope with 'compressing' satellite digital data into larger units for mapping at different scales. Subsequently it has been decided to complete the fynbos mapping programme at a 1:250 000 (reconnaissance) scale as it best utilizes the satellite data (Jarman, Bossi and Moll 1981).

However, the flexibility of the digital data is an important factor. If it can be shown to be effective at various scales of operation, it will be useful to a management oriented user.

This report therefore deals with the detail of a mapping operation at a particular scale, but attempts to place it in perspective to general vegetation mapping using remote sensing techniques. The topic cannot be dealt with in isolation, because 'success' or 'failure' of a technique in a particular application does not demonstrate universal applicability/non-applicability of the technique.

PART I GENERAL INTRODUCTION

1.1 LANDSAT TECHNICAL DETAILS

The first of the Landsat series of satellites was launched in 1972. This marked the development of space-craft borne multi-spectral scanner systems with the capability of providing repetitive global coverage, considerable sensor spectral range and covering extensive areas. It has also meant the provision of a volume of data on a scale never previously available.

The Landsat satellites collect data globally in a uniform way. The characteristics of the satellites which allow for this are:

1. A near polar orbit, which allows for covering the entire earth's surface.
2. A sun-synchronous orbit, which means that all areas of the earth's surface are viewed essentially at a mid-morning hour ($\approx$ 09h45 local time). This means a nearly uniform angle of illumination.
3. Carrying a multi-band sensor, which allows for calibrated measurements.
4. Twenty passes over a specific geographical area each year.
5. Uniformity of calibrated measurements.
6. High altitude (900 km), and therefore small scanner system deflection.

(Fleming and Hoffer 1977).

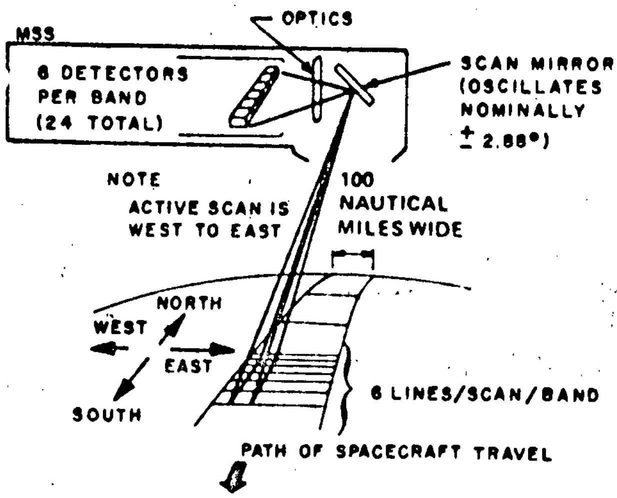
The satellite orbits at an altitude of 900km. The basic scanning arrangement of the Landsat system, the Landsat ground coverage pattern and typical ground trace for one day are shown in Figure 1.1 (from NASA 1972).

The Landsat 1 satellite originally carried two sensing systems; the Return Beam Videcon (RBV) and the Multi-spectral Scanner (MSS). The selected channels for the RBV were:

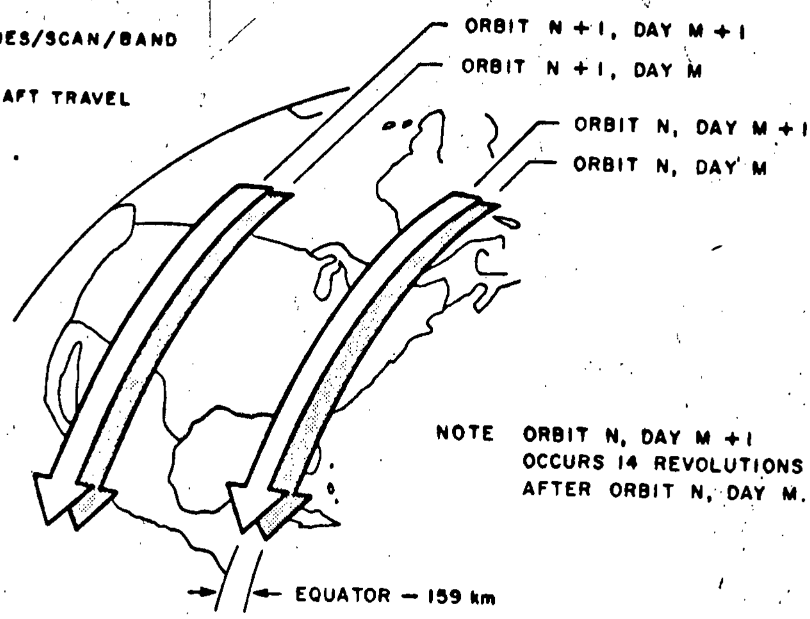
0,475	-	0,575 μm	(blue-green)
0,580	-	0,680 μm	(green-yellow)
0,69	-	0,83 μm	(red and infra-red)

The three channels were focussed for 100 percent overlap.

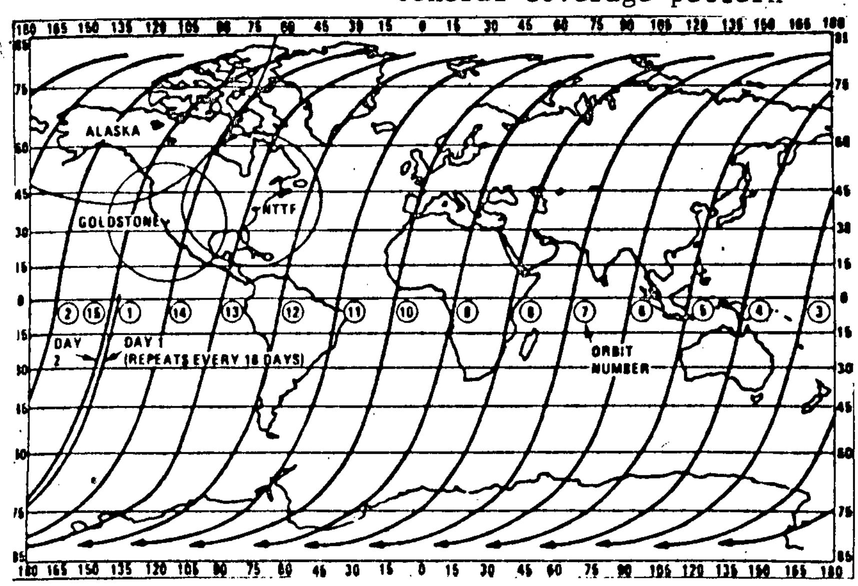
This system generated some data of excellent quality initially but was shut down due to high energy consumption (Lintz and Simonett 1976).



Scanning arrangement



General coverage pettern



Typical ground trace

Figure 1.1 Scanning arrangement, general coverage pettern and typical ground trace for the Landsat system (after NASA 1972).

The second sensor is a multi-spectral band scanner which measures energy in the range from 0,5 to 1,1 μm. Table 1.1 indicates the bands and their corresponding wavelength regions.

Table 1.1 Scanner parameters for the Landsat MSS data

Band	Wavelength μm	Calibration factor (milliwatts/cm^2 - sr)
4	0,5 - 0,6 (green)	2,48
5	0,6 - 0,7 (red)	2,00
6	0,7 - 0,8 (near I-R)	1,76
7	0,8 - 1,1 (near I-R)	4,60

The scanning technique employs an oscillating plane mirror and covers a path 185 km in extent with each scan. The effect of the scanning is to divide a scene into a rectangular grid of small cells, 56 x 79m in extent (pixels or picture elements) and the radiance for each pixel for each wavelength is measured and recorded. Digital counts are recorded, but can be converted to radiance values as indicated in Table 1.1.

An additional thermal infra-red channel (10,4 - 12,6 μm) with a spatial resolution of 240m is scheduled for inclusion in later satellite systems.

Figure 1.2 is an illustration of portion of the electro-magnetic spectrum, showing where the Landsat bands fit in. The quantity of reflected solar energy detected by Landsat is determined partially by atmospheric conditions and the physical characteristics of the biotic and abiotic components of the ground-cover under surveillance. Atmospheric aerosols, water vapour and dust do attenuate reflected radiation both spectrally and temporally; however these effects are minimised on clear days. Physical surface characteristics such as texture, shape, moisture content and colour of individual components of the ground-cover affect the quantity and intensity of their spectral reflectance. The effects that various ground-cover components have on their reflectance depends on the frequency or wavelength of the radiation concerned. Such effects are illustrated in Figure 1.3 which shows generalized reflectance curves for three basic land-cover features (water, healthy green vegetation and soil) in the spectral region covered by the Landsat MSS.

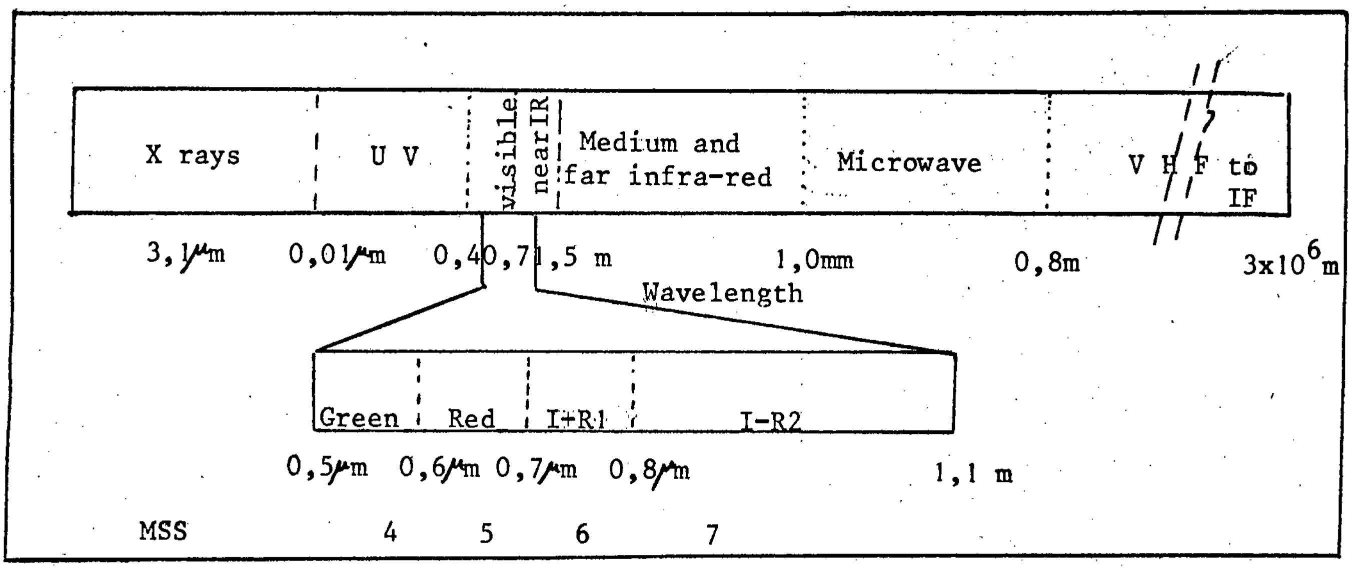


Figure 1.2 Portion of the electromagnetic spectrum

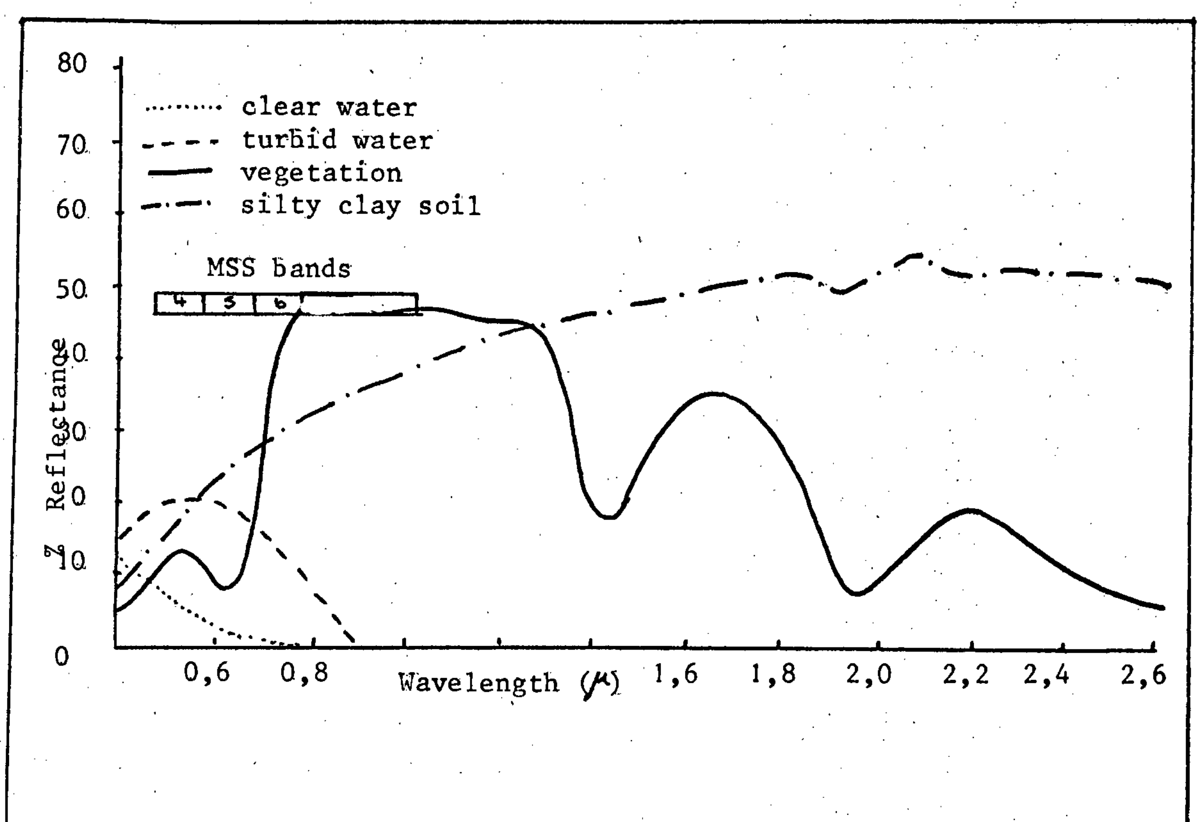


Figure 1.3 Generalized reflectance curves for three basic land cover types

The properties of the Landsat multi-spectral scanner system which make it so useful for detection of land cover surface features are:

1. Identical geometry in each channel, achieved by beam splitting, leading to close geometric congruence (band-to-band registration within one picture element or pixel). This greatly facilitates computer pattern recognition studies and the production of three-colour image combinations, using three channels or ratios of channels.
2. High radiometric fidelity – a characteristic typical of multi-spectral scanners but not of either RBV or cameras.
3. Wide range in recorded grey-scale values (wide dynamic range), considerably greater than that available in black and white photography in the same bands. This wide dynamic range is divided into 256 equal grey-scale steps, a number far in excess of the corresponding value for film recording. The digital tapes therefore include many data lost when film recording is used.
4. Digital data record in x-y format, readily and directly usable for computer processing. The digital tapes are thus referred to as CCT's (computer-compatible tapes).

(Lintz and Simonett 1976)

Multi-spectral satellite products from Landsat can be obtained as photographic output from computer optronics processing in the form of single wave band black and white photo prints, black and white negatives, 3-band false colour composites and 3-band false colour transparencies.

1.2 OTHER SOURCES OF DIGITAL DATA

Aerial photographs can be digitized by using a scanning microdensitometer to convert the photographs to a digital format. This can provide users with units of digital information (numeric values corresponding to grey scale categories recorded on black and white imagery, or intensity on colour or other photo products) of varying size; with resolution as large as 0,50 metres. (Scoggings personal communication).

Alternatively aircraft borne MSS systems can be employed to acquire digital data at aircraft levels of resolution. The advantages of using aircraft for specific purposes over limited geographic areas to record the MSS data are that the band widths can be adjusted to meet specific requirements.

1.3 IMAGE PROCESSING SYSTEMS

Satellite data is received at a ground station, processed and delivered to users in the form of CCT's and/or photographic images. It then has to be converted into information of use, i e it must be interpreted in some way.

For photographic products this amounts to visual pattern recognition processes; and the image processing is done by eye. For CCT's, processing is done by or employs digital image processing techniques.

Digital image processing involves three main branches:

1. Image restoration processes which recognize and compensate for data errors, noise and geometric distortion introduced in the scanning and transmission processes.
2. Image enhancement processes which modify an image in order to alter the impact on the viewer.
3. Information extraction processes which utilize the decision making capability of computers to identify and extract specific groups of information.

(Sabins 1978).

Therefore an image processing system is essentially designed to cater for images in the form of CCT's from a variety of sources in digital form. The digital format of the data allows for flexible manipulation with the aid of computer processing techniques.

A user's manual for a particular system provides an overview of the general working and capability of the system. For example, the University of Cape Town Image Processing System (UCT IPU) is designed to cater for images from a variety of sources; namely: Landsat 1, 2 and 3 satellites, NOAA 4 and NOAA 5 weather satellites, and the CZCS (Nimbus-G) oceanographic satellite. The use of any of a large selection of processing modules to produce output allows the user to better understand and analyze his data.

Output from image processing systems is dependent on the sophistication of the system. It can be on line printer, photographic negative or viewed on a TV interactive system.

1.4 COMPUTER ANALYSIS OF DIGITAL DATA

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

The processing involved in analyzing digital data has been categorized above. In vegetation mapping, classification is implied. When faced with a highly processed, precision corrected, edge enhanced photographic product from Landsat data, a vegetation mapper is readily able to identify features but is literally 'not seeing the wood for the trees'. Of the 20 000 hues which his eye is able to detect, he needs to 'group' these hues into perhaps $\pm$ 10 categories on the basis of some ground feature criteria. Classification techniques which simplify an image are utilized by vegetation mappers, as opposed to image enhancement processes which draw attention to detail.

Therefore the "information processes which utilize the decision making capability of computers to identify and extract specific groups of information" (Sabins 1978) are utilized.

The information extraction processes use computer classification techniques on two or more bands of the Landsat multi-spectral scanner (MSS) data. Processing of the multi-band image is made possible by recognizing and classifying the spectral signatures in their numerical form. Each pixel is assigned to a specific class by matching the spectral signature with the range of signatures determined for the class. The preprocessing leading up to the classification is geared toward locating and identifying representative groups of signatures called training classes and ensuring that they are sufficiently different to prevent confusion among them. This type of pattern recognition in digital image processing is statistical in character, and includes "statistical space" in which the "pattern" is a vector made up of a number of measurements, in an n-dimensional space, where n represents the number of MSS bands utilized. The pattern recognition system seeks to partition or place boundaries in the n-dimensional space so that each region of the image can be assigned to a class of patterns (Hajic and Simonett 1976). A mosaic of the image may thus be simplified into a manageable number of relatively homogeneous spectral classes.

There are two major methods of obtaining training classes. The first, referred to as the supervised approach (Hoffer 1972) involves locating individual pure areas of pixels on the image which represent a single cover type of interest to the user. This selection is based entirely on ground truth. These areas are used to obtain statistical training classes and the pixels in the image would be associated with one of the specified classes. In this way only the data describing the classes of interest is classified thus providing a final map of informational value. The disadvantage with this approach lies in misclassification of pixels as a result of overlap in spectral characteristics obtained from the natural variations in ground-cover.

In the second method, the unsupervised approach (Wacker and Landgrebe 1970), an algorithm is used to delineate groups of pixels within the sample that are spectrally similar in a representative sample from the image.

Ground-truth data is then used to relate these spectral classes to features on the ground. This method is particularly useful in a heterogeneous scene in which the likelihood of observing several adjacent pixels of the same cover type is low.

A hybrid approach involves locating several areas which together represent the different cover types on the image. Each area is then processed as in the unsupervised approach to identify the training spectral classes. A choice based on ground-truth is made to decide which of the classes are valid and a final classification is then obtained from the statistical data of the chosen classes.

The technique used in unsupervised approaches utilizes an iterative clustering algorithm to create classes which can then be used to furnish a maximum likelihood classifier with the required data input. The iterative clustering algorithm used by the UCT CATNIPS system is based on the ISODATA technique of Ball and Hall (1965) and the Bayesian Maximum likelihood classifier used as described by Shlien and Goodenough (1973b).

As the clustering algorithm is iterative, it uses a considerable amount of computer time and is consequently expensive. To minimize computer expenses, the procedure used to classify large areas involves the selection of one or more representative training sets which are iteratively classified in order to obtain discrete spectral signatures for input into the Bayesian classifier.

PART II. FIRST PAPER: REMOTE SENSING IN VEGETATION MAPPING IN SOUTH AFRICA

M L Jarman, N G Jarman and D Edwards

2.1 ABSTRACT

Effective use of remote sensing techniques for vegetation mapping and monitoring is a function of scale, resolution, season of imagery, kind of vegetation, sensor and spectral sensitivity, processing of the remote sensing product and speed and precision of transfer of information into a map product.

The usefulness of types of data collected from a remote location for vegetation mapping is described. Various types of aerial photographic products usually obtained from aircraft altitudes optimize spatial resolution, and visual interpretation techniques are generally employed. Digital products recorded and stored on computer compatible tapes, from both aircraft and satellite altitudes, optimize temporal aspects and particular spectral characteristics and utilize numerical processing techniques.

Season of imagery and timing of photography can either enhance or mask features. In well vegetated areas the season of maximum contrast between dominant elements is the best season for imagery. In low cover areas season of maximum leaf standing crop is the best season to mask soil effects.

The general relationships between scale of study, scale of mapping and scale of remote sensing products are dealt with. The schemes dealing with those relationships appropriate to the South African situation both for visual and digital analysis are presented. A description of the type of remote sensing product and processing and the type of field exercise appropriate to each is described. The purpose of producing maps at each scale is also dealt with. The potential of imagery as a monitoring tool is discussed. Lack of repetitive imagery of any type to date has not allowed for the full investigation of this potential. Careful planning at a national level is necessary to ensure availability of imagery for monitoring purposes.

Map production processes which are rapid and accurate should be utilized. Computer processing of digital imagery has the advantage of the map production process being part and parcel of the whole automated operation.

An integrated approach to vegetation mapping and surveying, which incorporates the best features of both visual and digital processing, is recommended for use.

2.2 INTRODUCTION

"Remote sensing is the acquisition of physical data of an object without touch or contact" (Lintz and Simonett 1976). Effective use of remote sensing techniques for vegetation mapping and monitoring is a function of scale, resolution, season of imagery, kind of vegetation, sensor and spectral sensitivity, processing of the remote sensing product and speed and precision of transfer of information into a map product.

The field of remote sensing has expanded over the past thirty years from the use of small scale panchromatic photographs taken from aircraft primarily for trigonometrical work, to a wide variety of remotely sensed products taken from various platforms, from helicopters to spacecraft, used in many disciplines.
In this paper the potential of a variety of products available to South African users and the processing facilities available will be discussed in the context of vegetation science.

The current awareness by planners of the important role that vegetation plays in maintaining a stable environment has created a demand for vegetation mapping and monitoring at various scales. The majority of these surveys can be more efficiently and accurately done with the aid of remotely sensed products.
However, although air photographs have been widely used as support products in vegetation studies in this country, there have been few published studies into the comparative effectiveness of different products for specific purposes. Most workers have had one film or remotely sensed product made available to them, or, at best have been in a position to order a particular product because of prior knowledge of its effectiveness. This paper attempts to bring together information on various remote sensing products and the processing of them which would be relevant to vegetation science workers.

In any vegetation study the problem, or aims and objectives, must be clearly defined prior to embarking on the study, and especially before obtaining any remote sensing products.

If a map is to be used to illustrate the results of a vegetation survey the amount of information to be gathered by fieldwork and from remote sensing media should be applicable to the final mapping scale. It is essential to understand the relationships and differences between the terms 'scale of survey', 'scale of mapping' and 'scale of remote sensing' (Küchler 1967; Edwards 1972a). The scale of remote sensing and mapping is entirely dependent on the scale of survey, which is dictated by the problem which has to be solved and how the results are to be presented. For purposes of convenience vegetation surveys have been grouped into five major classes:

1. General and general-reconnaissance surveys
2. Reconnaissance surveys
3. Semi-detailed surveys
4. Detailed surveys and studies
5. Ultra-detailed surveys and studies
(after, Edwards 1972a; Edwards 1972b; Edwards and Jarman 1972).

It is implicit in the interpretation of remotely sensed products for vegetation mapping purposes that a classificatory process is involved (Webb 1954). This emphasizes an important distinction between the approach of a vegetation mapper and a geologist mapping geological surface features. The geologist is trying to enhance images for <u>detail</u>, whereas the vegetation worker is aiming to simplify the detail into manageable categories - or classify ground cover types on certain criteria.

It is essential that the nature and requirements of the classificatory process being applied is clearly understood. For vegetation survey, the view taken here is that the properties of the vegetation should be the primary criteria for its classification.

The chief vegetational criteria by which vegetation has been classified, singly or in combinations, are physiognomy/structure and dominance, floristic composition and successional relationships. Again, scale of survey, scale of mapping and scale of remote sensing product determine the classificatory process used. Non-vegetational criteria such as habitat and geomorphology are used where vegetation units may not be the prime consideration, such as in land use surveys.

When discussing scale in this paper, large scale includes scales of from 1:20 000 to 1:10 000 and larger, and small scale includes scales of 1:20 000 to 1:3 000 000 and smaller.

With the current availability of remote sensing products, use of which will be described in separate categories in the following account, it is highly recommended that an integrated approach to the use of remote sensing products be adopted. This implies a particular discipline and order in the collection and recording of all levels of data - from precise (co-ordinate identification) location of sample sites in the field; corresponding location of field sites on remote sensing products; choice of size of sample site (it might well be necessary to take a series of nested samples); recognition of the level of detail to collect at different scales; use of different products or processing throughout an area in order to highlight different features of the area; and storing of data in a grid system which could be used by other workers in a variety of disciplines. It is also necessary that nationally acceptable and applicable classification systems should be adopted for describing extant vegetation or land cover samples. There has recently been a system devised for the structural characterization of vegetation in the Fynbos Biome (Campbell et al 1981), which has produced encouraging results when compared to vegetation map units produced by classification of Landsat imagery in the Langebaan area (Jarman Part IV- this report).

2.3 REMOTE SENSING MEDIA FOR VEGETATION SURVEYS

The procedure adopted in producing a vegetation map can be broken down into three basic steps; data collection, interpretation and product generation (Fleming and Hoffer 1977). Two basic approaches to vegetation mapping are the image oriented system and the numerically oriented system (Landgrebe 1973). Both approaches utilize data collected from a remote location. Aerial photography is usually obtained from aircraft altitudes, optimizes spatial resolution, and is recorded on photographic film. Multispectral scanner (MSS) data are recorded and stored in digital or analog format on computer compatible tapes. Temporal and wavelength characteristics are optimized and data are collected from both aircraft and satellite altitudes.

2.3.1 Photo products for visual interpretation.

2.3.1.1 Panchromatic prints

South Africa has complete aerial photographic coverage in panchromatic film at scales from 1:20 000 to 1:75 000. These photographs are available from the Director of Trigonometrical Survey Office in Pretoria. Photographs of this type are used primarily for trigonometrical work, but have also provided a basis for most vegetation mapping carried out with the aid of remote sensing media, in South Africa.

Panchromatic photographs are not as efficient, or as accurate for some interpretation projects as certain other media, but these have often to be used in the absence of more suitable media.

They have good tonal contrast in comparison to monochrome prints, with the human eye being able to distinguish 200 tones of grey.

2.3.1.2 Infra-red black and white prints

Another air photograph product, in black and white print form, is the modified infra-red photograph. This film is sensitive to near infra-red wavelengths (i.e. 0,83 - 1,1 microns) as well as the visible wavelengths, but not thermal infra-red. If only infra-red wavelengths were recorded, shadows would be black, whereas detail in the shadows is visible in modified infra-red with red and green light present and blue light excluded by a filter.

Objects with high infra-red reflectance, such as plants which reflect infra-red from the cellulose cell walls (Blythe and Kurath 1968), show up in light tones, while objects with high infra-red absorption, especially water, show up black making this medium ideal for mapping vegetation in swampy areas. Black and white infra-red photography was used extensively for forest inventories in North America, before more sophisticated media became available, as the different types of timber trees could be recognized by their differing infra-red reflectance signatures (Jensen and Colwell 1949, Schulte 1951, Stellingwerf 1969). Very successful vegetation studies were also made using black and white infra-red photography (Ives 1939, Schulte 1951).

Useful qualities of infra-red film are its penetration of haze and its detection of free water surfaces which show up pitch black (Spurr 1960). Haze penetration is of particular importance in tropical areas where atmospheric moisture decreases the clarity of normal panchromatic photographs.

2.3.1.3 Colour aerial photographs

Experiments carried out overseas produced conflicting results about advantages gained from the use of colour prints for vegetation studies. Mott (1966), Anson (1969) and Goodier and Grimes (1970) all state that colour photography gives no added information over panchromatic photography for vegetation studies, while

Becking (1959) and Heller et al (1964) found colour to be advantageous. Goodier and Grimes (1970) suggest however, that not enough basic research has been done to show final conclusions.

Colour has been tried and proved useful. Its major advantage lies in assisting interpreters who do not have a wealth of experience, as they are able to recognize patterns on hue as well as textural differences and site factors, and not merely on slight tonal variations, textural differences and site factors as in use of panchromatic products (Duddek 1967). The eye can detect 20 000 different hue variations compared with a mere 200 tonal variations (Evans 1948). Photo hues also correspond very closely to the actual vegetation colours on the ground, which facilitates recognition of species. The disadvantages of this film type are that flying conditions, due to its inability to penetrate haze, and the processing, are more critical than panchromatic film and the cost is higher.

Colour transparencies have better resolution than colour prints (Welch 1968) and possibly colours are more readily standardized as there are fewer processing steps. Transparencies, however, are inconvenient for fieldwork as they require a light table for viewing and annotation is more difficult. A field apparatus for viewing transparencies has, however, been described by Wear (1960). The major disadvantages with this product are that there is no negative master copy so that the transparencies cannot be duplicated with ease.

2.3.1.4 Colour infra-red

Colour infra-red photographs, also termed "false" colour photographs, record the same wavelengths as the black and white infra-red but different dyes in the film are sensitive to the different wavelengths which create different hues on processing (Smith 1968, Stellingwerf 1969). Hues on this medium represent the following hue image features on the ground. The red image colours on the photographs represent all objects on the ground with high infra-red reflectivity such as active vegetation; ground features with red and green hues are represented by green and blue photograph image hues respectively, while objects with blue hues are excluded from the image by using a blue filter.

The use of the longer wavelengths improves haze penetration, which gives photo images sharp boundaries, thereby improving resolution and making this medium useful for very detailed work. Because of its haze penetration properties this film can be used to great effect in high level photography (Pease and Bowden 1969, Pease 1970).

Colour infra-red film has been claimed by overseas workers to be ideal for vegetation studies (Anson 1969, Colwell 1967, Driscoll 1971). Anson (1969) claimed that twice the detail could be retrieved on this film type than from panchromatic or even colour film. The use of this film medium is claimed by Lauer (1968) to decrease interpretation time by 25 percent, while Haack (1962) however was, after statistical analysis, not convinced of the overall advantage of this medium. The various claims for this film type cannot be evaluated unless the particular problem for which it is to be used is clearly defined.

2.3.1.5 Multi-spectral photography

A comparatively new product is multi-spectral photography described by Yost and Wenderoth (1968) and Smith (1968). Light reflected from various objects is recorded by wavelength separately on black and white film. The separation of light into the various wavelengths is done by using a number of lenses each with a different filter combination. Pictures are then reconstituted by superimposing the different black and white transparencies.

Being able to select the various wavelengths to be recorded makes this an extremely versatile medium (Malila 1968, Ross 1971).

The multi-spectral approach has great potential for analyzing vegetation and recognizing vegetation patterns, and has been used in a number of studies. The Landsat series utilizes a multi-spectral system as one of its two systems for recording data.

Depending on the scale used this type of remote sensing can detect individual species (Weber 1966) or make inventories of large areas (Lent and Thorley 1969). This process is available in South Africa but has not been used for general vegetation mapping from aircraft levels of resolution apart from brief experimental natural resource studies of vegetation.

Multi-spectral satellite products from Landsat 1 and 2 in the form of single wave band black and white prints, black and white negatives, 3 - band false colour composites, and 3 - band false colour transparencies are all available at any suitable scale of any specified portion of a Landsat scene (185 x 185 km) from the

Satellite Remote Sensing Centre (SRSC). The standard products of a whole Landsat scene (185 x 185 km) are issued as 1:1 000 000 scale, 1:500 000 scale and 1:250 000 scale products (18,5 cm; 37,0 cm and 74,0 cm sizes).

Specially processed high quality Landsat black and white or colour composite imagery can be obtained from the same source. Enhancement includes haze removal, de-striping, edge enhancement and correction of systematic errors, all following standard procedures. UTM grids can also be provided. The absolute geographical accuracy of grids depends on how well the satellite orbital parameters are known, but it is generally better than ± 15 kilometres. It should be noted that no ground control points are used.

Precision geometric correction using ground control points can also be performed on Landsat imagery within the Republic of South Africa where 1:50 000 survey maps are available. Under favourable conditions geographic accuracies of better than one 80 metre by 80 metre picture element can be obtained. Similar precision geometric corrections can also be performed on Landsat imagery outside the Republic of South Africa if the user can provide 1:50 000 maps of the particular area.

Imagery processed on a non-standard way to meet the particular requirements of specific experimental projects in remote sensing may be provided dependent on the operational workload of the SRSC and subject to negotiation with the Council for Scientific and Industrial Research (CSIR).

2.3.1.6. Other photographic media

Other remote sensing products include K-band radar (Morain and Simonett 1967), Lewis and Waite 1973) and thermal infra-red imagery (Colwell 1967, Sabins 1973). Neither of these have been successfully applied to vegetation mapping and appear better suited to geological applications.

The 1:10 000 black and white ortho-photo product produced by the Directorate of Trigonometrical Survey is also available for specific areas. These are maps produced from 1:30 000 scale black and white photos. They are paper products, not available as stereopairs, but have contour intervals of 5 metres drawn in on them. In areas where they are available, they are a tremendous asset to field location of sites and are generally a practical product to use in the field.

2.3.2 Digital imagery for computer-aided analysis

The emphasis internationally in the use of remote sensing imagery for mapping purposes has swung away from purely visual or image oriented interpretation of data, to numerical, computer assisted classification techniques. These fall within the general heading of digital image processing.

Image processing can be regarded as any operation carried out on an image once it has been recorded on some medium. Recording of spectral reflectance from a portion of the electromagnetic spectrum in digital form allows for flexible manipulation of data with the aid of computer processing techniques. Digital image processing comprises three main branches:

1. Image restoration processes which recognize and compensate for data errors, noise and geometric distortion introduced in the scanning and transmission processes.

2. Image enhancement processes which modify an image in order to alter the impact on the viewer.

3. Information extraction processes which utilize the decision making capability of computers to identify and extract specific groups of information (Sabins 1978).

Visual interpretation of imagery in the form of photo products is equivalent to information or feature extraction processes when applied to digitally stored spectral information.

The information extraction processes use computer classification techniques on two or more bands of multi-spectral scanner (MSS) digital data. Processing of the multi-band image is made possible by recognizing and classifying the spectral signatures in their numerical form. Each picture element (pixel) is assigned to a specific class by matching the spectral signature with the range of signatures determined for the class. The preprocessing leading up to the classification is geared toward locating and identifying representative groups of signatures called training classes and ensuring that they are sufficiently different to prevent confusion among them. This type of pattern recognition in digital image processing is statistical in character, and includes "statistical space" in which the "pattern" is a vector made up of a number of measurements, in an n-dimensional space, where n represents the number of MSS bands utilized. The pattern recognition system seeks to partition or place boundaries in the n-dimensional space so that each region of the image can be assigned to a class of patterns (Hajic and Simonett 1976). A mosaic of the image may thus be simplified into a manageable number of relatively homogeneous spectral classes.

2.3.2.1 Landsat computer compatible tapes

Since January 1981, Landsat imagery has been directly received in digital form on computer compatible tapes (CCT's) at Hartebeeshoek Satellite Remote Sensing Centre. Digital imagery dating back to 1972 when the first Landsat satellite (ERTS - A) was launched is also obtainable via the Satellite Remote Sensing Centre, from NASA. MSS Landsat data is recorded in four bands on computer compatible tape for units called pixels (picture element 56 x 79 m or 0,44 ha). The wavelengths of the bands are:

Band 4	(Green)	0,5 - 0,6 μ
Band 5	(Red)	0,6 - 0,7 μ
Band 6	(near I R)	0,7 - 0,8 μ
Band 7	(near I R)	0,8 - 1,1 μ

Processing of this digital imagery is being carried out for vegetation/land cover/land use mapping purposes at the Satellite Remote Sensing Centre; at the National Physics Research Laboratory (NPRL), Council for Scientific and Industrial Research (CSIR), using the VICAR system on an IBM system 370/158 (see Fink and van Zyl 1977); at the University of Cape Town on a UNIVAC 1100 Model 18 Computer (see Cape Town Image Processing System (CATNIPS) Manual); and at the Department of Survey, University of Natal on a UNIVAC computer. (see Portable Image Processing System (PIPS)).

2.3.2.2 Digitized air photos

The Satellite Remote Sensing Centre has the facility to digitize standard air photos on request. This is done by scanning the photo with a scanning microdensitometer and recording the grey scales from black and white imagery, or colour intensity on other imagery in digital form. Scoggings and Ward (personal communication) are involved in a vegetation study of the Kuiseb river region, using imagery which has been processed in this way. All the techniques of digital processing carried out on Landsat products are relevant to these digitized products. They provide a superb interface between satellite imagery and air photos, and between visual interpretation and computer analysis feature extraction processes.

2.4 SEASON OF IMAGERY - TIMING OF PHOTOGRAPHY

As maximum information on remote sensing imagery is associated with maximum contrast on the ground, remote sensing products should usually be made at the time of maximum vegetal contrast on the ground. This time of contrast varies, depending on climate and structure of the vegetation.

In grassland, in South Africa, maximum contrast, in the visible wavelengths would be in the autumn period of April and May, when the different grass species take on their autumn colours prior to being bleached by the winter climate. Similar results are reported by Driscoll (1971) in America. The exact time for ideal photography will, however, vary from year to year depending on local variation in the rainy season.

If it were necessary to make the imagery at a less favourable time, such as during mid-summer, when all grasses appear a uniform green, it is possible to change the remote sensing medium from, for example, colour prints to infra-red colour prints, or multi-spectral photographs where the possible difference in species could be detected using additional infra-red wavelengths or a particular section of the electromagnetic band.

If, however, the aim were to detect shrubs and trees in open woodland, remote sensing products should be made when contrast between shrubs and trees and grass is maximal, which would probably be prior to the trees losing their leaves, when perhaps the grass is dying back, or after the first flush of spring, when the trees' leaves are green, but the grass is still its winter yellow colour.

Repetitive imagery from Landsat 1 and 2 has shown the effect of seasonal change in obscuring or enhancing certain patterns in the landscape. In summer imagery over the summer rainfall region of South Africa vegetative growth masks certain cultural features, yet enhances some geological features. In winter, evergreen vegetation is clearly separated from seasonal vegetation, whereas in summer the differences are less marked as there is less contrast. The timing of imagery is therefore dependent entirely on the aim of the particular project.

Work done by Jarman (Part IV, this report) on digital imagery in the Langebaan area, and by Lane (1980) on digital imagery in the Verlorenvlei area has revealed an interesting aspect of the importance of seasonal variation. With good cover West Coast Strandveld (Acocks' Veld Type 34) communities (> 70 percent projected canopy cover) in the Langebaan area, summer imagery provides greater distinction between the drought deciduous elements (losing leaves in summer) and the evergreen elements. However, further north at Verlorenvlei, as the ground cover drops to values of 5 - 25 percent, summer imagery containing the drought deciduous elements gives no distinction from the background soil characteristics. It would appear that in the lower cover categories (below 50 percent ground cover), the time of maximum leaf standing crop is the best time for vegetation mapping. In good ground cover areas (> 50 percent) the time of maximum contrast between dominant elements should be chosen.

Time of the day at which imagery is taken is also important. Careful selection of sun angles can utilize shadow to enhance features. Photographs taken at midday in some areas can also introduce a haze problem. The Landsat satellite orbit is sun-synchronous, and the satellite passes over a particular area at the same time of the day at each pass. However, throughout the year, the sun angle is changing all the time. Thus repetitive Landsat imagery can reveal/enhance certain features because of the changing sun angle. This is an advantage when it comes to enhancement for feature extraction purposes - but a disadvantage when change detection is the main objective.

2.5 SCALE OF SURVEY, SCALE OF MAPPING AND REMOTE SENSING

Küchler (1967) stresses the relationships between the scale at which the survey is planned, the final mapping scale and the scale of suitable remote sensing products. Different scales of survey will detect different types and sizes of vegetation pattern. The survey scale hence indicates the degree of precision at which the vegetation is studied, recognized and described. Table 2.1 is not intended as a rigid system, but is a suggested system relating these three factors.

The major groups of scales of survey with their inherent restrictions as to field methods of vegetation analysis and scale of remote sensing products are presented in this table. Scale of remote sensing products is usually larger than the mapping scale.

The remote sensing product contains more information than is actually required on the map. The scale difference is in order to make boundaries as accurate as possible. It does mean, however, that for mapping, much of the information on the remote sensing product has to be classified into major types to make the map easily intelligible.

The classing of survey scales given in Table 2.1 based on Edwards (1972b) is one of many similar classifications. However, it has been designed for specific use in South Africa. It is appropriate to visual interpretation of photo-products.

Table 2.2 (from Jarman, Bossi and Moll 1981 - Table 3.1) relates to the use of computer classification procedures as applied to Landsat digital imagery.

It gives a breakdown of selected scales of mapping based on Table 2.1, giving the minimum size of map unit recognized at each scale, and what this means in terms of the number of pixels involved in classification in each instance.

In the Jarman, Bossi and Moll (1981) study involving computer classification of digital data it was decided to limit investigation to four scales of operation, namely:

1. detailed (1:10 000)
2. semi-detailed (1:20 000)
3. semi-detailed (1:50 000)
4. reconnaissance (1:250 000)

These four scales of operation were selected because of the availability of maps, standard air photo products, and orthophoto products at these scales.

2.5.1 General and general reconnaissance surveys

The purpose of these surveys is to ascertain the major classes of vegetation at regional and sub-regional landscape levels and the main climatic, soil and biotic relationships (biomes). Major extensive functional processes prevailing in the ecosystems involved, such as the main plant successional trends, or retrogressions, leading to prevailing climax, sub-climax and disclimax types would be identified. These surveys are based on either general observational data or on indeterminate stand data, that is, sample plots without a specific size, such as those in Acocks' method (Acocks 1953). Mapping scales used to show the distribution of vegetation are at 1:1 000 000 or smaller. The value of such surveys is for general and

Table 2.1 General relationship between scale of study, scale of mapping and scale of remote sensing product using visual interpretation techniques (after Edwards and Jarman 1972)

Scale of Survey	Aim	Final Map Product Scale	Appropriate Air Photo Product Scale	Appropriate field sampling procedures
General and General Reconnaissance	Ascertain major classes of vegetation at regional and sub-regional landscape levels	1 : 1 000 000 or smaller	1 : 500 000 – 1 : 1 000 000	Descriptive, non-defined non-regular samples usually recording physiognomic types
Reconnaissance	Determine the main plant communities/ecological relations within regions or sub-regions	1 : 50 000 – 1 : 1 000 000	1 : 40 000 – 1 : 500 000	Non-regular samples, low density of plot samples recording structural types & dominant floristics
Semi-detailed	Investigation of physiognomic/structural and floristic structure of communities and habitat relations	1 : 10 000 – 1 : 50 000	1 : 5 000 – 1 : 20 000	Defined samples, moderately high density, recording structural types and total floristics
Detailed	Study of structure and function of community or part of community	1 : 500 – 1 : 10 000	1 : 5 000 or larger	Intensive quantitative sampling on defined plots
Ultra-detailed	Study within community species/species group/habitat relations	1 : 500 or larger	1 : 500 or larger	Intensive quantitative sampling on defined plots/species

Table 2.2 Relationship between map scale, smallest recognizable map unit (in ha) and number of spectral units used in numerical classification of digital remote sensing data (from Jarman, Bossi and Moll 1981).

Final map scale	Smallest map unit recognized = 2 print characters		Units used in classification	
	No. of pixels	(ha)	No. of pixels	(ha)
General and General Reconnaissance >1 : 1 000 000	3 200	1 408,0	1 600 (40 x 40)	704,0
Reconnaissance 1 : 250 000	200	88,0	100 (10 x 10)	44,0
Semi-detailed 1 : 50 000	8	3,5	4 (2 x 2)	1,8
1 : 20 000	2	0,8	1	0,4
Detailed 1 : 10 000	1	0,4	1	0,4
Ultra-detailed <1 : 500	Beyond the limits of resolution of current Landsat series			

regional planning and for determining problem areas requiring further investigation. The map products would be prepared for those in the planning and administration levels.

For such surveys the obvious choice of remote sensing product to detect the main landscape vegetation patterning is small, of the order of that obtained by high altitude, ultra wide angle photography and satellite imagery. Photo scales used are thus 1:500 000 or smaller.

At these scales stereoscopic coverage is often not possible. The Landsat Return Beam Videcon and MSS do overlap sideways sufficiently for stereoscopic viewing (Lintz and Simonett 1976). Stereoscopy at this scale, however, is often not even required as these images are required only as mosaics.

The remote sensing medium, by nature of the distances involved, between 'sensed' surface and recording surface, must be highly sophisticated, and the accepted forms are multi-spectral imagery as well as active and passive radiometric methods, whose images may be displayed in the form of a computer print-out.

The application of computer classification techniques to compressed Landsat digital data at this scale would not be suitable. Compressing information into 40 x 40 pixel blocks at a 1:1 000 000 scale of operation would lose too much information (Jarman, Bossi and Moll 1981).

Maps resulting from these surveys, at scales of about 1:1 000 000, cover large areas and delimit major vegetation types. The usual approach to this type of mapping would be either from combining information from larger scale maps or from photographic images at extremely small scales, such as the photographic imagery from Landsat 1 and 2, which is commonly available at a scale of 1:1 000 000.

The only vegetal detail to be considered at this level would be gross physiognomic types, which are often associated with major geographical divisions as expressed by Drued (in: Cain and Castro 1959), for example; equatorial forests and monsoon forests, or recognizing only the vegetation formation types like forest (Fosberg 1961). These vegetation maps are not based on any detailed fieldwork.

African maps produced for these purposes include the AETFAT Vegatation Map of Africa, South of the Tropic of Cancer (Keay 1959), at a scale of 1:10 000 000 and a map at a scale of 1:4 000 000 by Pole Evans (1936) of the Vegetation of South Africa.

The best known map of the vegetation of South Africa is that by Acocks (1953) at a scale of 1:1 500 000. This map represents an exception to the general rule for surveys at these scales, as the vegetation classification is based on floristic data and site type criteria from 'samples' which provides unusual detail at this level of survey. On every landscape type, or area within the same farming potential, Acocks (1953) recorded all the species present and their abundance, and on this his Veld Types were based. In this case the information was initially mapped at 1:500 000 and then reduced to 1:1 500 000 to give a more concise picture and a more practical and manageable map.

2.5.2 Reconnaissance surveys

The purpose of these surveys is to redefine and confirm more accurately the main classes of vegetation established by the general surveys, but specifically to determine the main communities. Ecological relationships in terms of habitat and biotic relations, and functional community processes such as plant succession, are investigated in greater detail for the main plant communities. Such surveys may be based upon lists of species from non-defined samples, or on a low density of sample plots within the main community types that are defined by relatively gross physiognomic, floristic and ecological criteria. Mapping scales are from 1:1 000 000 to 1:50 000. Appropriate air photo scales for visual photo interpretation in such surveys are between 1:40 000 and 1:500 000, obtained from fairly high altitude and wide angle air photography.

At the smaller scale stereoscopic cover is not necessary, but at the larger scales it becomes desirable to assist in more detailed interpretation.

The photographic products of small scale vary from sophisticated satellite-borne media, such as multi-spectral imagery and radiometric methods, to infra-red false colour for high-level photography (scale 1:150 000). The only larger scale photo products, which have until recently been available, are panchromatic film or infra-red colour photography. Colour photography is not usually recommended due to the problem of haze penetration making colour photography impractical.

In areas where cloud cover is virtually continuous and atmospheric moisture level is extremely high, as in Nicaragua (Crook and Kyle 1972) and Panama (Crandall 1969) in Central America, radar has been used as a remote sensing device which can penetrate cloud to give imagery for this scale of survey.

Use of computer classification procedures of feature extraction on digital imagery at this scale of operation is ideal. Compressing the spectral information to a 10 x 10 pixel matrix, with each unit used in the subsequent processing being 44,0 ha in extent, results in a computer print out map product which is approximately 1:250 000 in scale. This is an ideal scale for operation due to the availability to all potential users of 1:250 000 Topographic and Topocadastral series produced by Trigonometrical Survey for the whole of South Africa.

Jarman, Bossi and Moll (1981) found that the reconnaissance scale of operation best utilizes the digital satellite data, as the classification routines involved compress the spectral information into manageable proportions. The returns on time and the amount of field control work necessary to produce a satisfactory classification are very good.

The final map product of this scale of survey is between 1:1 000 000 and 1: 50 000, while remote sensing products would be at scales of 1:500 000 to 1:40 000. This would require a reduction in scale of between 10 and 2,5 times from the remote sensing image to the map.

The classification of vegetation used here remains general with divisions on gross criteria such as major physiognomic formations being recognized, together with qualifying floristic data in terms of major dominance types. This type of mapping has been used extensively in areas where basic resource surveys of developing countries were required to enable initial apportionment of an area for efficient land utilization.

The field information required to produce maps of this type is based on a low density of actual samples. This means that communities recognized have a type situation where some method of vegetation analysis was applied and a number of these type situations were grouped to give a vegetation classification. The community type is then associated with its aerial photo image and, often, a site type and an overall picture is obtained of the vegetation by annotating recognizable vegetative communities. This scale of survey is carried out by the Directorate of Overseas Surveys, United Kingdom (Aitchison et al 1972), with vegetation communities such as Acacia raddiana tree and shrub savanna, Boswellia Woodland/Tree savanna being recognized.

This scale of survey has not been much used in South Africa, possibly as air photography in South Africa was, until the late 1950's, taken at scales of 1:20 000 and 1:30 000 only. Acocks' Vegetation map, although published at a scale of 1:1 500 000 and therefore grouped as a General or General Reconnaissance Survey, contains detail sufficient to be classed as a Reconnaissance Survey.

2.5.3 Semi-detailed surveys

These have the objective of discerning, defining and investigating vegetation upon the basis of the plant community. The physiognomic and floristic structure of the community and its habitat are determined by analysing circumscribed sample plots. Mapping of the plant communities is at scales from 1:10 000 to 1:50 000. This corresponds approximately to the medium scale of the Directorate of Overseas Surveys, who recognize scales from 1:25 000 to 1:125 000 as the medium scale limits, but with an emphasis on 1:50 000 (Read et al 1973). These surveys are of major importance in defining, classifying and studying community and habitat relations from quantitative or semi-quantitative data. They provide also the main classificatory reference framework for ecosystems from which the extrapolations and predictions provided by more detailed studies can be made. They are the type of survey upon which most management procedures of an area are based. Appropriate air photo scales for such surveys are from 1:5 000 to 1:20 000, for upon these air photograph scales can be determined the various plant communities, and measurement of vegetation density and cover can be made with reasonable accuracy appropriate to the scale of survey. However, where some photo scales are not available, use can be made of 1:30 000 to 1:40 000 scale photos for devising appropriate sampling strategies and tactics, as well as for the final mapping of the vegetation.

The main remote sensing product used in the past was panchromatic prints. This level of survey is, however, ideally suited to colour photography.

The emphasis in this scale of survey is on a moderately high plot sample density which records vegetation pattern at an Association level (Shimwell 1971), and air photos are important in all phases. As they are especially important in the field, positive transparencies are impractical.

Stereoscopic coverage is essential at this level of survey to increase accuracy of visual interpretation and, thereby, use the imagery to its maximum advantage.

There are a number of classification methods which may be used to group vegetation into classes at this scale. The methods most commonly used are physiognomic/floristic (dominants) ones similar to the previous survey scale, but the pattern of vegetation recognized is finer.

Floristic methods too may be applied effectively to classify vegetation. Computer classification techniques applied to Landsat digital imagery can be utilised at this scale of operation, but must be based on good ground truth and precise location of samples using ground control points. One of the benefits of digital Landsat imagery is its versatility when it comes to scale of operation. It can be used from a map scale of 1:20 000 to 1:250 000, and the units of resolution can be adjusted to meet the requirements of each scale of operation. At a semi-detailed level of investigation single pixels are used as classification units (Jarman, Bossi and Moll 1981).

These techniques were applied with some success at a semi-detailed level of investigation in the Langebaan area (see Jarman and Jackson Part III - this report). In this study, the map units defined were structural units and not floristic ones.

Computer classification of digitised standard air photo products would be more appropriate to this level of survey, in that the floristic differences which are not always discernible from satellite imagery become so on air photo products of 1:20 000 and larger.

2.5.4 Detailed surveys

These have the purpose of studying in detail the structure and functioning of one or more of a group of closely related plant communities (or ecosystems). Such surveys are based on intensive quantitative sampling of vegetation and environment and mapping is at scales larger than 1:10 000. The results of these surveys can be extrapolated and predicted on the basis of the classificatory reference framework provided by the semi-detailed and coarser surveys.

Air photograph scales that are used must be larger than 1:5 000 so as to allow species of trees and large shrubs to be recognized, measurements of heights, density and cover of the strata plants to be made, and large scale mapping to be done.

This scale of survey provides the largest range of possibilities for using remote sensing techniques. Standard panchromatic and colour prints may be used for a synoptic view, fieldwork, and orientation within a particular area. For better definition, positive transparencies, especially of the infra-red colour type, may be used. Enhancement of certain features requires multi-spectral photography.

Radiometric methods, such as radar, may be also used. These methods provide information in various forms, especially computer compatible tapes, but thus far have not often been used.

The scale requirements of the various products are varied and the platforms required to raise the remote sensing instruments vary from aircraft, helicopters, balloons (Rosetti 1963, Whittlesey 1970) to booms and ladders (Whittlesey 1966, Pierce and Eddleman 1970), while in the other survey scales vertical and stereoscopic products of remote sensing are required in order to give photogrammetrically correct images. In detailed work some recordings may be made from oblique angles, where, although scale is variable and stereoscopy often not possible, the desired detail is obtained (Harris and Haney 1973).

The object of carrying out detailed surveys is usually not merely to record the position of plant communities, or individual plants, depending on the particular scale, but to study community or individual form and function. There are usually other measurements required and the map is merely to record where, and in what state, the vegetal components are at a particular time.

Methods of studying and classifying vegetation are often quantitative at this level of investigation, though other methods such as the Braun-Blanquet approach can be used, provided the desired pattern of vegetation is reflected in the communities recognized.

Although computer classification of Landsat data can be carried out at these levels, using single pixels as classificatory units, it is at the limit of resolution for this imagery.

Again, the digitization and classification of air photoproducts would be more appropriate.

2.5.5 Ultra-detailed surveys

These surveys consist of detecting patterns of within plant community species groups - sociability ratings - microhabitat species specificity, and microhabitat structural/ functional relationships, phenological studies, linking to ecophysiological approaches, biomass estimates, etc. Remote sensing platforms are essentially ground-based, e.g. tethered balloons, frames, ladders, etc., and ground sampling is intensive and quantitative. Succession can be monitored after fire, and measurements are made directly off the photos. Stereoscopy is helpful in the instance of wanting to make direct measurements off photos, but not essential. There are techniques of taking pictures from directly above, and at right angles to the sample site from which measurements can be made (Adams, personal communication). Imagery is not used in ultra-detailed studies to the degree that it should be. As a permanent record at a moment in time it cannot be bettered.

2.6 MONITORING VEGETATION CHANGE

The objectives of vegetation monitoring must be defined so that appropriate choice of techniques can be made. For instance it is necessary to know what must be measured and what degree of detail and precision is required: height, cover, density, or productivity of dominant or certain species; growth form; community or regional changes, or small sample plot changes. The regularity of recording of imagery to meet these requirements must be ascertained, i.e. when and how often should measurements be made? Finally, careful consideration must be given to what ground observation requirements for calibration and verification are necessary in order to make the appropriate choice of remote sensing product and interpretation technique.

Once the objectives have been defined, then the appropriate scale of operation can be selected and the appropriate type of remote sensing product must be motivated for. Monitoring something like normal regional habitat change would require, for example, Landsat imagery taken at yearly intervals. Monitoring incidence of and extent of fires on a regional basis would require at the minimum seasonal coverage, and preferably coverage as regularly as it becomes available during the fire season. At the theoretical best this is once every eighteen days for Landsat imagery.

At the scales for which processing of digital Landsat data is best suited (1:50 000 to 1:250 000), provided the various programme parameters are kept constant and cloud cover percentage controlled, once a scene has been processed for one date, change can readily be detected on subsequent dates. It is not necessary to define what the change is in terms of precise detail, but to identify where it is for subsequent field checking would be sufficient advance. Work done in the Langebaan area has shown the strong link between plant community height, canopy cover, type of substrate and spectral map class (Jarman Part IV - this report). Incidence of normal successional changes in plant communities will not be easy to detect, but the incidence of dramatic changes in canopy cover and height of dominant strata due to accelerated erosion, fire, brush-cutting, clearing of areas for development, etc. will be readily monitored.

2.7 AVAILABILITY OF IMAGERY

The importance of this cannot be stressed sufficiently. In South Africa, imagery available to all users not requiring special motivation is the standard black and white panchromatic product produced by Trigonometrical Survey.

For its own purpose of mapping the country at a scale of 1:500 000, the office of the Director General of Surveys plans to cover the Republic with panchromatic photography at a contact print scale of 1:50 000 in approximately ten year cycles. The first cycle was initiated in 1971. They are currently also conducting experiments with 1:150 000 photography for the purpose of monitoring changes. Depending upon the nature and scale of changes detected, it will be decided whether or not additional second cycle photography at 1:50 000 is required. This means that areas subject to rapid development will probably be re-flown at 1:50 000 earlier than static areas, and ultimately of course, more often.

Other photography is organised and supervised by the Director General of Surveys on the following basis:-

1. Areas for which orthophoto mapping has been requested and approved are flown at 1:30 000 specifically for the production of the orthophoto maps, at a scale of 1:10 000;
2. Black and white photography requested by other Departments, such as Department of Agriculture & Fisheries, is normally flown at a scale of 1:30 000 or 1:40 000;

3. Special jobs at other than the scales mentioned above and including colour photography are considered individually and treated according to merit.

The whole air survey programme, including both photography required for the Director General of Surveys' own mapping work and any requested by other Departments, is considered by the National Advisory Survey Committee. The size and content of the programme approved by the committee depends largely upon available funds, and the motivations submitted by other departments.

As can be seen from the foregoing it is most unlikely that the major established conservation areas will be included in areas flown on a routine basis, because, by their very nature, they are areas of zero, or very limited, development or change. The scale of routine photography (1:50 000 or 1:150 000) has so far in any case proven to be of limited value for interpretation and mapping of vegetation, even for transfer to base maps at 1:50 000 (Bands 1978).

Availability of Landsat imagery to date, prior to direct reception from Hartebeeshoek, was sporadic to say the least. Within the study carried out on Fynbos Biome mapping, of the 15 Landsat images needed to cover the whole Fynbos Biome geographic area only 12 were available for the whole of the 1972/73 period. (Bossi, personal communication. It was not possible to investigate either monitoring of habitat change or effects of season on vegetation mapping from the available imagery in the investigation carried out by Jarman, Bossi and Moll (1981). Even with direct, regular reception, availability of imagery remains a problem. Cloud cover is a problem, especially along coastal and mountainous areas. Fraser and Curran (1976) report on two hypothetical satellite survey missions in which the success of the first mission requires at least one observation of the entire 185x185km² field of view without cloud, and the second permits viewing whatever cloud free areas exist. On successive satellite passes new cloud free areas may appear, and a mosaic of the field of view can thus be assembled.

The results of this theoretical exercise showed that the entire field of view could be seen on mosaicing with high confidence after 7 satellite passes, whereas the entire field of view could be seen with only 50% probability after the same number of passes. In fact 22 passes were needed for 90% probability of success.

This emphasizes the importance for informed national integrated planning when it comes to motivating for adequacy of scale of product and regularity of recording of imagery to be used in vegetation monitoring or seasonality studies.

2.8 MAP PRODUCTION

It is not intended to deal in any detail with the variety of photogrammetric instruments and approaches to cartography available to vegetation mappers. It suffices to say that the development of map categories, consistent identification of photo units in visual interpretation, and subsequent transfer of information on to a map presents the biggest obstacle to most workers - more often than not, maps are not produced.

Thus at the larger scales in semi-detailed work, tying large scale air photo products to digital processing at the map production stage is a very practical solution. It is also suggested that establishing contact with photogrammetric and cartographic units, and professional assistance at this stage saves time and money in the long run.

Computer classification of digital imagery has the advantage of the map production being part and parcel of the processing. Products can be viewed/photographed off TV screens; can be in map computer paper print-out form with suitable correction to scale as part of the processing; or can be in photo print form from computer optronics output. Again the latter can be produced at any desired scale.

2.9 SYNOPSIS OF AN INTEGRATED APPROACH TO VEGETATION SURVEYING AND MAPPING

The approach to use of remote sensing products for vegetation mapping can be broken down into three basic steps: data collection, interpretation and product generation. Developments in the techniques involved in interpreting imagery have tended to polarise the approaches into either image oriented approaches or numerically oriented approaches. Figure 2.1 from Fleming and Hoffer (1977) shows the interrelationships between the image oriented and numerically oriented system and the possible links between the systems.

Although both approaches utilize data collected from a remote location, the characteristics and format are different. The first step, or data collection, is covered in Section 2.3 in this report, which describes the products available to vegetation mappers either as aerial photographs, or digital products.

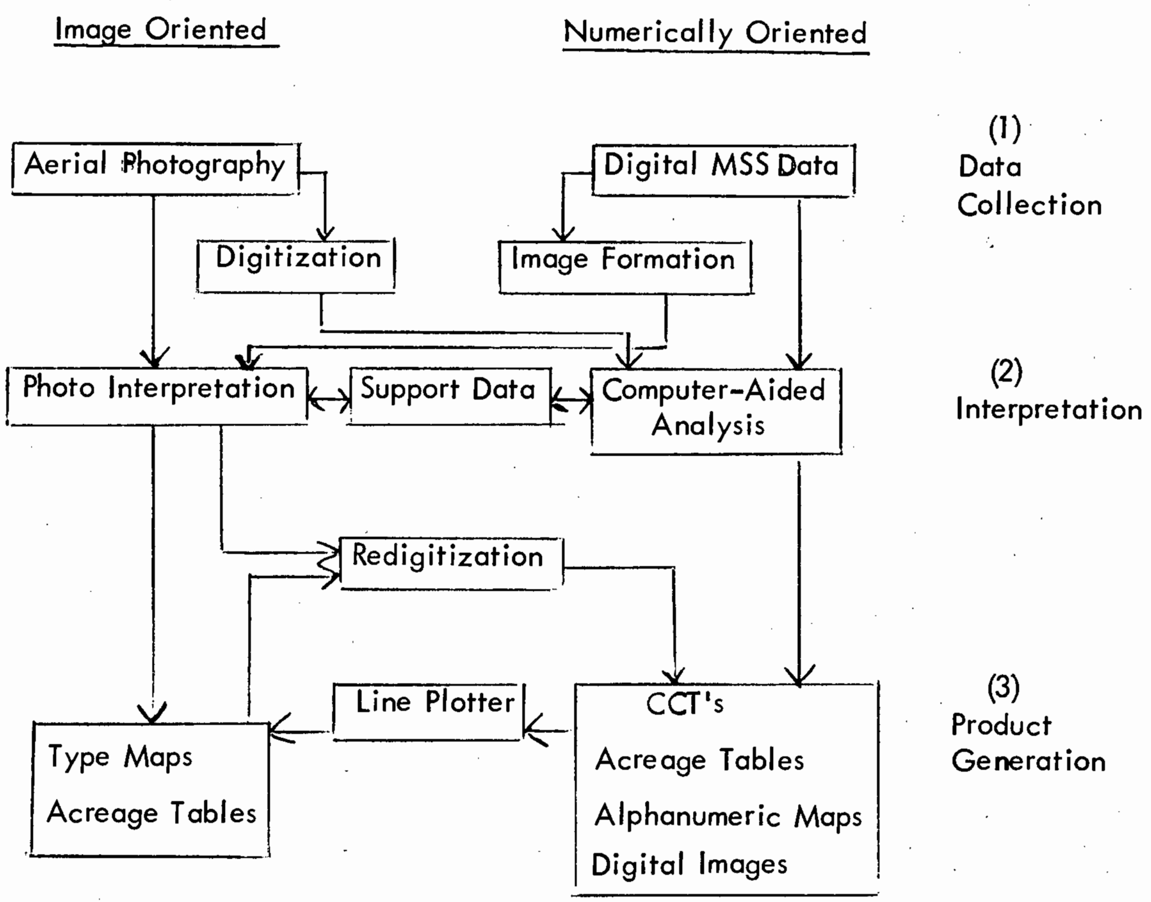


Figure 2.1 Interrelationships between the image oriented and numerically oriented system and the techniques of going from one system to the other (after Fleming and Hoffer 1977).

At the second step different approaches are used. Photo interpretation relies on trained interpreters to do the analysis by identifying and delineating the various vegetation types. Computer aided analysis techniques replace the repetitive steps of identification and recording of decisions with a computer, thus reducing bias and increasing speed (Bauer 1976).

The third step in both approaches is dependent on the feature extraction process. Product generation for the image oriented approach entails producing a map by transferring boundaries from annotated photo-units into a base map. Areas of features of interest are measured using dot grid or planimeter techniques.

In the numeric approach, the interpretation is recorded on CCT's as the decisions are made. Alphanumeric maps, digital images and estimates of map class areas are produced by computer algorithms that summarise data from the CCT's.

Figure 2.1 shows the interrelationships between the two approaches. Aerial photography can be digitized by a scanning microdensitometer to convert the photographs to a digital format. Conversely, digitized photographic or MSS data can be converted to an image on a TV screen or on photographic film. Once data have been displayed interactive systems allow for interpretation, redigitization and storing on CCT's. Map products from visual interpretation techniques can be digitized, stored and handled on CCT's (Boyle 1972 a and b). The reverse can also be achieved in that digital information can be presented as line type maps on a plotter system.

It is recommended that the best aspects of both approaches be utilized in a fully integrated approach to a mapping problem.

2.10 CONCLUSIONS

Plants are a measure of the conditions under which they grow and act as an index for soil and climate (Clements 1928). The fact that changes in vegetation occur is visible proof of the dynamic nature of the environment. It is necessary to be able to record and follow the vegetation changes in order to predict and determine and control any changes which could severely upset the balance of nature.

The various scales of surveys are required to provide planners with a complete picture. The small scale surveys at the general and general reconnaissance levels provide overall pictures of the global situation and modern satellite imagery can quickly and effectively monitor changes.

Regional surveys provide the information for broad policy determination and planning for areas which have similar problems.

The semi-detailed survey provides for resource management planning even down to the farm level.

Detailed surveys include studies for ecosystems. Knowledge of the structural and functional attributes of ecosystems provides the means whereby appropriate ecosystem management can be devised by the pasture or other applied scientist. The role of vegetation mapping is therefore of major importance.

Remote sensing products are desirable for most surveys at any scale. The advantage of having remote sensing products is that they provide a permanent record of a situation at a particular time. Differences may then be plotted over a number of years if so desired. There are certain areas which are inaccessible by normal transport and areas of this nature can best be surveyed using remote sensing techniques. In other areas, although it is possible to work without remote sensing, the rate of progress would be considerably slower and boundaries would not be as accurate as those given by the synoptic view. The time and effort saved in fieldwork offsets the additional cost of acquiring imagery.

Remote sensing products are therefore almost essential for survey work; however, their use should be restricted to situations where the information required can actually be obtained using this approach.

2.11 ACKNOWLEDGEMENTS

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PART III SECOND PAPER: USE OF LANDSAT DATA IN MAPPING VEGETATION AT A SEMI-DETAILED SCALE IN THE LANGEBAAN AREA, SOUTH AFRICA.

M L Jarman and A Jackson

3.1 ABSTRACT

A remote sensing project in the south western Cape aimed to determine the extent of the Fynbos Biome and of the major landuse types within it. This study forms part of an investigation into the usefulness of various remote sensing products in achieving this aim. In particular, available Landsat 1 multi-spectral scanner (MSS) data in the form of computer compatible tapes (CCT's) obtained from the National Aeronautics and Space Administration (NASA) via the Satellite Remote Sensing Centre (SRSC) at Hartebeeshoek were utilized. The development of the Cape Town Image Processing System (CATNIPS) suite of programmes at the University of Cape Town Image Processing Unit (UCT IPU) and the VICAR system at the National Physics Research Laboratory (NPRL), Council for Scientific and Industrial Research (CSIR), made the application of computer classification routines to this satellite data feasible.

The classification routines used in the two image processing systems are an iterative clustering routine based on the ISODATA technique (Ball and Hall 1975) and the Bayesian Maximum Likelihood classifier (Schlein and Goodenough 1973).

A study area in the Langebaan-Saldanha area was chosen on the basis of the availability of ground truth. Application of the classification routines to the MSS data resulted in a classification map which matched well with available ground truth and with a vegetation map produced from visual interpretation of colour air photographs backed by field checking of the annotated photo units.

3.2 INTRODUCTION

Fynbos is a broad category of heathland vegetation formations whose communities characteristically include growth forms of the restioid, ericoid and proteoid types (Taylor 1977). These comprise Acocks' (1975) Veld Types 47 (Coastal Macchia), 69 (Macchia) and 70 (False Macchia). The Fynbos Biome is a geographic area whose limits were set for the purposes of the Fynbos Biome Project as extending roughly from 31° to 35°S and 18° to 27°E. This encompasses the above Veld Types and also two transitional shrubland types 34 (Strandveld of the West Coast) and 46 (Coastal Renosterbosveld) (Day et al 1979), which are not true 'fynbos' communities.

This study forms part of an investigation into the usefulness of various remote sensing products in determining the extent of the Fynbos Biome and identifying and mapping its major vegetation components.

The Langebaan area (33°05'S, 18°E) was chosen as a training site within the Fynbos Biome as there was ground truth available to test the usefulness of Landsat 1 imagery for vegetation mapping. The vegetation of the Langebaan area was mapped by Boucher and Jarman (1977) using 1:10 000 standard colour aerial photographs, produced by the Department of Surveying, University of Natal, after a flight over the area on 26 March 1975 (Job 195). Comparison between this ground truth and computer analysis of portion of Landsat 1, multi-spectral scanner (MSS) image E - 10055-08064 taken on 16 September 1972, was carried out in this preliminary investigation, prior to extending mapping over the remainder of the Fynbos Biome. The product of this investigation also provides a base map for monitoring any changes in extent of various vegetation features using data from subsequent Landsat imagery provided the various parameters used in the classification routines, and the percentage cloud cover, are controlled.

3.3 METHODS

Standard air photo interpretation procedures were carried out using 1:10 000 scale colour aerial photographs in producing the vegetation map of the Langebaan area used as ground truth in this study (Jarman 1977). The annotated photographs were also available for detailed examination of features of interest.

Landsat 1 imagery was analyzed in this study using the CSIR/VICAR digital image processing system as implemented on an IBM system 370/158 and the UCT CATNIPS system as implemented on a UNIVAC 1100 Model 18 computer. Both these systems are general image processing systems which allow a variety of manipulations and analysis techniques to be applied to MSS data. For details of the VICAR system as implemented at the CSIR, NPRL see Fink and van Zyl (1977), and for details of the CATNIPS system as implemented at UCT see the CATNIPS Manual, UCT IPU.

Image processing can be regarded as any operation carried out on an image once it has been recorded on some medium. Landsat records spectral reflectance from a portion of the electromagnetic spectrum in digital form. This allows for flexible manipulation of data with the aid of computer processing techniques. Digital image processing involves three main branches:-

1. Image restoration processes which recognize and compensate for data errors, noise and geometric distortion introduced in the scanning and transmission processes.

2. Image enhancement processes which modify an image in order to alter the impact on the viewer.

3. Information extraction processes which utilize the decision making capability of computers to identify and extract specific groups of information (Sabins 1978).

The information extraction processes use computer classification techniques on two or more bands of the four band Landsat MSS data. Processing of the multi-band image is is made possible by recognizing and classifying the spectral signatures in their numerical form. Each pixel is assigned to a specific class by matching the spectral signature with the range of signatures determined for the class. The preprocessing leading up to the classification is geared toward locating and identifying representative groups of signatures called training classes and ensuring that they are sufficiently different to prevent confusion among them. This type of pattern recognition in digital image processing is statistical in character, and includes "statistical space" in which the "pattern" is a vector made up of a number of measurements, in an n-dimensional space, where n represents the number of MSS bands utilized. The pattern recognition system seeks to partition or place boundaries in the n-dimensional space so that each region of the image can be assigned to a class of patterns (Hajic and Simonett 1976). A mosaic of the image may thus be simplified into a manageable number of relatively homogeneous spectral classes.

There are two major methods of obtaining training classes. The first, referred to as the supervised approach, involves locating individual pure areas of pixels on the image which represent a single cover type of interest to the user. This selection is based entirely on ground truth. These areas are used to obtain statistical training classes and the pixels in the image would be associated with one of the specific classes. In this way only the data describing the classes of interest is classified thus providing a final map of informational value. The disadvantage with this approach lies in misclassification of pixels as a result of overlap in spectral characteristics obtained from the natural variations in ground-cover.

In the second method, the unsupervised approach, an algorithm is used to delineate groups of pixels within the sample that are spectrally similar in a representative sample from the image.

Ground truth data is then used to relate these spectral classes to features on the ground. This method is particularly useful in a heterogeneous scene in which the likelihood of observing several adjacent pixels of the same cover type is low.

A hybrid approach involves locating several areas which together encompass the different cover types on the image. Each area is then processed as in the unsupervised approach to identify the training spectral classes. A choice based on ground truth is made to decide which of the classes are valid and a final classification is then obtained from the statistical data of the chosen classes.

In this study unsupervised clustering techniques were applied to the MSS data for selected test areas (see Figure 3.2), to define training sets of spectral reflectance values for subsequent analysis.

An iterative clustering algorithm based on the ISODATA technique of Ball and Hall (1975) was applied to the standard untransformed Landsat data for each test area using single picture elements (pixels) as classification units. The classes obtained by this technique were then compared with units on aerial photography and the ground truth data. Slight parameter changes were made to optimise the fit of the data. When a satisfactory fit had been achieved, the data for the area were then used to train a Bayesian (Maximum Likelihood) classifier using a multivariate normal assumption for application to the whole of the study area. For a description of this technique see Shlein and Goodenough (1973).

As the clustering algorithm is iterative, it uses a considerable amount of computer time and is consequently expensive. The procedure described of selecting small test areas for the iterative processing minimizes computer expenses.

3.4 RESULTS

Application of the ITCLUS algorithm to 'representative' areas within the study area (scene ID E 10055-08064, 16 September 1972; start line 1173 - start pixel 1890; T1 + T2 = 10,5 + 7,0 respectively), resulted in the production of fourteen distinct spectral classes and two mosaic classes. Some of these classes are not related to the vegetation but reflect for example sand classes and water depth. The classification map based on these classes is shown in Figure 3.1.

Comparison of this map with the ground truth map of Boucher and Jarman (1977) in Figure 3.2 is made by depicting the map classes in each instance which are equivalent with the same shading. The original field samples were located as accurately as possible on the computer classification, in order to arrive at the equivalent map classes (see Jarman, Part IV - this report). Throughout this paper the Boucher and Jarman (1977) map class symbols A to M and computer spectral class numbers 1 - 14 are used.

Table 3.1 gives a breakdown of the computer classification map classes and their counterparts in the Boucher and Jarman (1977) floristically based vegetation map. The latter classes can be divided into five major physiographic categories: those occurring on unconsolidated dunes; those on consolidated dunes; those on limestone outcrops and ridges; those on coastal shelf sandy granitic locations and those in low-lying marsh situations. The sixteen computer map spectral classes can be divided into twelve structural/floristic vegetation units categorized on the basis of the scheme produced by Campbell et al (1981) for structural characterization of vegetation in the Fynbos Biome. These structural types are also named in Table 3.1. The remaining four classes are sand and water classes. The sequence of computer classes from top to bottom on Table 3.1 corresponds to increasing reflectivity in Band 5. Generally, active vegetation and water have low reflection values in Band 5, whereas bare, dry, non-vegetated areas have high reflectivity.

Classes 1 and 7 are deep and shallow water respectively. In the case of class 7, the underlying sand has an influence on the relative reflectivity of the cover class. Classes 11, 12, 13, 14, 4 and 2 correspond to map classes located in the marsh areas. The low reflection values in Band 5 are due to water-logged conditions with surface water often being present and to the closed canopy of vegetation. Class 11 corresponds to Mb - (*Cliffortia strobilifera*) and Mc (*Typha capensis*) forms of Dense

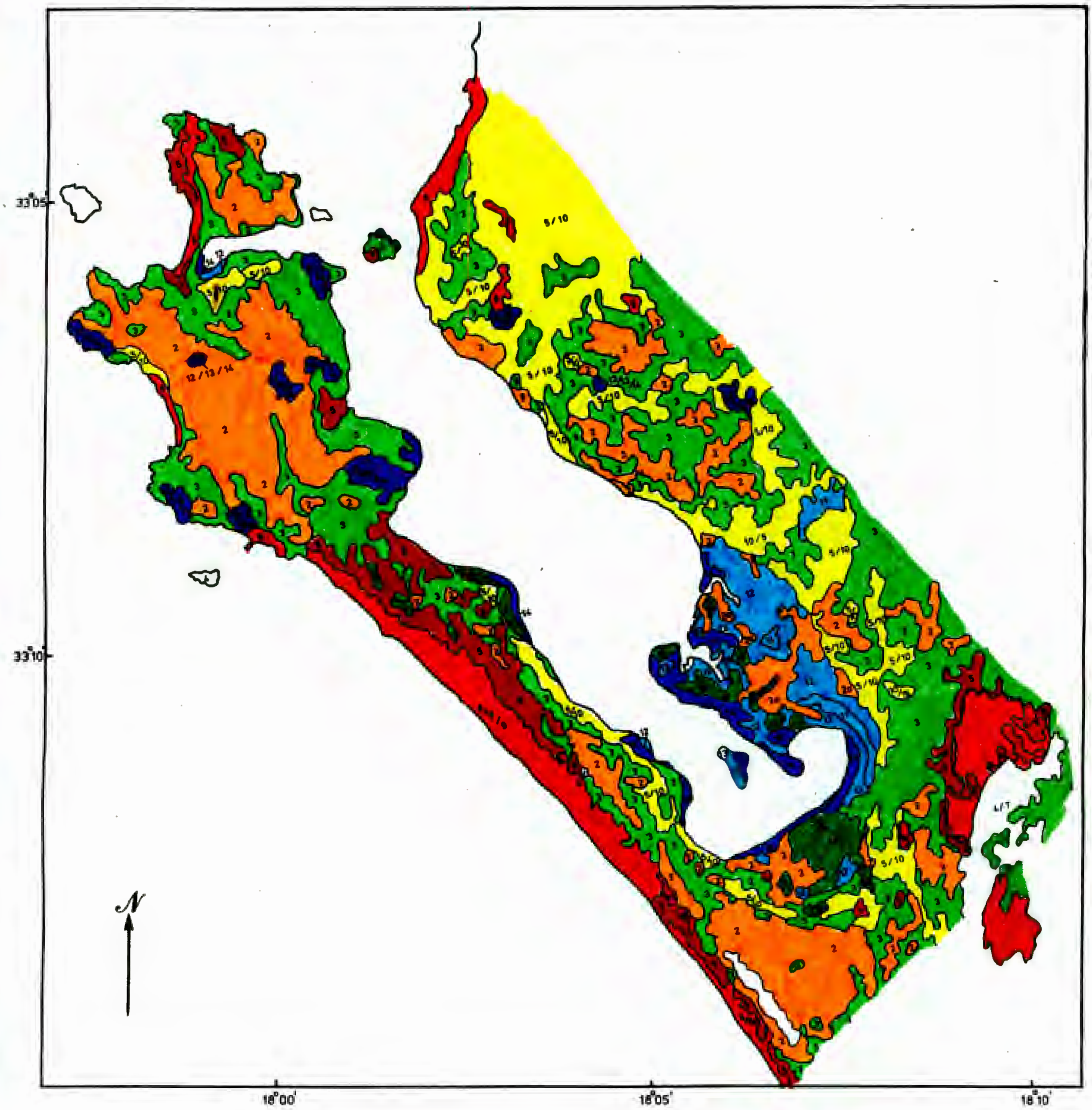

Figure 3.1 A 16 class computer classification of the vegetation of the Langebaan area. These classes are structural/ floristic vegetation classes; influenced by substrate and aspect

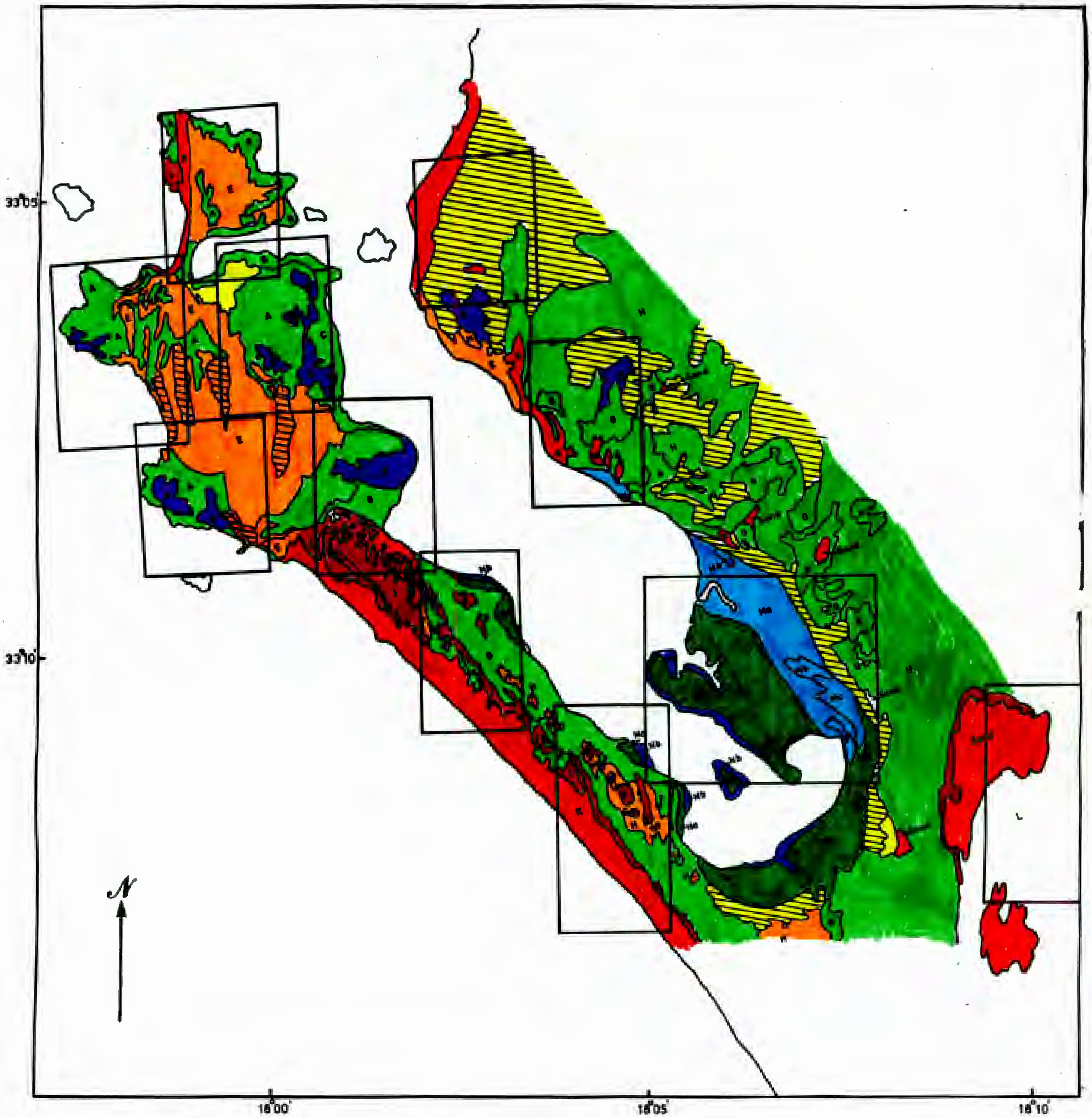

Figure 3.2 Vegetation map of the Langebaan area, produced by Boucher and Jarman (1977) from standard colour 1:10 000 air photographs, and field checking. The map classes are floristically based, but also carry a structural designation. (Test areas used in the computer analysis of Landsat data are indicated).

TABLE 3.1 A comparison of the computer generated classes with ground truth plant communities in the Langebaan Area, South Africa

Comp. Class No. (3)	Computer Class Description: Substrate	Average % Plant Cover	Average Height of Dominant Strata (m)	Plant Community Structural Type (2)	Landscape position	Air-photo identified plant community (floristic/structural type) (1)
1	Deep water	?100	?100	-		
11	Water-logged	100	3,0	Tall Closed Sedgeland	Flat lowlying marsh area	Mb - Cliffortia strobilifera form of Dense Sedgeland
11	Water-logged	85	2,0	Tall Closed Sedgeland	Flat lowlying marsh area	Mc - Typha capensis form of Dense Sedgeland
14	Surface water	100	0,14	Dwarf Closed Grassy Sedgeland	Edges of shallow water channels on flat marsh	Nb - Spartina - Triglochin form of Dense Dwarf Succulent Sedgeland
14	Surface water	100	3,5	Tall Closed Sedgeland	Edge of shallow & deep water channels	Md - Phragmites australis form of Dense Sedgeland
12/ 13/ 14	Granite boulder outcrops	71	1,5 3,0 0,4	Mid-high Mid-dense Shrubland with emergent trees & a Tall Sparse Grassland	Convex and shadow	D - Ehrharta - Maurocenia Hillside Dense Shrubland
13	Water-logged sand	0	0	-	Flat	
12	Water-logged sand	100	0,75	Low Closed Sedgeland	Flat raised marsh areas	Ma_1 - Juncus kraussii Dense Sedgeland
4	Some surface water - water-logged sand	95	0,08	Dwarf Closed Sedgeland	Flat raised marsh areas	Na - Limonium - Disphyma form of Dwarf Succulent Sedgeland
4	Moist site hollows	90	2,0	Tall Closed Restioland	Damp hollows dense canopy grey black image	I - Thamnochortus spicigerus Consolidated Dune Dense Restioland
2	Consolidated dune sand	50	1,0	Low Mid-dense/Open Evergreen Shrubland	Oblique - West	H - Willdenowia striata Consolidated Dune Dense Evergreen Restioid Shrubland
2	Raised dry marsh sand	70	1,0	Low Mid-dense Cyperoid Shrubland	Flat to Convex	Ma_2- Nidorella - Senecio Mixed form of Dense Sedgeland
2	Limestone outcrop on shallow sand	55	0,3 1,0	Low Mid-dense Evergreen Shrubland	Oblique - West	E - Nenax - Maytenus - Zygophyllum Limestone Evergreen Shrubland
3	Consolidated dune sand	80	1,0	Low Closed Evergreen Shrubland	Oblique - West	H - Willdenowia striata Consolidated Dune Dense Evergreen Restioid Shrubland
3	Sandy, gravelly coastal shelf	68	0,32	Low Mid-dense Grassy & Succulent Shrubland	Flat	B - Pelargonium - Muraltia Coastal-Shelf Dwarf Shrubland
3	Gravelly, sandy coastal shelf	71	0,1 0,82	Dwarf Mid-dense Succulent Shrubland with a Low Sparse Succulent Shrub Overstorey	Flat	A - Atriplex - Zygophyllum Coastal-Shelf Dwarf Shrubland
3	Granite soils coastal shelf	70	0,5	Low Mid-dense Succulent Shrubland	Steep - East facing	C - Galenia - Senecio Hillside Closed Dwarf Shrubland
3	Consolidated dune sand	82	1,2	Low Closed Evergreen Shrubland	Convex	G - Maytenus - Kedrostis Consolidated Dune Dense Evergreen Shrubland
7	Cloud over sea Shallow water on sand	100	0			
10	Unconsolidated dune sand	60	0,25	Dwarf Open Grassy Shrubland	Concave dune slacks	J - Hermannia pinnata Littoral-dune Dwarf Succulent Shrubland
5	Unconsolidated dune sand	40	0,2	Dwarf Open Grassy Shrubland	Convex dune crests	J - Hermannia pinnata Littoral-dune Dwarf Succulent Shrubland
5	Exposed limestone shallow sand	40	0,3	Dwarf Open Evergreen Shrubland	Convex	F - Pteronia uncinata Limestone Evergreen Dwarf Shrubland
8	Unconsolidated sand	20	0,45	Low Sparse Grassland	Oblique - East and West	K - Didelta - Psoralea Littoral-dune Open Grassland (Eragrostis cyperoides dominant)
6	Unconsolidated dune sand	10	0,40	Low Sparse Grassy Shrubland	Flat-convex outcrops	K - Didelta - Psoralea Littoral-dune Open Grassland (dwarf succulent pioneers)
9	Bare white sand	0	0	-	Flat	

(1) Boucher and Jarman (1977)
(2) Using structural scheme of Campbell et al (1981)
(3) Sequence of computer classes from top to bottom of Table corresponds to increasing reflectivity in band 5 of the average reflectance values for each class

Sedgelands. These communities are both tall reed beds (2 - 3m) with dense cover and are designated Tall Closed Sedgelands in the structural scheme. Class 14 is located on the edge of shallow and deep water channels where there is surface water present. Plant communities Nb (Spartina - Triglochin) and Md (Phragmites australis) forms of the Dense Sedgelands comprise this class. These again are 'reed-like' communities in terms of dominant growth form, but there is considerable difference between the two forms in terms of height (0,05 m as opposed to 3,5 m). The shorter form is designated as Dwarf Closed Grassy Sedgeland, and the taller is a Tall Closed Sedgeland. This Tall Closed Sedgeland differs from those in Class 11 in terms of spectral reflectance due to the presence of surface water. The presence of surface water would appear to be the main unifying criterion which distinguishes this class. Class 13 corresponds to bare water-logged sandy areas within the marsh; Classes 12 and 4 correspond to flat slightly raised better drained portions of the marsh area and support Ma_1 (Juncus krausii form of the Dense Sedgelands) and Na (Limonium - Disphyma form of the Dwarf Succulent Sedgeland) respectively. Both these plant communities have the dwarf succulent mat-like understorey dominant plant Arthrocnemum pillansii var pillansii. Computer Class 4 appears to have more surface water present; while Class 12 has the presence of a second dominant plant species (Juncus krausii) which is a $\pm$ 1,0 m tall, spiky reed-like plant. There is also a height difference between the two forms. Class 12 supports a Low Closed Sedgeland, while Class 4 supports a Dwarf Closed Sedgeland.

Computer Class 2, besides representing extensive areas of more open shrub communities in the terrestrial locations, corresponds to Class Ma_2 (Nidorella - Senecio mixed form of the Dense Sedgelands). This occurs on raised dry marsh situations. It is in the same height and canopy cover category as the low cover Class 2 consolidated dune community H (Willdenowia striata Dense Evergreen Restioid Shrubland) and similar in physiognomy. They are both designated as "Low Mid-dense Shrublands" (Campbell et al 1981). This structural designation is also given to the remaining computer Class 2 map unit, an extensive plant community located on limestone outcrops on shallow sand; namely E (Nenax - Maytenus - Zygophyllum Evergreen Dwarf Shrubland). This is a heavily grazed and utilized category of plant communities.

Wherever there are granite boulder outcrops, and shadow associated with these topographic features, a mosaic of Classes 12/13/14 occurs. This corresponds to plant community D (Ehrarta - Maurocenia Hillside Dense Shrubland); which is a Mid-high Mid-dense plant community occurring at the base of granite boulder outcrops.

Another mosaic of computer Classes 4 and 7, corresponding to water-logged consolidated dune sand situations represents areas occupied by plant community L (Metalasia-Myrica Dense Evergreen Ericoid Shrubland). This community occurs on a series of parallel dune ridges and valleys. In the Campbell et al (1981) scheme it is a Mid-high Closed Evergreen Small-leaved Shrubland.

Computer Class 3 corresponds to three gravelly, sandy, coastal shelf plant communities, the B (Pelargonium - Muraltia), A (Atriplex - Zygophyllum), and C (Galenia - Senecio Dwarf Shrublands. It also corresponds to the extensive consolidated dune community G (Maytenus - Kedrostis Dense Evergreen Shrubland). These communities fall into the Low Dwarf height categories (0 - 100 cms) and the Mid-dense cover category (50 - 75 percent). They share a common dominant specie in Zygophyllum morgsana and all contain a large number of succulent elements. They also share a number of drought deciduous elements, but with this being a September image, summer leaf-fall would not be a factor in influencing the nature of the spectral reflectance. Plant community I (Thamnochortus spicigerus Dense Tall Restioid Shrubland) occurring on consolidated dune and limestone soils, has been classed as computer map Class 4 but on the whole the areas supporting this community are not extensive enough to be resolved at this semi-detailed level of mapping.

Classes 10, 5, 8, 6 and 9 are all associated with unconsolidated dune situations. Class 10 corresponds to an open, heavily grazed form of plant community J (Hermannia pinnata Dwarf Succulent Shrubland), occurring in dune slacks. Class 5 corresponds to the dense cover, lightly browsed form of the same community, which occurs on slight crests and ridges within the dune valleys and on exposed dune ridges. These two computer classes represent the Dwarf Open Grassy Shrublands structural type. Classes 8 and 6 correspond to two forms of plant community K (Didelta - Psoralea Open Grassland). Class 6 represents the low, open canopy, dwarf succulent pioneers on undulating sea-facing dune slopes, while 8 corresponds to the grassed dune ridges, or Eragrostis cyperoides dominated form of plant community K. They are a Low Sparse Grassy Shrubland and a Low Sparse Grassland respectively.

Finally Class 9 corresponds to bare sand areas, and has the highest reflection value of all the computer map classes in all four wave bands.

3.5 DISCUSSION

All remote sensing techniques currently employed detect radiation in some part of the electromagnetic spectrum. This radiation either is emitted, or, as in the case of aerial photography and multi-spectral scanners, reflected. The Landsat 1 data analyzed in this study consist of a series of reflectance measurements in four bands of the electromagnetic spectrum. The clustering and classification procedures employed will thus classify each ground area for which readings are taken into classes which have similar reflectance characteristics in the particular four spectral bands. It is obvious therefore, that the classifications are not necessarily classifications in terms of specific ground features.

Two major conclusions follow from this: Firstly, a computer based study is likely to be more precise and consistent, when it comes to delineating spectral boundaries, than one which uses visual photo interpretation techniques on the same data. Visual interpretation introduces observer fatigue and individual bias in making decisions. Small areas may easily also be overlooked, especially if they are not very distinct from their surroundings. The ground resolution (i e 56 x 79 m, or one pixel) of Landsat data is such that small areas of a distinct community will not occur on a map if they occupy less than 0,5 hectare. This fortunately corresponds to the minimum size of map unit recognized at a semi-detailed scale of operation (Edwards and Jarman 1972), as in this study.

Secondly, ground features with similar reflectance characteristics in the four Landsat spectral bands will all be placed in the same class by any classification procedure. Thus concrete and bare sand, whilst totally distinct in terms of texture, are almost identical in terms of reflectance and will therefore always appear in the same class, if only reflectance data are considered. Therefore the maps produced by these classification routines are not claimed to be directly related to plant communities in terms of their floristic composition or to provide more than a reconnaissance overview of the main structural types for plant divisions found in an area. Structural plant communities are usually also identified by dominant species. Floristically defined plant communities are however defined on species which need not dominate the photo image. For instance the Atriplex - Zygophyllum, Pelargonium - Muraltia and

Galenia - Senecio granite coastal shelf communities are floristically distinct, but because of similar reflectance characteristics, are unlikely to be resolved in a study of this type.

None of the twelve land-based floristically defined communities described in the Boucher and Jarman (1977) vegetation description was separated as distinct entities on a spectral basis in this study. However eight spectral categories were obtained, which corresponded closely to the structural, functional types obtained when re-analyzing the site data according to the Campbell et al (1981) structural scheme for describing fynbos plant communities. Two of the six marsh community floristic forms were separated on spectral criteria alone. Again, in all, five spectral categories were obtained in the marsh situation, which corresponded closely to habitat and plant community structural features.

3.6 CONCLUSIONS

Initially classifications of Landsat imagery were carried out using supervised procedures. The majority of these were based on assumptions of the quality of ground-truth available and the distribution of the pixels in a given class in the 4-dimensional space defined by the reflectances in the four spectral bands. Although widely used because of the mathematical simplicity and computational convenience of the method, the validity of the procedure was questioned on both procedural and statistical grounds (see, for example, Nagy, Shelton and Tolaba 1971; Armstrong 1975).

One of the major problems with the analysis of Landsat imagery, using supervised procedures, is the definition of homogeneous areas which represent a specific ground target. A second problem is ensuring that the selected test areas include features which can be discriminated in the MSS data. The use of unsupervised techniques avoids both of these problems. However, although ensuring identification of homogeneous and discriminable land surface features, such techniques do not guarantee that the classes formed are meaningful to the user. Thus, instead of completely removing subjective interpretation from the process, these techniques move the interpretation to a different level.

Because of the nature of this study as part of the overall Fynbos Biome mapping project, it was decided that from the beginning unsupervised procedures should be used to establish signatures and training sets. Most of the Fynbos Biome has inadequate ground control to utilize supervised procedures. In these regions unsupervised procedures would be essential if Landsat classified data were to be used. As ground truth is available for the Langebaan area, it was decided to use this as a test area to determine whether these unsupervised procedures produced results which were of suitable quality for application to the Fynbos Biome as a whole.

It is felt that the close agreement with structural plant communities and computer classifications, bearing in mind the effect of substrate, makes the continued use of these techniques in vegetation mapping desirable.

There are advantages and disadvantages to the technique. It is a rapid process. To achieve the final product at the level of mapping illustrated by Figure 1 took approximately forty man hours for the total area of 400 km^2. To achieve the final product in the Boucher and Jarman (1977) vegetation map, where fourteen land-based vegetation communities were identified, took four man months.

It is a relatively objective process. Subjectivity comes into the choice of test area, in that the method assumes that the test area is in some sense typical of the area to be classified. The technique can easily be applied to large areas (Jarman, Bossi and Moll 1981). Each satellite image covers an area of 185 x 185 km^2. It also automatically generates class areas.

Disadvantages to the use of the technique are as follows: It is not suitable for detailed floristic mapping of a small area, but is best suited to vegetation structurally based semi-detailed, general and general reconnaissance, and reconnaissance scales of survey (Jarman, Bossi and Moll 1981). These are surveys designed to ascertain major classes of vegetation at regional and sub-regional landscape levels, and to determine major plant communities. Use of the technique will never eliminate ground control. Field work will always be necessary, as a back-up to the process. Another disadvantage to the technique is that it requires access to a computer and remote sensing interpretative expertise. Difficulties can also arise in application of the technique where there is pronounced topography in the area. This was not the case in the Langebaan area.

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PART IV THIRD PAPER: THE RELATIONSHIP BETWEEN PLANT COMMUNITY STRUCTURE, SPECTRAL REFLECTANCE CATEGORIES AND SCALE OF OPERATION IN MAP CLASSES PRODUCED BY COMPUTER ANALYSIS OF LANDSAT DATA IN THE LANGEBAAN AREA, SOUTH AFRICA.

M L Jarman

4.1 ABSTRACT

An investigation into the usefulness of various remote sensing products in mapping and studying the vegetation of the Fynbos Biome included the application of computer classification routines to digital Landsat 1 imagery in the Langebaan area, South Africa (33°05'S, 18°E). Eighty-five field sample sites used in the original air photo based survey of the Langebaan area (Boucher and Jarman 1977) were located on various computer produced map products. The sites were also re-analyzed on the basis of a scheme for structural characterization of vegetation in the Fynbos Biome (Campbell et al 1981). The CCT digital data from Landsat 1 imagery were classified using the Ball and Hall (1975) ISODATA technique and the Shlien and Goodenough (1973) Bayesian Maximum Likelihood Classifier. The relationship between floristic/structural; pure structural plant communities and spectral reflectance values was investigated. Computer classification matches well with major structural divisions; finer structural sub-division descriptions of sample plots correlate well with floristic divisions. A combination of digital analysis and field checking based on structural classification schemes will produce useful vegetation maps quickly. The repetitive cover provided by Landsat imagery makes the monitoring potential of this technique worth investigating.

4.2 INTRODUCTION

Vegetation mapping is a prerequisite to planning and management. Mapping implies classification. There are various ways of classifying vegetation. The floristically based techniques, which provide detail of the actual components of the vegetation on an individual species basis, are very important when successional trends, effect of fire as a management tool or other management practices are at issue. However, they also require detailed taxonomic knowledge of plants and experienced workers to carry them out. They are very slow.

Use of remote sensing products, and particularly air photographs, has been linked to vegetation studies for some time. Good quality, large scale colour air photographs (> 1:20 000) have been shown to produce photo units which are linked to field site situations which can be classified on a basis of floristics, as well as plant structural characteristics (Boucher and Jarman 1977, Jarman 1977).

Application of a structurally based scheme of characterization or classification of plant communities as extant units requires less experience and is a more rapid process. If it can be shown to provide good matching with rapid computer analysis of remote sensing products, then the potential for rapid mapping and monitoring of vegetation cover is good.

Computer classification of digital imagery in the form of Landsat computer compatible tapes (CCT's) has shown the versatility of this remote sensing product over conventional photography in terms of the usefulness of one set of data at a range of mapping scales from 1:20 000 to 1:250 000 (Jarman, Bossi and Moll 1981).

A structurally based scheme of vegetation classification such as that drawn up by Campbell et al (1981) for structural characterization of vegetation in the Fynbos Biome is sufficiently open-ended to accommodate the detail required to discriminate categories at a 1:50 000 semi-detailed level of investigation, and to accommodate major divisions encountered at a 1:250 000 scale of investigation.

This report deals with the detail of an investigation into the relative merits of floristic versus structurally based classifications when compared to computer classification of Landsat digital imagery; and the relationship between plant community structure, sub-strate and reflectance values.

4.3 METHODS

Air photo interpretation was carried out on colour air photographs at a 1:10 000 scale. Photo units were demarcated on the basis of hue, textural and physiographic differences. Field samples were located in representative photo units. These were 5 x 10 metre phytosociological samples (Taylor 1969, Boucher 1972), recording species presence on a cover-abundance scale. Number of strata, height of dominant strata and percentage canopy cover was recorded for each sample site; as were various site factors such as substrate, aspect, slope and degree of moisture.

The floristic samples were analyzed according to the Braun-Blanquet table-making method (Werger 1973). The photo units were found to agree with the floristically defined units obtained in the analysis of the site data; and a map classification was devised which was based on floristics, position on the landscape, and general vegetation structural characteristics common to the plant community (after D Edwards, Botanical Research Institute, Pretoria) e g Atriplex - Zygophyllum Coastal Shelf Dwarf Succulent Shrubland (Boucher and Jarman 1977).

The eighty-five sample sites were originally classified into twelve land based floristically defined communities and six marsh floristic communities. These sites were re-classified according to height of dominant strata and percentage canopy cover, on the basis of the Campbell et al (1981) scheme for structural characterization of vegetation in the Fynbos Biome (see Table 4.1 in Appendix).

Digital analysis of the relevant Landsat MSS data was carried out using a procedure adopted within the overall Fynbos Biome mapping project for vegetation classification from digital imagery. This is equivalent to the processes one goes through in carrying out visual interpretation of photo-products. Figure 4.1 is a flow-chart showing the steps in the procedure, with computer-aided analysis of digital MSS data being equivalent to visual interpretation of photo-products. The procedure utilizes available University of Cape Town Image Processing System routines (CATNIPS) and includes:

1. Identification and extraction of the area for study from the whole Landsat tape which covers an area 185 x 185 km^2.
   In this case the area of study was the Langebaan area from CCT scene ID E 10055-08064 of 16 September 1972. Its co-ordinates were start line 1173, start pixel 1890, and it covered an area 244 lines by 420 samples in extent (20 x 20 km). A complete Landsat CCT is 3 240 pixels horizontally by 2 340 lines vertically. The top left hand corner of an image corresponds to position 0 pixel number, 0 line number.
   The required CCT data was copied on to the UCT UNIVAC 1100/80 computer system using the routine INTAPE, thus generating a tape containing four files of the four bands of MSS information.

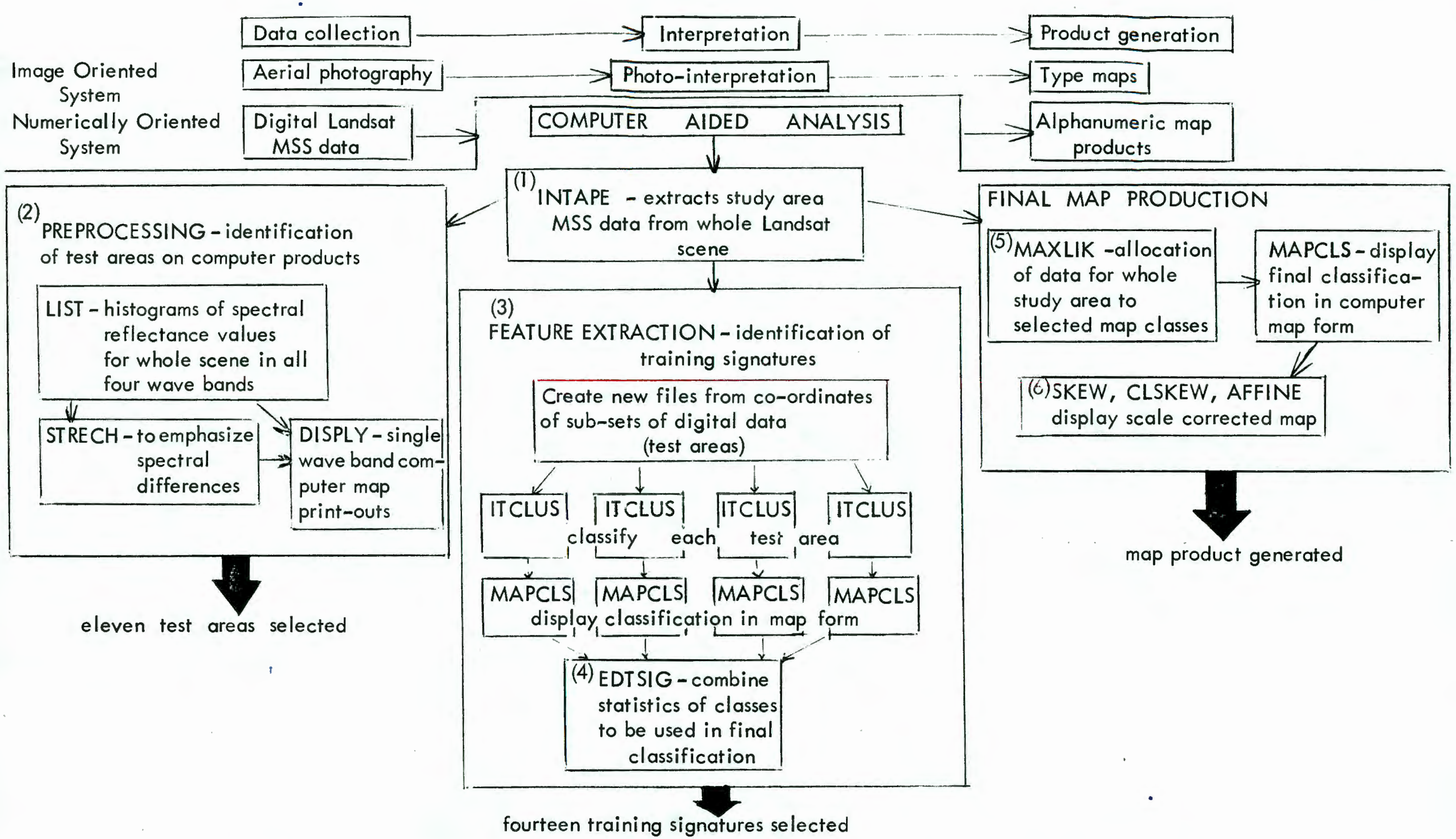


Figure 4.1 Flow chart showing routines available in the UCT, CATNIPS manual for computer-aided analysis of digital MSS data, in vegetation mapping

2. Pre-processing or identification of test areas containing training signatures or photo units to be used.

LIST, STRECH and DISPLY routines were used to achieve this. The digital imagery being utilized was multi-spectral. Histograms of the distribution of spectral reflectance values for the whole study area were listed for all four wave bands of the MSS data. On the basis of the distribution of spectral reflectance in a particular scene it might be considered necessary to do stretching routines to emphasize differences between features which might not be apparent in using unstretched data. Single wave band map print-outs of stretched and unstretched data were generated. These are the equivalent of black and white negatives of separate MSS bands – in that symbols on the print-outs correspond to grey scale categories on normal black and white air photo products. It was necessary to examine these products in order to ensure including the full-range of grey scale categories present in the scene, in all four wave bands, when locating the equivalent of photo units or training signatures within test areas.

The sample sites originally used in the air-photo interpretation (Boucher and Jarman 1977) were located on the single wave band print-outs. On the basis of the distribution and range of grey scale categories which these sample sites covered, eleven test areas were selected for further analysis (see Figure 4.2).

3. Feature extraction or identification of training signatures to be used in final classification (recognition of photo units).

New files were extracted from the data of the whole study area, corresponding to the data for each test area. The Ball and Hall (1975) ISODATA iterative clustering routine, was applied to the raw data of the test areas followed by a printing out of the classifications of these areas (ITCLUS and MAPCLS). The classifications were examined in terms of the known sample site characteristics. The annotated 1:10 000 photographs were also examined to aid in identifying features of interest. The average spectral reflectance values for classes in the various classifications were also examined to see which classes were similar in the various classifications and therefore likely to correspond to the same field soil/vegetation features (see Table 4.2).

Fourteen training sets of spectral values (equivalent to photo units) were selected for use in the final classification.

Table 4.2 Showing the number of clusters attained in each test area and the origin of the 14 training signatures used in the final classification

Test Area No.	No. of clusters	14 training signatures used in final classification													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1A (1)	9	3/6	8	7		9						(1)	(2)	(3)	(4)
2A	10	1/4	8	3	2			6	(5)/9	7	(10)				
2B	10	(1)/4	8	3	(2)			(6)	5/9	(7)	10				
2C	4	2		1		3					4				
2D	4			2		4	3			1					
3A (2)	7	3	(4)	(7)		(1)		6						5	
3B	5	3	2	4		5		1							
3C	5	2	3	4		5	(1)								
3D	3	3	2	1											
3E	5	1	2	4				5			3				
3F	3			2		1					3				

(1) T 1/T 2 * values of 6,0/4,0 used for this test area

(2) T 1/T 2 * values of 7,5/4,0 used for this test area

* Cluster splitting/combining threshold parameters – alteration of these changes the number of classes achieved in a classification.

4. Compilation of final map classification (annotation of representative photo units and development of map classification units).

   An editing programme was employed to combine the statistics of cluster classes to be used in the final classification process (EDTSIG).

5. Final classification of whole study area.
   The extrapolation phase then followed with the final pixel allocation to map classes being made and display of the classification being achieved (MAXLIK and MAPCLS). A Bayesian Maximum Likelihood classifier (Shlein and Goodenough 1973) was used to obtain the final allocation of all pixels for the whole study area into the cluster classes they closest represent.

6. Classification map scale corrections.
   The final computer processing involved scale corrections and geometric corrections in the production of a classification at a desired scale. All classification map products up to this stage of the operation had been at a scale of ± 1:24 000; single pixel units having been used as units of classification. This again is consistent with standard air photo interpretation techniques, in that annotation of photos (feature extraction processes) is carried out at a larger scale than the scale of the final map product.

   The final classification was produced at a scale of 1:50 000 using the routines SKEW and CLSKEW (see Figure 4.3).

Each sample site was listed with its floristic/structural/site designation (A - N) (Boucher and Jarman 1977); its structural designation - including percentage canopy cover, height of dominant strata and dominant species (after Campbell et al 1981); its aspect relative to sun-angle; substrate; biotic factors; its computer class category (1 - 14) and spectral reflectance values for all four wave bands of the MSS data (see Table 4.1 Appendix).

Decisions were taken as to the relationship between the floristic groupings, structural groupings and spectral classes (see Summary Tables 4.3 and 4.4).

4.4 RESULTS

The result of the field checked air-photo interpretation is the map reproduced in Figure 4.2, produced by Boucher and Jarman (1977). Figure 4.3 is the final classification achieved after computer analysis of digital Landsat imagery (Jarman and Jackson Part III - this report). Overlays to both maps show the positions of the original eighty-five sample sites.

The analysis of the eighty-five sample sites on the basis of dominance and structural characteristics is itemized in Table 4.1, columns 3, 4 and 5; Table 4.3 summarizes these structural categories as they relate to the floristic map categories, computer class designation and average spectral class values in all four wave bands for each computer map class.

Table 4.3 gives the structural/floristic categories recognized in this study. In most instances a spectral class encompasses more than one structural type at this detailed level of definition. For instance Class 2 corresponds to both Low Mid-dense Evergreen Shrublands and a Low Mid-dense Cyperoid Shrubland. The only structural difference between these classes is the growth form of the dominant elements. These differences are not sufficient to be distinguished on a spectral basis at this level of resolution. Floristic differences also exist in that Class 2 encompasses three floristic plant communities. All three of these have specific site characteristics: one is the raised drier areas in the marsh situation Ma_2 (Nidorella - Senecio); one occurs on limestone outcrops confined to the tip of the peninsula area of the Langebaan Lagoon E (Nenax - Maytenus - Zygophyllum) and the remaining sites falling into Class 2 represent the heavily grazed form of a third floristic community H, (Willdenowia striata) on consolidated dune sand. Using this computer class as an example, it is possible to relate computer Class 2 to floristic classes E, H_2 and Ma_2 by designating the final map classes as 2E, $2H_2$ and $2Ma_2$ respectively (see Figure 4.8).

Similarly Class 3 map areas are further subdivided into 3A, 3B, 3C, 3G and $3H_3$; Class 4 becomes 4I and 4Na; Classes 5 and 10 become 5F, 5/10J, and 5/10 agriculture; Classes 6 and 8 together become 6/8K; Class 11 becomes 11Mc and 11Mb; Class 12 becomes 12Ma; Class 14 becomes 14Md and 14Nb; Mosaic Class 4/7 becomes 4/7L; Mosaic Class 12/13/14 becomes 12/13/14D. Classes 1 and 7 remain water classes, and Classes 9 and 13 remain dry and moist sand classes respectively.

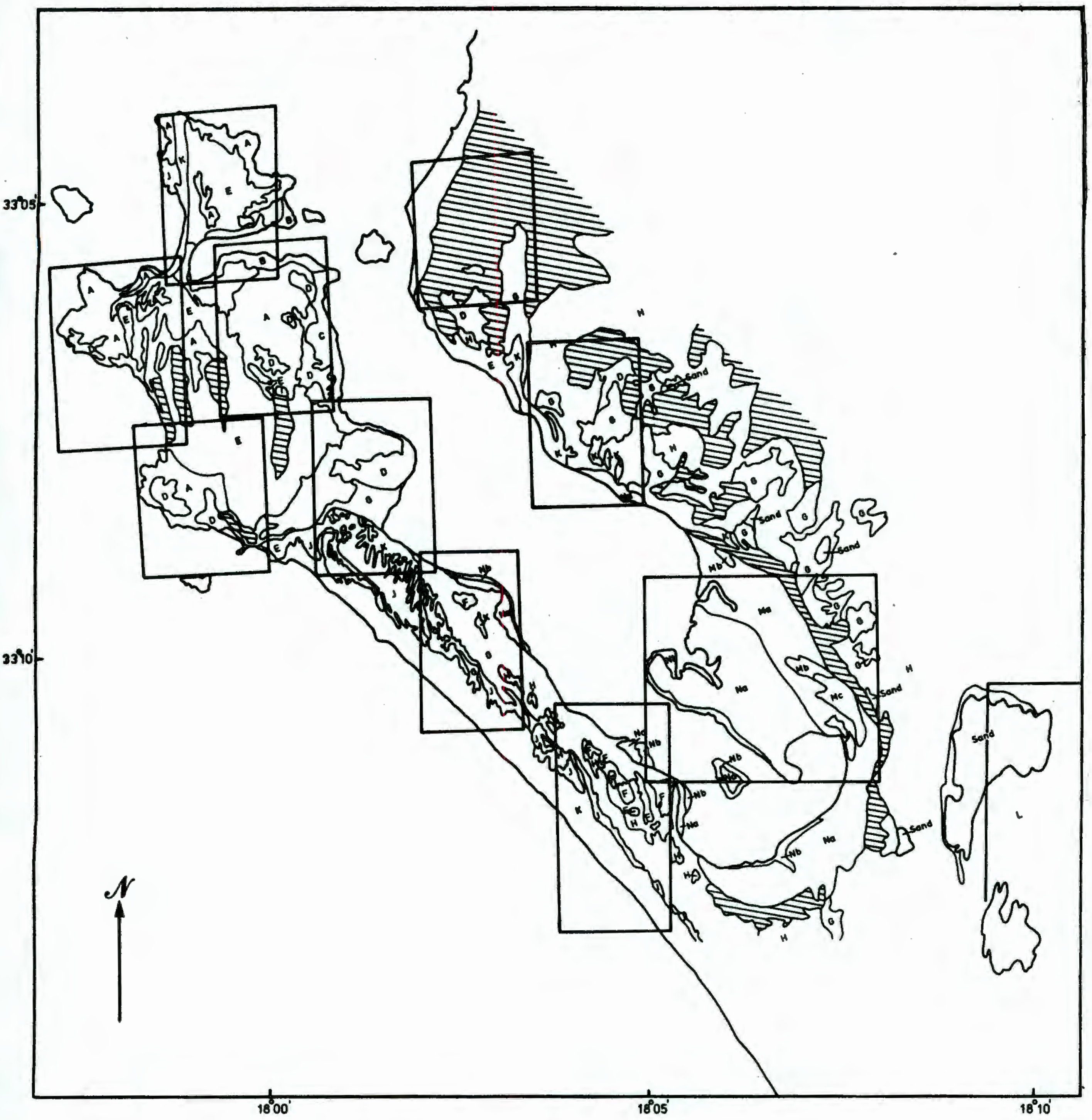


Figure 4.2 Vegetation map of the Langebaan area, produced by Boucher and Jarman (1977) from standard colour 1:10 000 air photographs, and field checking. The map classes are floristically based, but also carry a structural designation. (Test areas used in computer analysis of Landsat data are indicated).

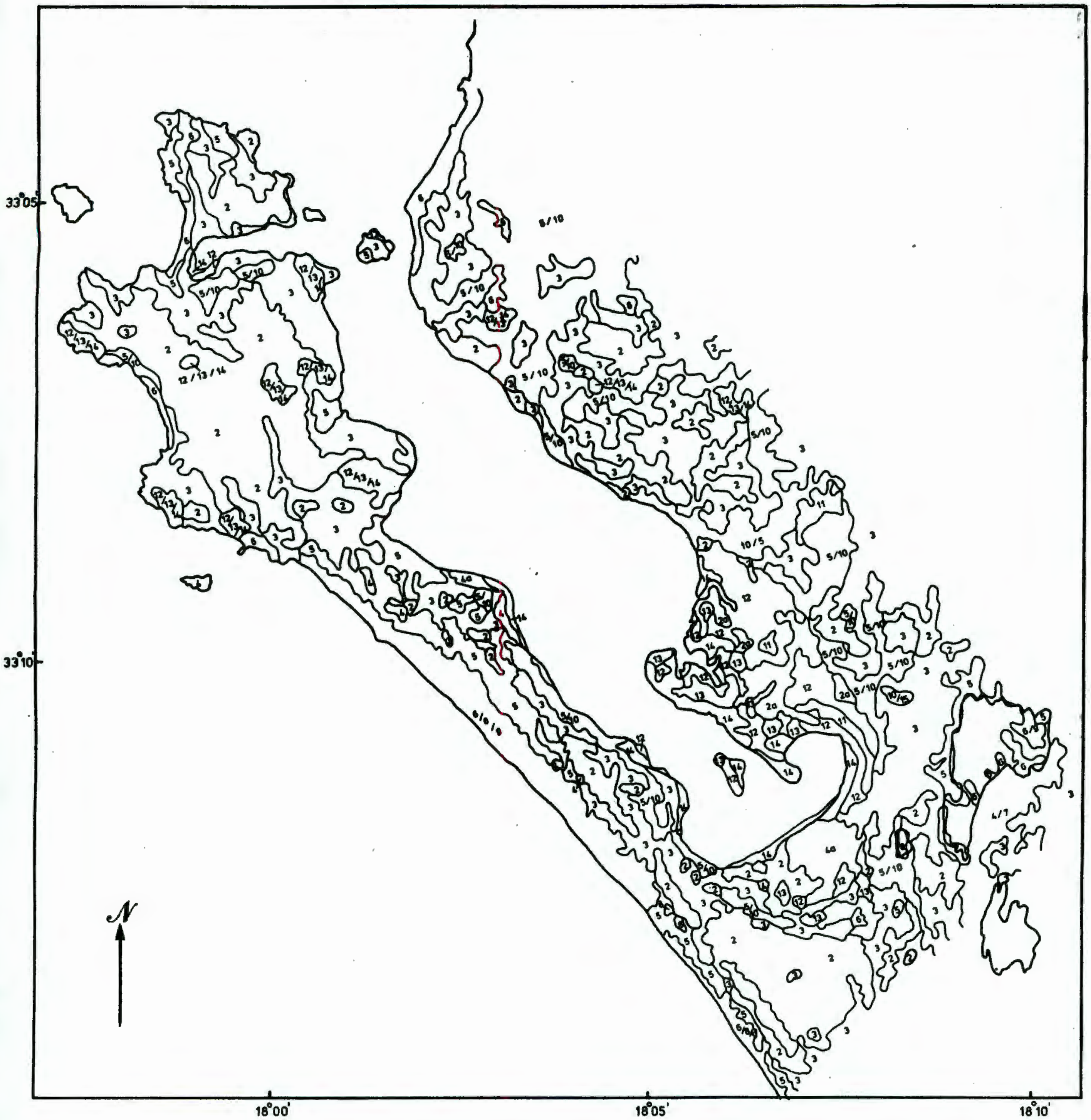


Figure 4.3 A 16 class computer classification of the vegetation of the Langebaan area. These classes are structural/floristic vegetation classes; influenced by substrate and aspect.

.BLE 4.3 A comparison of the floristic groupings, structural groupings and spectral class categories in the Langebaan Area, South Africa (after Jarman and Jackson, Part III - this report)

·.	Computer Class Description: Substrate	Average % Plant Cover	Average Height of Dominant Strata (m)	Plant Community Structural Type (2)	Landscape position	Air-photo identified plant community (floristic/structural type) (1)	Ave. spectral reflectance values for each wave band: 4	5	6	7	Ave. v for all ba
	Deep water	³100	³100	-			53,46	29,75	18,92	9,40	29,70
	Water-logged	100	3,0	Tall Closed Sedgeland	Flat lowlying marsh area	Mb - Cliffortia strobilifera form of Dense Sedgeland	51,88	36,88	42,06	40,70	42,88
	Water-logged	85	2,0	Tall Closed Sedgeland	Flat lowlying marsh area	Mc - Typha capensis form of Dense Sedgeland	51,88	36,88	42,06	40,70	42,88
	Surface water	100	0,14	Dwarf Closed Grassy Sedgeland	Edges of shallow water channels on flat marsh	Nb - Spartina - Triglochin form of Dense Dwarf Succulent Sedgeland	56,40	39,20	33,51	24,41	38,38
	Surface water	100	3,5	Tall Closed Sedgeland	Edge of shallow & deep water channels	Md - Phragmites australis form of Dense Sedgeland	56,40	39,20	33,51	24,41	38,38
	Granite boulder outcrops	71	1,5 3,0 0,4	Mid-high Mid-dense Shrubland with emergent trees & o Tall Sparse Grassland	Convex and shadow	D - Ehrharta - Maurocenia Hillside Dense Shrubland	54,99	39,40	47,37	44,75	47,47
	Water-logged sand	0	0	-	Flat		53,59	39,60	61,23	65,09	54,88
	Water-logged sand	100	0,75	Low Closed Sedgeland	Flat raised marsh areas	Ma_1 - Juncus kraussii Dense Sedgeland	53,97	41,03	50,82	50,82	49,16
	Some surface water - water-logged sand	95	0,08	Dwarf Closed Sedgeland	Flat raised marsh areas	Na - Limonium - Disphyma form of Dwarf Succulent Sedgeland	59,88	42,86	43,11	36,18	45,51
	Moist site hollows	90	2,0	Tall Closed Restioland	Damp hollows dense canopy grey black image	I - Thamnochortus spicigerus Consolidated Dune Dense Restioland	59,88	42,86	43,11	36,18	45,41
	Consolidated dune sand	50	1,0	Low Mid-dense/Open Evergreen Shrubland	Oblique - West	H - Willdenowia striata Consolidated Dune Dense Evergreen Restioid Shrubland	57,31	44,53	54,77	55,15	52,94
	Raised dry marsh sand	70	1,0	Low Mid-dense Cyperoid Shrubland	Flat to Convex	Ma_2- Nidorella - Senecio Mixed form of Dense Sedgeland	57,31	44,53	54,77	55,15	52,94
	Limestone outcrop on shallow sand	55	0,3 1,0	Low Mid-dense Evergreen Shrubland	Oblique - West	E - Nenax - Maytenus - Zygophyllum Limestone Evergreen Shrubland	57,31	44,53	54,77	55,15	52,94
	Consolidated dune sand	80	1,0	Low Closed Evergreen Shrubland	Oblique - West	H - Willdenowia striata Consolidated Dune Dense Evergreen Restioid Shrubland	60,48	49,15	62,57	65,16	59,34
4	Sandy, gravelly coastal shelf	68	0,32	Low Mid-dense Grassy & Succulent Shrubland	Flat	B - Pelargonium - Muraltia Coastal-Shelf Dwarf Shrubland	60,48	49,15	62,57	65,16	59,34
3	Gravelly, sandy coastal shelf	71	0,1 0,82	Dwarf Mid-dense Succulent Shrubland with a Low Sparse Succulent Shrub Overstorey	Flat	A - Atriplex - Zygophyllum Coastal-Shelf Dwarf Shrubland	60,48	49,15	62,57	65,16	59,34
3	Granite soils coastal shelf	70	0,5	Low Mid-dense Succulent Shrubland	Steep - East facing	C - Galenia - Senecio Hillside Closed Dwarf Shrubland	60,48	49,15	62,57	65,16	59,34
3	Consolidated dune sand	82	1,2	Low Closed Evergreen Shrubland	Convex	G - Maytenus - Kedrostis Consolidated Dune Dense Evergreen Shrubland	60,48	49,15	62,57	65,16	59,34
7	Cloud over sea Shallow water on sand	100	0				68,06	50,20	40,49	30,27	47,26
0	Unconsolidated dune sand	60	0,25	Dwarf Open Grassy Shrubland	Concave dune slacks	J - Hermannia pinnata Littoral-dune Dwarf Succulent Shrubland	76,07	68,95	80,07	79,24	76,08
5	Unconsolidated dune sand	40	0,2	Dwarf Open Grassy Shrubland	Convex dune crests	J - Hermannia pinnata Littoral-dune Dwarf Succulent Shrubland	79,63	72,69	83,78	85,32	80,11
5	Exposed limestone shallow sand	40	0,3	Dwarf Open Evergreen Shrubland	Convex	F - Pterania uncinata Limestone Evergreen Dwarf Shrubland	79,63	72,69	83,78	85,32	80,11
8	Unconsolidated sand	20	0,45	Low Sparse Grassland	Oblique - East and West	K - Didelta - Psoralea Littoral-dune Open Grassland (Eragrostis cyperoides dominant)	111,21	112,85	108,02	99,76	107,96
6	Unconsolidated dune sand	10	0,40	Low Sparse Grassy Shrubland	Flat-convex outcrops	K - Didelta - Psoralea Littoral-dune Open Grassland (dwarf succulent pioneers)	111,83	115,89	116,11	110,40	113,56
9	Bare white sand	0	0	-	Flat		125,61	130,19	126,34	117,56	124,93

(1) Boucher and Jarman (1977)
(2) Using structural scheme of Campbell et al (1981)
(3) Sequence of computer classes from top to bottom of Table corresponds to increasing reflectivity in band 5 of the average reflectance values for each class

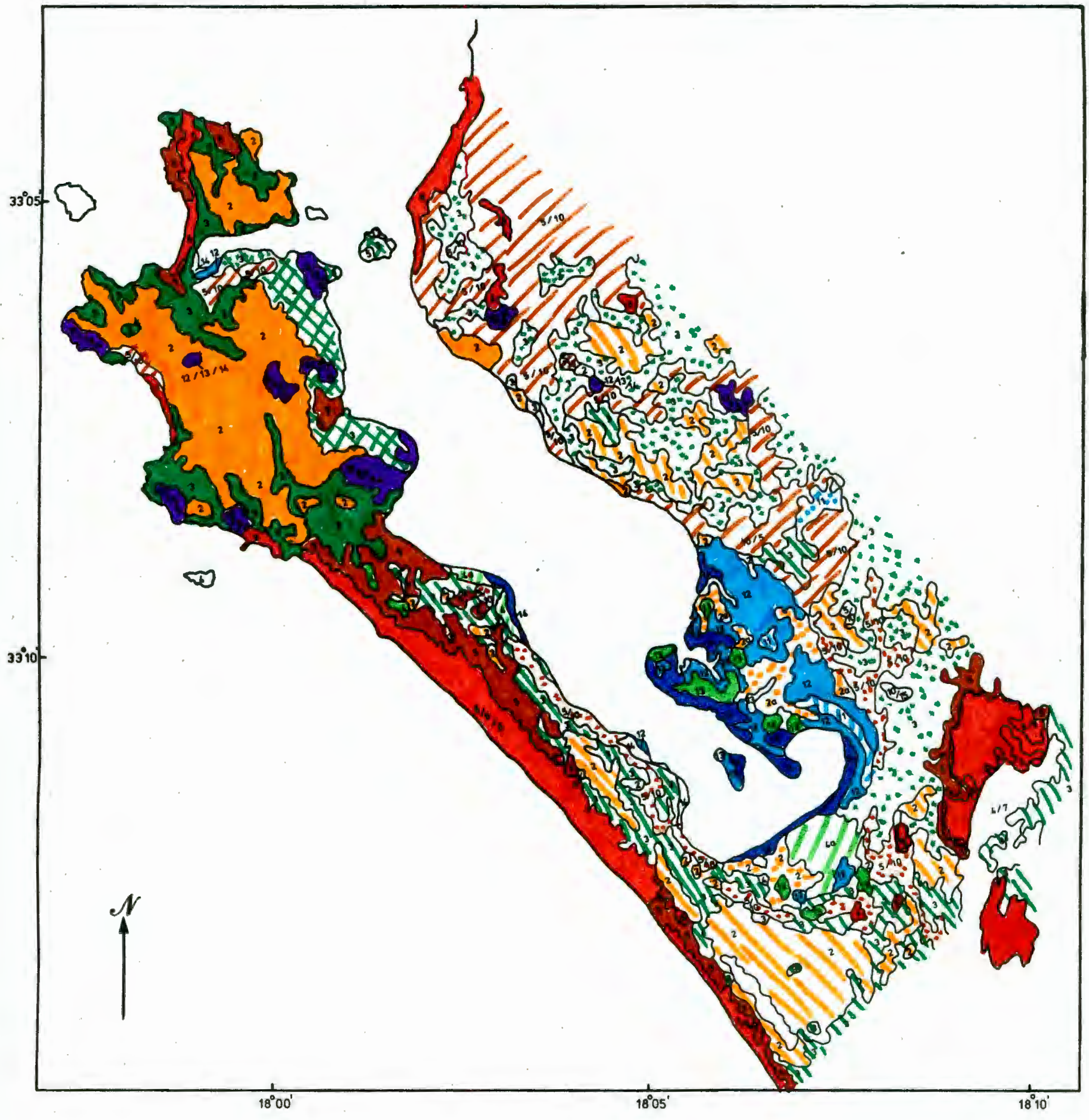


Figure 4.8 Final map produced from a combination of major structural divisions and minor floristic/ structural divisions

In this way by combining the sample site floristic and structural information, a map has been produced where the major divisions are structural, but where the minor divisions are floristic (see Figure 4.8).

Table 4.4 summarizes some of the structural formations recognized by computer analysis of satellite imagery in the West Coast Strandveld and Coastal Fynbos communities in this study (Acocks' Veld Types 34 and 47).

4.5 DISCUSSION

In referring to Table 4.4, the details of the main structural categories recognized emerge. The table is arranged in sequence from the lowest average reflectance value in band 5 to the highest, i e deep water to bare sand. Classes 1 to 12 are all very much influenced by the effect of water and moisture in lowering reflectance particularly in the near infra-red bands 6 and 7. Surface water present (Class 14); water-logged conditions (Classes 11 and 4); moist sand (Classes 12 and 13) all cause low reflectance values. Superimposed on this is the dense closed canopy of marsh plants where they are present. They all fall in the category of 75 - 100 percent cover. Active vegetation has low reflectance values in band 5 particularly. Therefore a combination of low reflection due to water/moisture in bands 6 and 7, with low reflection due to active vegetation in band 5 accounts for the generally low reflection values of these classes.

Minor differences, either in height of strata, shape of reflecting surface, or substrate are masked by the effect of water. For instance; due to sample site information, we know that computer Class 14 represents both Tall Closed Sedgelands (> 2m) and Dwarf Closed Grassy Sedgelands (< 0,25 m). However, both have surface water present; and both have 'reed-type' 'grass-like' growth forms. The difference in height is not sufficient to distinguish these two forms of computer Class 14. Field site data information readily show the differences.

Similarly, Class 4 has two different structural types; one a Tall Closed Restioland (< 2 m) and one a Dwarf Closed Sedgeland (> 0,25 m). Their locations separate them completely; one being on moist hollows and depressions on consolidated dunes, while the other occurs on water-logged marsh sand. Again it is simple to separate them in the final mapping exercise on the basis of their location.

TABLE 4.4 Characteristics of structural formations recognized by computer analysis of satellite imagery in the Langebaan Area, South Africa

Computer Class no	Projected Canopy Cover of dominant stratum (1) %					Height of dominant stratum (1) (m)				Substrate								Shape of reflecting surface				Biotic factors		Structural type (1)
	0,1–5	5–25	25–50	50–75	75–100	<0,25	,25–1,0	1,0–2,0	>2,0	Granitic soil	Limestone outcrops & ridges	Consolidated dune sand	Littoral dune sand	Moist marsh sand	Water-logged marsh sand	Shallow water	Deep water	Convex	Concave	Flat	Oblique + shadow	Heavily grazed	Non-utilised	
1					X				X								X			X				Deep water
14					X				X							X								Tall Closed Sedgeland
14					X	X										X								Dwarf Closed Grassy Sedgeland
11					X				X						X			X						Tall Closed Sedgeland
4					X				X			moist X							X					Tall Closed Restioland
4					X	X									X			X						Dwarf Closed Sedgeland
4/7				X				X				X						X	X					Mid-high Mid-dense Evergreen small-leaved Shrubland
7					X	X										X				X				Shallow water
12/13/14				X					X	X											X			Mid-high Mid-dense Shrubland with emergent trees and Tall Sparse Grassland
12					X		X							X				X						Low Closed Sedgeland
2				X			X				X	X									X	X		Low Mid-dense Evergreen/Cyperoid Shrubland
13	X					X								X						X				Moist marsh sand
3					X	X	X			X		X						X		X				Dwarf/Low Closed Succulent Shrubland
10			X			X							X						X			X		Dwarf Open Grassy Shrubland
5			X			X					X		X					X				X		Dwarf Open Evergreen/Grassy Shrubland
8		X					X						X					X						Low Sparse Grassland
c		X					X						X								east X			Low Sparse Grassy Shrubland
9	X					X							X											Bare dry sand

(1) According to Campbell et al scheme (1981)

Classes 2 to 5 are the good ground cover (25 - 100 percent) and Dwarf to Low height class communities (0 - 1,0m). In each instance each spectral class has a different combination of factors. Class 2 structural types are Low Mid-dense Evergreen or Cyperoid Shrublands; Class 3 types are Dwarf/Low Closed Succulent Shrublands; Class 10 types are Dwarf Open Grassy Shrublands and Class 5 types are Dwarf Open Evergreen/Grassy Shrublands. Classes 10 and 5 are closely related, but one occurs on convex reflecting surfaces and one on concave reflecting surfaces.

The next major division is the group of classes which have Low height (0,25 - 1,0m) and Sparse cover (5 - 25 percent). Classes 8 and 6 fall into this category. The minor differences in composition of vegetation or site location are reflected by differences in spectral classes, i e high grassy component and convex versus oblique reflecting surfaces.

The map classes on the computer classification correspond to vegetation structural types. Table 4,5 lists the common dominant species for each of these spectral/ structural types. (Dominant species were recorded for each sample site). The high percentage occurrence of these common dominants must contribute to the spectral characteristics of the land cover type.

Table 4.5 Dominant species occurring in each spectral/structural map class

Spectral Class	Dominant species	Growth form
14 (tall)	Phragmites australis	(tall reed)
14 (dwarf)	Spartina capensis	(dwarf grass)
11	Typha capensis	(tall reed)
11	Cliffortia strobilifera	(tall reed)
4 (dwarf)	Arthrocnemum pillansii	(dwarf succulent sedge)
4 (tall)	Thamnochortus spicigerus	(tall restio)
4/7	Passerina paleaceae	(mid-high evergreen ericoid)
12/13/14	Rhus glauca	(mid-high broad-leaved evergreen shrub)
12	Juncus kraussii	(low cyperoid)
2	Senecio floribunda	(low evergreen composite shrub)
3	Zygophyllum morgsana	(low dwarf succulent shrub)
10	Eragrostis cyperoides	(dwarf grass)
5	Limonium perigrinum	(dwarf evergreen shrub)
8	Eragrostis cyperoides	(dwarf grass)
6	Senecio elegans	(dwarf composite shrub)

Figures 4.4 to 4.7 are three-dimensional plots and contour diagrams of average structural types and average reflectance values for bands 5 and 7 of computer classes generated in the Langebaan area.

Figures 4.4 and 4.6 relate to band 5 mean values per spectral class. Figures 4.5 and 4.7 to band 7 mean values per spectral class. These diagrams have been included to illustrate the kind of groupings being achieved in the classifications and how they relate to structural plant factors. Plotting average height of dominant strata (x axis) against average canopy cover (y axis) gives the relative position of the different structural types which agrees with spectral groupings. The 'bumps' and 'dips' in contours, reflected by 'bumps' and 'dips' in the three-dimensional plots correspond to irregularities caused by high soil moisture, shadow, surface water, high canopy cover on bright reflecting surfaces, etc. In other words, it gives a 'thumb print' of the nature of the structural/reflectance categories in a scene. Band 5 and 7 data have been shown separately to emphasize the advantages of using MSS data in these applications. Band 7 separates high canopy plant categories associated with water and soil moisture from those on drier sites. Note that there are no plant communities in the Langebaan type of West Coast Strandveld which are Tall ($>$ 2m) and of low cover.

If these diagrams are 'good' reflections of the range of structural/spectral communities encountered in a scene, the relevant height and canopy cover data from any sample plot should fall within the contour interval of reflectance categories in which it would be classified.

It should be possible to characterize scenes of interest in this way for use as a monitoring tool in change detection.

Comparison with spectral categories obtained in other studies

1. Study at the same scale (1:50 000 semi-detailed scale)

At the 1:50 000 scale of operation as carried out in this study sixteen computer derived spectral classes were obtained which corresponded to plant structural communities. In a similar study carried out by Lane (1980) on 20 January 1973 imagery (E 1181-08065) sixteen spectral categories were also obtained for the Verlorenvlei area.

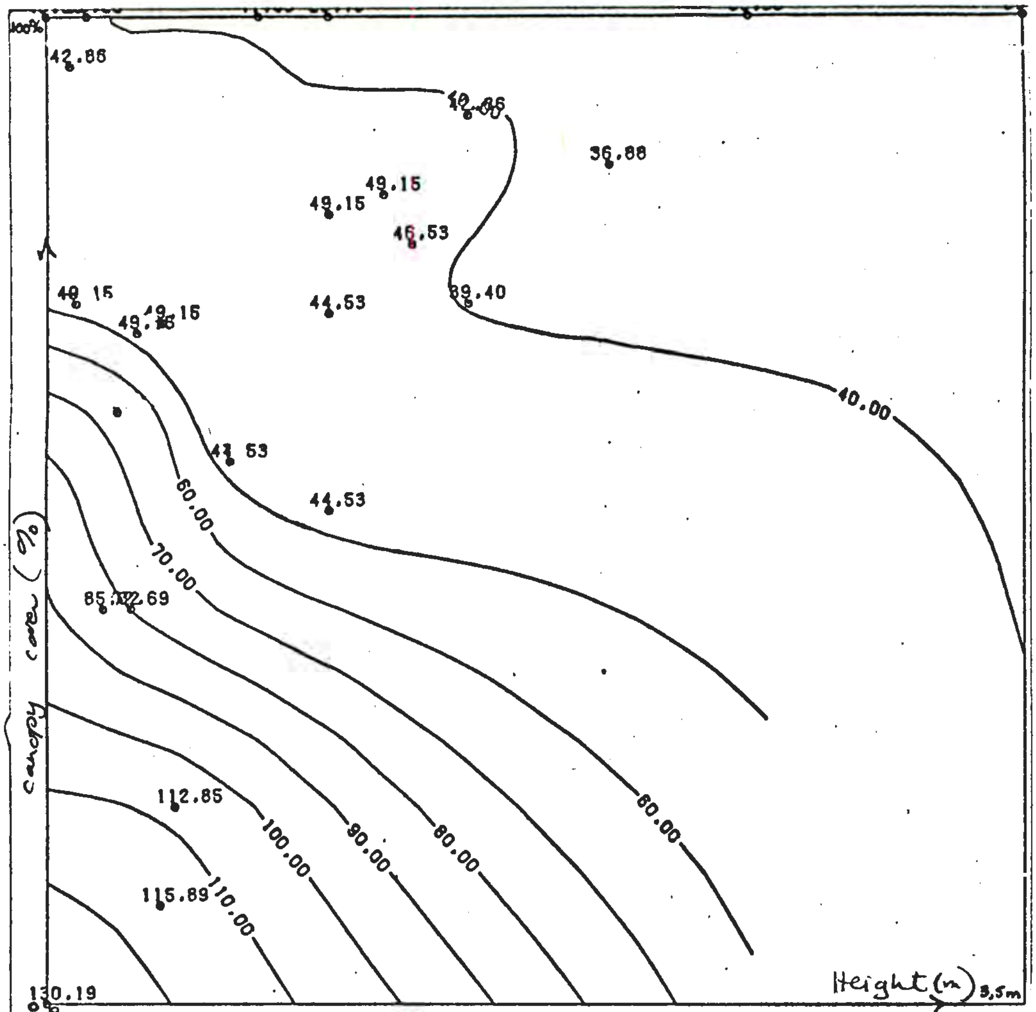


FIGURE 4.4 HEIGHT OF DOMINANT STRATA VERSUS CANOPY COVER AND BAND 5 MEAN VALUES.

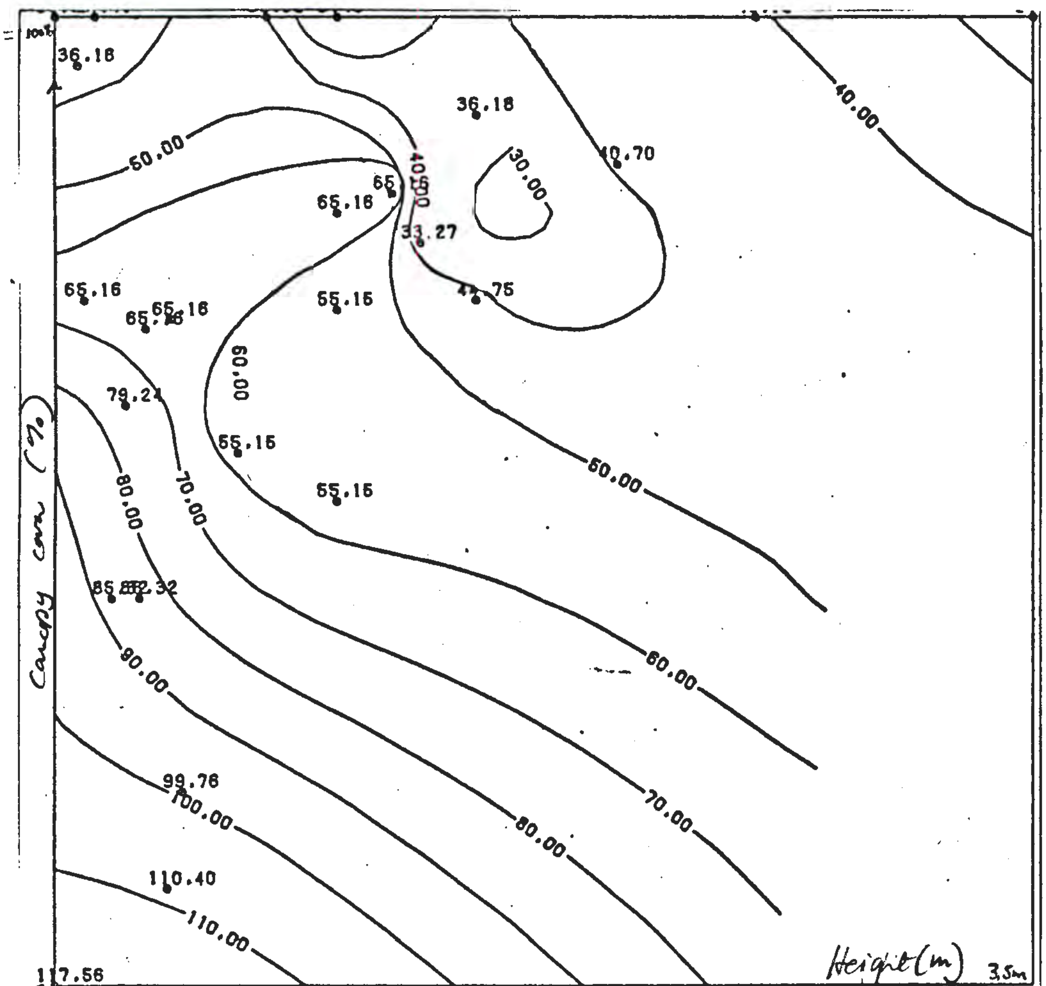


FIGURE 4.6 HEIGHT OF DOMINANT STRATA VERSUS CANOPY COVER AND BAND 7 MEAN VALUES.

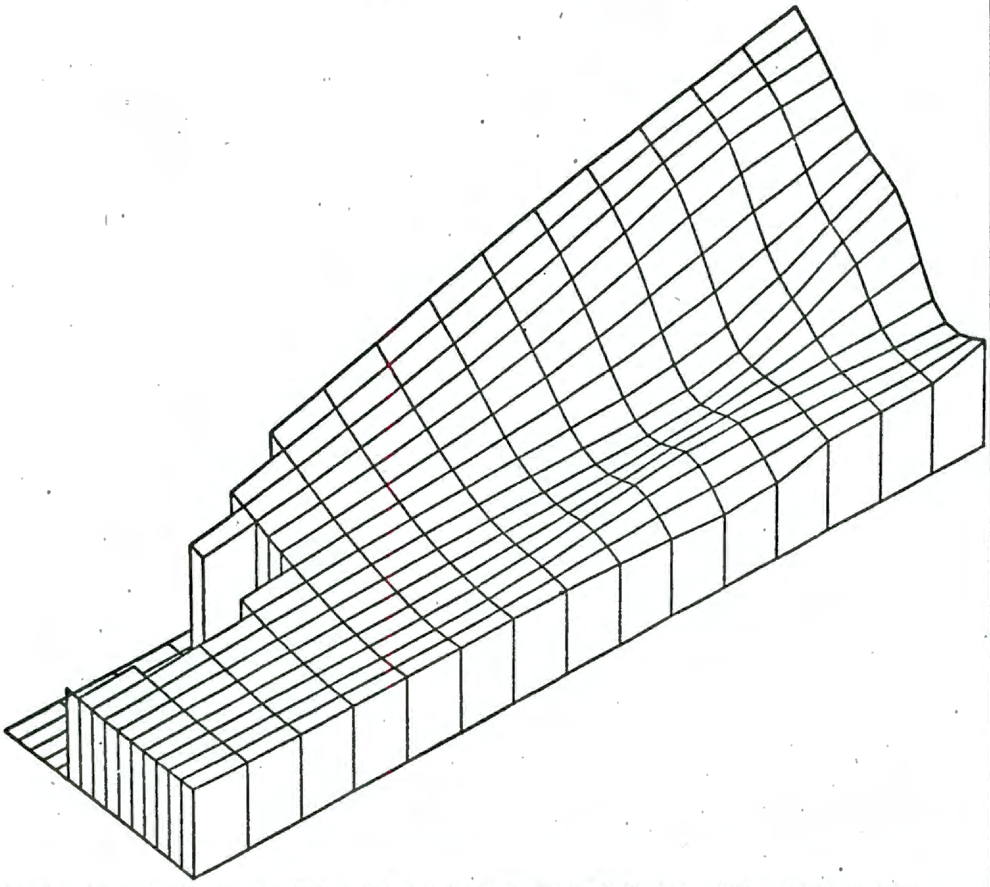


FIGURE 4.5 HEIGHT OF DOMINANT STRATA VERSUS CANOPY COVER AND BAND 5 MEAN VALUES.

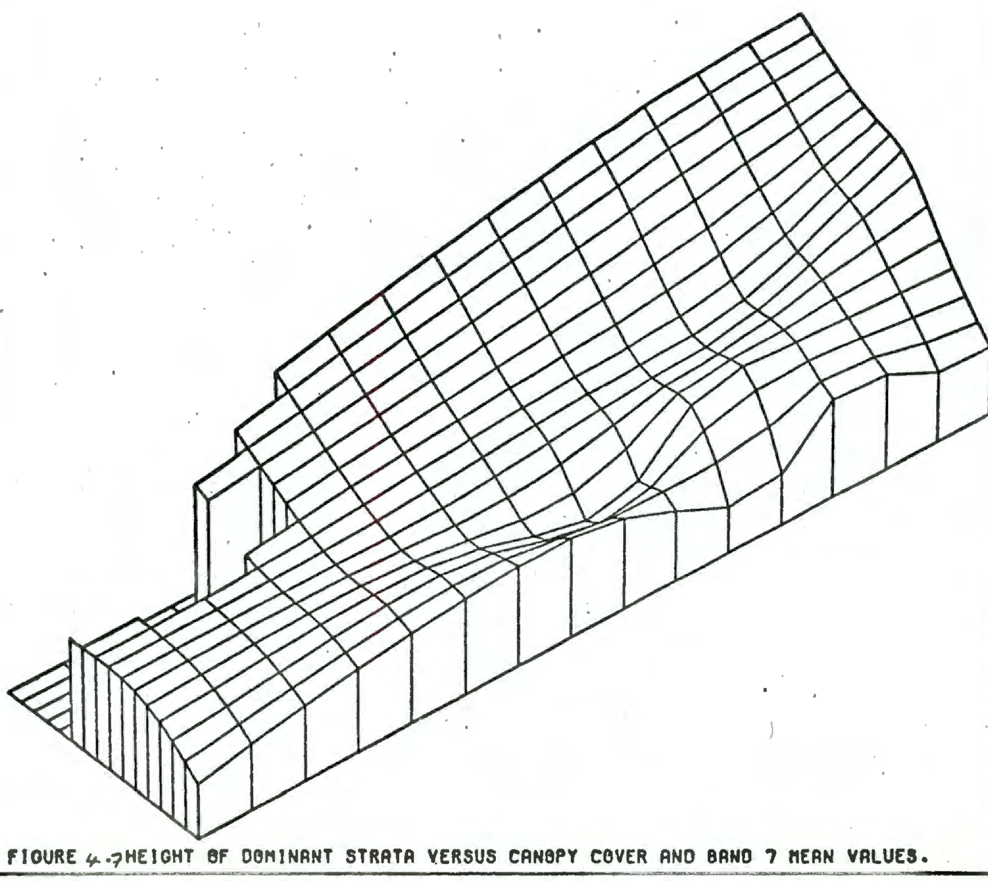


FIGURE 4.7 HEIGHT OF DOMINANT STRATA VERSUS CANOPY COVER AND BAND 7 MEAN VALUES.

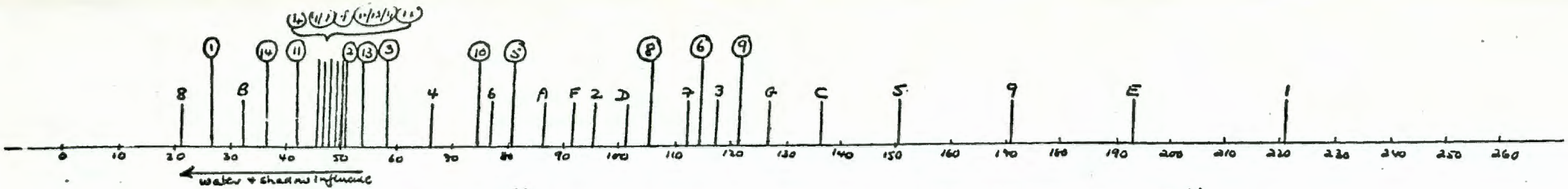
A two-dimensional plot of the average spectral reflectance values for all four wave bands in both studies is shown in Figure 4.9 (Langebaan data encircled and Verlorenvlei data not encircled). Taking into account the date of imagery (September for Langebaan, i e winter with generally lower reflection values due to increased soil moisture and activity of vegetation; and January for Verlorenvlei with higher reflection values for the opposite reasons) the Verlorenvlei area still has a greater number of high reflection, low vegetation canopy cover classes.

Grouping the reflection categories for the two studies in terms of canopy cover shows that: Langebaan Class 9 is equivalent to Verlorenvlei Class 1 (bare areas); Langebaan Classes 6 and 8 correspond to Verlorenvlei E, 9, 5, C, G, 3, 7 and D (0 - 25 percent canopy cover); Langebaan Classes 5 and 10 correspond to Verlorenvlei 2, F and A (25 - 50 percent canopy cover); Langebaan Class 2 has no Verlorenvlei counterpart (50 - 75 percent canopy cover); Langebaan Class 3 corresponds to Verlorenvlei Class 4 (〉 70 percent canopy cover); Langebaan Classes 13, 12, 7, 4, 11 and 14 are all associated with marsh and water features and have a counterpart in Verlorenvlei Class B; and finally both areas have deep water categories - Class 8 for Langebaan and Class 1 for Verlorenvlei.

Figure 4.9 shows a suggested breakdown of how the spectral categories relate to ground cover types.

At the stage when Lane (1980) processed the data for the Verlorenvlei area, the routine EDTSIG which combines the statistics of spectral classes from a number of test areas had not been developed. Fleming and Hoffer (1977) studied a number of approaches to classifying MSS digital data of a study area and found that their "multi-clustering blocks" approach was "optimal" in terms of utilizing the lowest amount of support data, requiring relatively few man-hours of time, reduced computer time and producing highest overall classification accuracy. The approach used involved selection of heterogeneous blocks of MSS data, individual clustering of each block, identifying cluster classes, and pooling spectral classes into informational classes - the procedure used in this study was the same.

Classification of some of the test areas used in the Langebaan study produced a number of high reflection, low cover categories. These could not be identified as corresponding to separate plant communities. They were 'lumped' together to form two low-cover classes (Classes 6 and 8). Lane (1980), in processing the



VERLORENVLEI STRUCTURAL TYPES (b)	Comp. Class No.	Canopy cover	Comp. Class No.	LANGEBAAN STRUCTURAL TYPES (a)	Height of dominant strata
	1	bare areas	(9)		
Pioneering shrubs herbs and grasses	E	0 - 5%			
	9	0 - 5%			
Grassland community	5	0 - 20%			
	C	5 - 25%	(6/8)	Low Sparse Grassy Shrubland	0,25 - 1,0 m
Mixed Shrubland	G				
- no restioids	3	20 - 25%			
	7	0 - 30%			
	D	5 - 40%			
Grassland community Mixed Shrubland - no restioids	2	15 - 50%			
	F		(5/10)	Dwarf Open Grassy/Evergreen Shrubland	<0,25 m
	A	15 - 70%			
Broad-leaved Shrubland with Grass,		55 - 70%	(2)	Low Mid-dense Evergreen/Cyperoid Shrubland	0,25 - 1,0 m
Acacia woodland Restioid Shrublands	4	>70%	(3)	Dwarf/Low Closed Succulent Shrubland	0 - 1,0 m
Increasing water and shadow influence		damp sand	(13)		
			(12)	Low Closed Sedgeland	0,25 - 1,0 m
		Shallow water	(7)		
		≤100%	(12/13/14)	Mid-high Mid-dense Shrubland with emergent trees (shadow)	1,0-2,0m (3 strata)
			(4/7)	Mid-high Mid-dense Evergreen Small-leaved Shrubland	1,0-2,0m (1 stratum)
			(4)	Dwarf Closed Sedgeland/Tall Closed Restioland	<0,25/>2,0 m
			(11)	Tall Closed Sedgeland	>2,0 m
	B		(14)	Dwarf Closed Sedgeland/Tall Closed Sedgeland	<0,25/>2,0 m
	1	Deep water	(8)		

(a) According to Campbell et al (1981) Structural Scheme
(b) Fram Lane 1980

Figure 4.9 A 2-dimensional plot of average spectral reflectance values for all four wave bands of MSS data in studies carried out in the Langebaan Area (circles) and the Verlorenvlei area.

Verlorenvlei data, classified the whole area using the Ball and Hall ISODATA classifier. This placed heavy reliance on the 'unsupervised' approach to produce spectral categories which could all be interpreted in terms of ground cover characteristics. The extreme fragmentation of the ground cover types of the area was attributed to the technique failing to 'map' vegetation in this low cover area; this could have been avoided by using the EDTSIG routine to reduce the number of meaningless high reflection categories.

By altering the cluster splitting/combining threshold parameters (T_1/T_2) which control the number of glasses obtained in a classification, processing of digital data from test area 2B in the Langebaan area produced classifications of from four to eighteen classes. Careful ground checking, and checking of air photographs showed that most of these classifications were meaningless in terms of ground vegetation cover. In fact the ten class classification, with T_1/T_2 of 10,5/7,0 respectively was the one which produced closest agreement with the ground cover situation. In the final classification for the whole study area, only four of these ten classes were utilized.

Lane (1980) found canopy cover to be the single most important factor in relating spectral reflectance to vegetation factors. The work done in the Langebaan area, however, shows height of dominant strata as well as canopy cover to be important in distinguishing plant communities at this scale of resolution. This would appear to be a function of ground cover, in that in the higher cover areas ($>$ 50 per cent), height of dominant strata becomes an important factor, whereas in lower cover areas ($<$ 50 percent) canopy cover remains of prime importance.

Comparisons between the two areas has also revealed an interesting aspect of the importance of seasonal variation. With good cover West Coast Strandveld (Acocks' Veld Type 34) communities ($>$ 70 percent projected canopy cover) in the Langebaan area, summer imagery provides greater distinction between the drought deciduous elements (losing leaves in summer) and the evergreen elements. However, further north of Verlorenvlei, as the ground cover drops to values of 5 – 25 percent, summer imagery containing the drought deciduous elements gives no distinction from the background soil characteristics. It would appear that in the lower cover categories (below 50 percent ground cover), the time of maximum leaf standing crop is the best time for vegetation mapping. In good ground cover areas ($>$ 50 percent) the time of maximum contrast between dominant elements should be chosen.

2. Study at the reconnaissance scale (1:250 000).

In work done at a 1:250 000 scale (Jarman, Bossi and Moll 1981) which incorporates the Langebaan area in a much larger scene (whole Landsat scene used i e 185 x 185 km), only three spectral categories are recognized. These correspond to:

- Dune sand (0 - 5 percent ground cover)
- Dwarf / Low Open/Sparse Shrublands (0 - 1,0 m and 5 - 50 percent ground cover)
- Low/Mid-high Mid-dense/Closed Shrublands (0,25 - 2m and 50 - 100 percent ground cover)

Identifying the 'cut-off' points at which these distinctions are made at each scale of operation is important, if the technique is to be used more widely for mapping purposes. The above divisions fall within the categories defined by Campbell et al (1981) for structural characterization of the Fynbos Biome.

4.6 CONCLUSIONS

Generally in providing classification maps from remote sensing data to meet prescribed specification accuracy standards some form of reliable statistical testing is necessary. The sampling strategy used to test this should require the minimum number of field checks, and yet ensure that results are statistically valid.
A stratified random technique is described by van Genderen and Loch (1977) and Hay (1979). Stratified random techniques have been accepted as the most appropriate method of sampling accuracy in land-use studies using remote sensing imagery, so that smaller areas can be satisfactorily represented. Hay (1979) concludes that a minimum sample size of fifty samples per category is necessary for accuracy checking. This makes it possible not only to determine accuracy in general terms, but to identify under-estimation, over-estimation, and the presence of a significant frequency of misclassification between two categories.

The nature of this exercise, which was primarily set up to test computer classification against an already available vegetation description has not allowed for any field based accuracy determinations. The original vegetation map was drawn up from field observations, and was accepted as "accurate".

No claims as to the accuracy of the mapping on a statistical basis are made. Direct visual comparison of the products; and of the listed site data serve to show the amount of agreement achieved.

None of the twelve land-based floristic groupings achieved from air-photo interpretation of colour 1:10 000 photos was distinguished as a separate spectral category in this study. However eight spectral/structural categories were obtained when re-analyzing the site data according to Campbell et al (1981) structural scheme for describing fynbos plant communities. Two of the six marsh floristic forms were separated on spectral criteria alone. Again, in all five spectral/structural categories were obtained in the marsh situation, which corresponded closely to habitat factors and plant community structural features.

Final map production in this study (Figure 4.8) utilized the advantages of automatic processing of data and of detailed knowledge of field samples. The processes which are tedious by hand have been automated, as have the processes which require consistency of identification. However, the decisions on 'training units' were based on the knowledge and experience of field workers.

4.7 ACKNOWLEDGEMENTS

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APPENDIX

TABLE 4.1 Listing of individual sample sites with their floristic/structural designation[1], structural data[2], computer class number[3], substrate and location, dominant species, and biotic factors

Plot No.	Map category[1]		Computer Class[3]	%	m [2]	Class	Substrate & location	Dominant Species	Other factors
260	A	Coastal-shelf Dwarf Succulent Shrubland	(3)	70	5-10cm 0,5-1	Dwarf Mid-dense Succulent Shrubland with a Low Sparse Succulent Shrub Overstorey	Granite Coastal Shelf	Zygophyllum cordifolium Zygophyllum morgsana	Dry soil Flat site
261	A	"	(3)	85	0cm 1,2	Dwarf Closed Shrubland with a Low Sparse Succulent Shrub Overstorey	"	Ruschia geminiflora Zygophyllum morgsana	"
262	A	"	(3)	70	5cm 0,6	Dwarf Mid-dense Succulent Shrubland with a Low Sparse Succulent Shrub Overstorey	"	Atriplex semibaccata Zygophyllum morgsana	"
303	A	"	(3)	50	5cm 0,5	"	"	Zygophyllum cordifolium Zygophyllum morgsana	"
304	A	"	(3)	45	30cm 0,6	Low Open Succulent Shrubland	"	Atriplex semibaccata Zygophyllum morgsana	Heavily grazed
305	A^x(E)	"	(2)	30	10cm 1,0	Low Open Shrubland	Granitic loam with calcrete	Exomis microphylla	Old land
306	A	"	(2)	80	10cm 0,75	Dwarf Closed Succulent Shrubland with a Low Sparse Succulent Shrub Overstorey	Granite + shadow	Atriplex semibaccata Zygophyllum morgsana	
307	A	"	(3)	85	5cm 0,75	"	Shallow loamy sandy	Zygophyllum cordifolium Zygophyllum morgsana	Very dry soil flat
317	A	"	(3)	60	5cm 0,35	Dwarf Mid-dense Succulent Shrubland with a Low Sparse Succulent Shrub Overstorey	Exposed limestone	Zygophyllum cordifolium Senecio floribunda	Very dry flat
313	B	Coastal-shelf Dwarf Succulent Shrubland	(3)	70	0,45	Low Mid-dense Grassy and Succulent Shrubland	Granite coastal shelf	Ehrharta calycina Muraltia dumosa	
314	B	"	(3)	50	0,35	"	Loose sandy loam coastal shelf	Pentaschistis thunbergii Ruschia geminiflora	
318	B	"	(3)	75	0,15	Dwarf Closed Grassy and Succulent Shrubland	Granite exposed boulders	Pentaschistis Ruschia geminiflora	
312	C	Hillside Closed Dwarf Shrubland (succulent)	(3)	70	0,50	Low Mid-dense Succulent Shrubland	Malmesbury shale	Senecio floribunda, Ruschia geminiflora, Zygophyllum morgsana	
339	C	"	(3)	75	0,45	Low Closed Succulent Shrubland	Granite coastal shelf	Zygophyllum morgsana Ruschia geminiflora	
340	C	"	(3)	78	0,20	Dwarf Closed Succulent Shrubland	Granite coastal shelf	Zygophyllum morgsana Ruschia geminiflora	
341	C	"	(3)	65	0,40	Low Mid-dense Succulent Shrubland	"	Zygophyllum morgsana Ruschia geminiflora	
308	D^x(A)	Hillside Dense Shrubland with scattered trees	(12/13/14)	80	1,2	Mid-high Closed Shrubland	Granite hillslope	Zygophyllum morgsana Rhus glauca, Othonna carnosa	Tree layer missing Shadow & steep slope
310	D	"	(12/13/14)	85	2,0m 4m & 40 cm	Mid-high Mid-dense Shrubland with scattered trees and a tall sparse grassland	Granite outcrop	Maurocenia frangularia, Rhus glauca, Rhus spinosa, Ehrharta erecta	Shadow at base of outcrop

Plot No.		Map category (1)	Computer (3) Class % m (2)	Class	Substrate & location	Dominant Species	Other factors
311	D	Hillside Dense Shrubland with scattered trees	(12/13/14) 75 1,75	Mid-high Closed Shrubland	Granite hill slope	Zygophyllum morgsana Exomis microphylla	Tree layer missing Shadow & steep slope
315	D	"	(12/13/14) 80 3-4cm 1,2 0,5	Mid-high Mid-dense Shrubland with scattered trees and a Tall Sparse Grassland	Granite outcrop	Rhus laevigata, Maurocenia frangularia, Ehrharta erecta	Shadow & steep slope
316	D	"	(12/13/14) 50 20cm 1,0 3,0	Mid-high Mid-dense Shrubland with scattered Trees and Tall Sparse Grassland	Granite outcrop	Maurocenia frangularia, Ehrharta erecta, Pterocelastrus tricuspidatus	Shadow & steep slope
297	E[x] J	Limestone Evergreen Shrubland	(2) 70 1,0	Low Mid-dense Evergreen Shrubland	Exposed limestone ridge	Rhus spinosa, Maytenus oleiodes, Zygophyllum morgsana	Slight slope heavily grazed
298	E	"	(2) 60 0,3	"	"	Senecio floribunda, Ehrharta calycina	heavily grazed
299	E	"	(2) 60 1,2 0,25	"	Limestone ridge	Rhus spinosa, Zygophyllum morgsana,	heavy grazing
301	E[xA]	"	(2) 60 0,3	"	"	Senecio floribunda, Zygophyllum cordifolium Ehrharta calycina	heavily grazed
302	E	"	(2) 65 0,4	"	Exposed limestone ridge	Zygophyllum cordifolium, Senecio floribunda, Ehrharta calycina	heavily grazed
309	E	"	(2) 40 0,7 0,25	"	"	Ehrharta calycina, Zygophyllum cordifolium	moderate grazing
338	E	"	(2) 40 0,3 1,0	"	Consolidated limestone	Zygophyllum cordifolium, Ehrharta calycina	grazed
268	F	Limestone Evergreen Dwarf Shrubland	(5) 40 0,3	Low Open Evergreen Shrubland	Exposed limestone ridge crest	Limonium perigrinum, Zygophyllum cordifolium, Psoralea, Exomis microphylla	grazed
292a	F	"	(3) 80 1,0	Low Closed Evergreen Shrubland	Exposed limestone outcrop	Clutia daphnoides, Ehrharta calycina, Psoralea	moderate/heavy grazing
342	F	"	(5) 45 0,6	Low Open Evergreen Shrubland	"	Limonium perigrinum, Zygophyllum morgsana	grazed
343	F	"	(5) 40 0,45	"	"	Psoralea, Clutia daphnoides	heavily grazed
276	G	Consolidated Dune Dense Evergreen Shrubland	(3) 80 1,2	Mid-high Closed Evergreen Shrubland	Stable dune drainage line	Zygophyllum morgsana, Maytenus oleoides	moderate grazing
279	G	"	(3) 70 1,3 0,75	Mid-high Mid-dense Evergreen Shrubland	Stable dune slight dip	Zygophyllum flexiosum, Limonium perigrinum	moderate grazing
281	G	"	(3) 80 1,2	Mid-high Closed Evergreen Shrubland	Calcified dune	Zygophyllum morgsana, Senecio floribunda, Putterlickia pyracantha	moderate grazing
286	G[x]	"	(2) 80 0,6	Low Closed Evergreen Shrubland	Limestone ridge, old calcified dune	Maytenus oleoides, Senecio floribunda	moderate grazing
287	G	"	(3) 90 1,2	Mid-high Closed Evergreen Shrubland	Stable dune slope	Maytenus oleoides, Senecio floribunda	light grazing

Plot No.		Map category [(1)]	Computer[(3)] Class %	m [(2)]	Class	Substrate & location	Dominant Species	Other factors
291	G	Consolidated Dune Dense Evergreen Shrubland	70	(3) 1,2	Mid-high Mid-dense Evergreen Shrubland	Stable calcified dune	Euphorbia mauretanica, Zygophyllum morgsana, Putterlickia, Othonna, Ruschia, Maytenus	
266	H	Consolidated Dune Dense Evergreen Restioid Shrubland	75	(3) 1,3	Mid-high Closed Evergreen Restioid Shrubland	Stable calcified dune	Zygophyllum morgsana, Salvia, Chrysanthemoides, Maytenus, Eriocephalus	grazed
269	H	"	75	(3) 0,75 1,0	Low Closed/Mid-high Closed Evergreen Restioid Shrubland	Stable dune, deep sand	Willdenowia striata	light grazing
270	H	"	90	(3) 1,0	Mid-high Closed Evergreen Restioid Shrubland	Fixed dune slope	Willdenowia striata, Zygophyllum morgsana, Putterlickia pyracantha	light grazing
290	H[x]	"	80	(3) 1,0	"	Consolidated dune slope	Willdenowia striata, Salvia africana-lutea	light grazing
336	H	"	50	(2) 1,3	Mid-high Mid-dense Evergreen Restioid Shrubland	Deep sand	Maytenus heterophylla, Willdenowia, Colpoon, Eriocephalus	heavy grazing
265	I	Consolidated Dune Dense Tall Restioid Herbland	100	(2) 2,0	Mid-high Closed Restioland	Consolidated dune hollow	Thamnochortus spicigerus, Limonium perigrinum	wet
294	I	"	90	(5) 2,0	"	"	Thamnochortus spicigerus, Colpoon compressum, Limonium perigrinum	
300	I	"	70	(2) 1,2	Mid-high Mid-dense Restioid Shrubland	Exposed limestone slope	Thamnochortus spicigerus, Briza maxima, Ehrharta calycina	heavy grazing
263	J	Littoral Dune Dwarf Succulent Shrubland	75	(5) 0,2	Dwarf Mid-dense Succulent Shrubland	Fixed dune sand	Chrysanthemoides monilifera, Ruschia, Amellus, Limonium	light grazing
267	J	"	70	(10) 0,10	Mid-dense Graminoid Shrubland	Dune slack	Salvia, Hermannia, Ehrharta calycina	heavy grazing
272	J	"	60	(10) 0,4 0,1	"	Dune slopes	Limonium perigrinum, Ruschia, Ehrharta	mole activity
273	J	"	85	(5) 0,3	Closed Grassland	Deep sand Dune ridge	Erogrostis cyperoides, Limonium perigrinum, Ruschia	exposed
274	J[x]	"	70	(3) 0,45	Low Mid-dense Succulent Shrubland	Dune sand valley	Limonium perigrinum, Ehrharta villosa	undisturbed
275	J	"	30	(10) 0,1	Dwarf Open Succulent Shrubland	Dune ridge	Ehrharta calycina, Restio eleocharis	heavy grazing
277	J	"	95	(5) 0,25	Closed Graminoid Shrubland	Dune crest in valley	Eragrostis cyperoides, Limonium perigrinum, Restio eleocharis	mole activity
278	J	"	75	(3) 0,3	Low Mid-dense Succulent Shrubland	Dune slack	Nylandtia spinosa, Ehrharta calycina, Ruschia	mole activity
280	J	"	40	(5) 0,10	Open Restioland/Sparse Graminoid Shrubland	Crest of dune ridge	Restio eleocharis, Ehrharta colycino, Ehrharta villosa	heavy grazing
282	J	"	35	(3) 0,4	Low Open Succulent Shrubland	Calcified stable dune	Lebechia, Ehrharta calycina	heavy grazing

Plot No		Map category (1)	Computer Class (3) % m (2)	Class	Substrate & location	Dominant Species	Other factors
285	J	Littoral Dune Dwarf Succulent Shrubland	(2) 50 0,5	Low Mid-dense Evergreen Shrubland	Ridge in dune valley	Ruschia cymosa, Limonium perigrinum Senecio floribunda	
288	J	"	(5/2) 60 0,15 0,75	"	Dune slack	Cnidium, Ruschia, Ehrharta calycina, Nylandtia spinosa	moist
289	J	"	(5) 80 0,3	Closed Graminoid Shrubland	Dune crest in valley	Eragrostis cyperoides, Ehrharta, Nylandtia, Ruschia	
293	J	"	(5) 40 0,25	Dwarf Open Succulent Shrubland	Exposed dune ridge	Ehrharta calycina, Ficinia	heavy grazing
295	J	"	(5) 67 0,45	Low Mid-dense Succulent Shrubland	Dune slack	Ehrharta calycina, Ehrharta villosa, Zygophyllum flexiosum	
296	J	"	(5) 70 0,35	Mid-dense Graminoid Shrubland	Dune crest in valley	Eragrostis cyperoides, Ehrharta calycina	
264	K	Littoral Dune Open Grassland	(8) 60 0,5	Low Mid-dense Grassland	Undulating dune field	Eragrostis cyperoides	
271	K	"	(8) 95 0,45	Low Closed Graminoid Shrubland	Undulating dune crests	Eragrostis cyperoides, Limonium perigrinum,	
283	K	"	(4) 85 0,5	"	Reclaimed dune crest	Ammophilia arenosia, Carpobrotus, Senecio	
284	K	"	(5) 90 1,4	Mid-high Closed Graminoid Shrubland	Semi-stable dune	Eragrostis cyperoides	
334	L	Dune Dense Evergreen Ericoid Shrubland	(4/7) 70 1,6	Mid-high Mid-dense Evergreen Small-leaved Shrubland	Undulating dune ridges	Passerina, Myrica, Anthospermum, Metalasia, Restio	dry light grazing
335	L	"	(4/7) 85 1,0	Mid-high Closed Evergreen Small-leaved Shrubland	Wide dune valley	Myrica, Passerina, Restio, Anthospermum	periodically moist
345	L	"	(4/7) 80 1,3	"	"	"	periodically moist
333b	L	"	(4/7) 67 1,2	Mid-high Mid-dense Evergreen Small-leaved Shrubland	Gully in dune ridge	Restio eleocharis, Metalasia muricata, Myrica quercifolia	dry light grazing
319	Ma_1	Juncus kraussii form of Dense Sedgelands	(12) 100 0,6 5cm	Low Closed Sedgeland	Upper lagoon edge	Juncus kraussii, Arthrocnemum pillansii	moist
324	Ma_1	"	(12) 100 1,0	Low Closed Sedgeland	"	"	slightly elevated moist
327	Ma_1	"	(12) 100 0,4	Low Closed Sedgeland	"	"	higher ground on marsh edge
320	Ma_2	Nidorella-Senecio form of Dense Sedgelands	(2) 70 1,3	Mid-high Mid-dense Shrubland	"	Senecio, Nidorella, Juncus kraussii	drier areas. some trampling
325	Ma_2	"	(2) 100 1,3	Mid-high Closed Shrubland	"	Senecio, Nidorella, Scirpus, Juncus	"
321	Mc	Typha capensis form of Dense Sedgelands	(11) 85 2,0	Tall Closed Sedgeland	Marsh edge	Typha capensis	surface water
326	Mb	Cliffortia strobilifera form of Dense Sedgelands	(11) 100 2,5	Tall Closed Sedgeland	"	Cliffortia strobilifera	wet upper marsh edge
322	Md	Phragmites australis form of Dense Sedgelands	(14) 100 3,5	Tall Closed Sedgeland	"	Phragmites australis	deep water
323 to 332	Nb	Spartina-Triglochin form of Dense Sedgelands	(14) 100 3cm	Closed Marsh Grassland	Lagoon edge	Arthrocnemum pillansii, Spartina	shallow water
328 to 333a	Na	Limonium-Disphyma form of Dense Sedgelands	(4) 98 10cm	Dwarf Closed Sedgeland	Raised areas on mud flats	Arthrocnemum, Chenolea, Ruschia, Drosanthemum	

PART V REPORT

REMOTE SENSING PRODUCTS FOR STUDYING AND MAPPING THE FYNBOS BIOME

AN ECO-LAB PUBLICATION

REMOTE SENSING PRODUCTS FOR STUDYING AND MAPPING THE FYNBOS BIOME

REMOTE SENSING PRODUCTS FOR STUDYING AND MAPPING THE FYNBOS BIOME

- an investigation into the usefulness of various techniques

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ABSTRACT

A remote sensing project initiated in the south western Cape aimed to determine the extent of the Fynbos Biome and of the major landuse types within it. Various remote sensing products were used, in particular available LANDSAT 1 and 2 multi-spectral scanner (MSS) data in the form of computer compatible tapes (CCT's) obtained from NASA via the Satellite Remote Sensing Centre at Hartebeeshoek. The development of the CATNIPS suite of programmes for the University of Cape Town Image Processing Unit (UCT IPU) made the application of computer analysis to this satellite data feasible.

The classification routines used in the UCT IPU system are an iterative clustering routine based on the ISODATA technique (Ball & Hall 1965) and the Bayesian Maximum Likelihood classifier (Schlein & Goodenough 1973b).

The procedure used to generate a classified map involves the following: identification and extraction of the area of study from the CCT; production of histograms of the distribution of spectral reflectance values for the area to be investigated for each of the four wave bands recorded; the application of stretching routines to that data when deemed necessary; the generation of single wave band map print-outs, enabling the user to decide on test areas within the study area to be extracted; the application of the classification routines to selected test areas and production of map displays of the classified data; the choice of final map classes from test areas; pixel allocation for whole study area to map classes and accompanying map displays (refinements of choice of map classes where necessary plus repetition of whole procedure); final processing of scale and geometric corrections to map display.

The Botanical Research Institute has laid down guide-lines as to the scale of vegetation mapping and the appropriate scale of survey in each case (Edwards & Jarman 1972). The remote sensing project demonstrated the versatility of satellite imagery over that of conventional air photo products when applied to the various scales of operation, in that classification was successfully carried out at a range of scales from 1:10 000 to 1:250 000 using the same basic CCT data. At the smaller scales of operation an averaging routine was developed for producing classification units consisting of groups of pixels. The 'reconnaissance' level of operation at 1:250 000 final mapping scale, has been selected as being the most suitable to meet the overall mapping objective of the Fynbos Biome Project. Direct reception of satellite data at Hartebeeshoek as from January 1981 will ensure availability of suitable up-to-date imagery.

1. INTRODUCTION

1.1 OBJECTIVES OF STUDY

1.1.1 Overall Fynbos Biome Project mapping objective

"Fynbos" is a local term for a category of vegetation formations whose communities characteristically include growth forms of the restioid (grass-like herbs), ericoid and proteoid types (Taylor 1976). Elements of these occur in Acocks' (1953) Veld Types 47 (Coastal Macchia = Coastal Fynbos for Fynbos Biome Project purposes); 69 (Macchia) and 70 (False Macchia) together referred to as Mountain Fynbos; and two transitional types, 34 (Strandveld of the West Coast) and 46 (Coastal Renosterbosveld. The geographic area encompassing Veld Types 47, 69, 70, 46 and the southern portion of 34 constitutes the Fynbos Biome, with approximate limits being 31° to 35°S and 18° to 27°E (Day et al 1979).

The Fynbos Biome Project, initiated in 1977, is one of several National Scientific Programmes within the National Programme for Environmental Sciences, administered by the CSIR.

A stated Phase I objective of the Fynbos Biome Project is "the definition of the geographical distribution and extent of the major vegetation types of the biome" (South African National Scientific Programmes Report No 28). The remote sensing project initiated within the Fynbos Biome Project aimed to help achieve this objective. It included the determination of the extent and distribution of wetlands, the extent of forest/plantation, the extent and distribution of dense alien plant distributions, and the extent of fire and post-fire regeneration.

1.1.2 Use of computer classification of LANDSAT data to meet this objective

South Africa was involved in the ERTS-A programme (LANDSAT previously called ERTS) in 1972-73, in the form of a project entitled "To assess the value of satellite imagery in resource evaluation on a national scale" (Malan 1973). Product quality was a problem in these investigations, because the imagery made available from NASA were poor quality 3rd and 4th generation 70mm positives and negatives. Investigators worked with photographic products and used visual identification of features on these products.

Generally, the outcome of these investigations was that ERTS imagery, particularly in the form of 1:500 000 scale false colour photolithographic prints, could speed up and facilitate resource surveys and geological mapping. Computer compatible tapes (CCTs) became available to local users subsequent to the completion of this national project.

Subsequently, the emphasis internationally in the use of satellite imagery for mapping purposes swung away from visual or image orientated interpretation of data to numerical, computer classification techniques. The Fynbos Biome Project remote sensing project was in a position to be able to utilize these procedures (see section 1.2). However, it should be stated at the outset, that various remote sensing products have been utilized at all stages of this investigation, as an intermediate level of feature identification.

1.1.3 Feasibility study

Successful experimentation with the application of computer classification techniques to Landsat I imagery and vegetation mapping was carried out at 1:20 000 scale in three test areas within the Fynbos Biome (see section 3.1.2). In order to meet the objective of mapping at 1:250 000 scale however, it became obvious that more detailed investigation into various problems which had arisen was necessary. In addition to this, the computer classification techniques being used to meet the long-term objective of mapping the Biome had not been tested using a fully operational local computing facility, namely the UCT Image Processing Unit (see section 1.3).

A feasibility study was therefore embarked on during 1980 within the National Programme for Remote Sensing, using the UCT facilities and already available computer classification techniques to answer the following questions:

(a) Is it possible to recognize and map vegetation types with consistency at the following scales:

Scale of survey	Final mapping scale
General and general reconnaissance	$>$1:1 000 000
Reconnaissance	1:50 000 to 1:1 000 000
Semi-detailed	1:10 000 to 1:50 000
Detailed	1:500 to 1:10 000
Ultradetailed	$<$ 1:5000

(after Edwards and Jarman 1972)

(b) Is it possible to build up a set of spectral reflectance values characteristic of different types of ground cover at these scales?

(c) How does the choice of test area affect the classification?

(d) How does the size of test area affect the classification?

(e) How does topographic variation affect the classification?

(f) What is the effect of the alteration of various programme parameters in this operation? Is it possible to build up a set of guide-lines for use of these procedures in different vegetation types?

(g) What is the effect of using imagery from different seasons on mapping of different vegetation types?

(h) To what extent can the classification techniques when applied to repetitive imagery be used to monitor short term habitat change, and the incidence of events such as fire?

The solution of these existing problems would make it possible to meet the overall Fynbos Biome Project mapping objective.

1.2 THEORETICAL BACKGROUND

1.2.1 Digital Image Processing

Image processing can be regarded as any operation carried out on an image once it has been recorded on some medium. The LANDSAT satellite records spectral reflectance from a portion of the electromagnetic spectrum in digital form allowing flexible manipulation of this data with the aid of computer processing techniques. Digital image processing involves three main branches:

(1) Image restoration processes which recognise and compensate for data errors, noise and geometric distortion introduced in the scanning and transmission processes.

(2) Image enhancement processes which modify an image in order to alter the impact on the viewer.

(3) Information extraction processes which utilize the decision making capability of computers to identify and extract specific groups of information (Sabins 1978).

1.2.2 Computer Classification Techniques

The information extraction processes use computer classification techniques on two or more bands of the LANDSAT multi-spectral scanner (MSS) data. Processing of the multi-band image is made possible by recognizing and classifying the spectral signatures in their numerical form. Each pixel is assigned to a specific class by matching the spectral signature with the range of signatures determined for the class. The preprocessing leading up to the classification is geared toward locating and identifying representative groups of signatures called training classes and ensuring that they are sufficiently different to prevent confusion among them. This type of pattern recognition in digital image processing is statistical in character, and includes "statistical space" in which the "pattern" is a vector made up of a number of measurements, in an n-dimensional space, where n represents the number of MSS bands utilized. The pattern recognition system seeks to partition or place boundaries in the n-dimensional space so that each region of the image can be assigned to a class of patterns (Hajic and Simonette 1976). A mosaic of the image may thus be simplified into a manageable number of relatively homogenous spectral classes.

1.2.3 Supervised versus unsupervised procedures

There are two major methods of obtaining training classes. The first, referred to as the supervised approach involves locating individual pure areas of pixels on the image which represent a single cover type of interest to the user. This selection is based entirely on ground truth. These areas are used to obtain statistical training classes and the pixels in the image would be associated with one of the specified classes. In this way only the data describing the classes of interest is classified thus providing a final map of informational value. The disadvantage with this approach lies in misclassification of pixels as a result of overlap in spectral characteristics obtained from the natural variations in ground-cover.

In the second method, the unsupervised approach, an algorithm is used to delineate groups of pixels within the sample that are spectrally similar in a representative sample from the image.

Ground-truth data is then used to relate these spectral classes to features on the ground. This method is particularly useful in a heterogenous scene in which the likelihood of observing several adjacent pixels of the same cover type is low.

A hybrid approach involves locating several areas which together represent the different cover types on the image. Each area is then processed as in the unsupervised approach to identify the training spectral classes. A choice based on ground-truth is made to decide which of the classes are valid and a final classification is then obtained from the statistical data of the chosen classes.

The technique used in unsupervised approaches utilizes an iterative clustering algorithm to create classes which can then be used to furnish a maximum likelihood classifier with the required data input. The iterative clustering algorithm used by the UCT CATNIPS system is based on the ISODATA technique of Ball and Hall (1965) and the Bayesian Maximum likelihood classifier used as described by Shlien and Goodenough (1973b).

As the clustering algorithm is iterative, it uses a considerable amount of computer time and is consequently expensive. To minimize computer expenses, the procedure used to classify large areas involves the selection of one or more representative training sets which are iteratively classified in order to obtain discrete spectral signatures for input into the Bayesian classifier.

1.2.4 Preclassification data manipulation

After extraction of an image from a CCT, various image display and manipulation routines must be applied in order to obtain an overview prior to classifying.

Image displays on a computer printout with the different print and overprint characters representing a grey-scale level, provide a basis for image manipulation.

Each pixel on an image is assigned a value between 0 and 255. This range of values is divided into 16 groups and each group is represented either by a print character for the computer printout or a grey-scale intensity value used in producing a photographic negative. A routine may be applied to obtain the frequency counts (histograms), percentages and decimal printout of each band of an image. From this, features of interest with particular spectral reflectances may be selected for emphasis on the image output. By using a stretching routine the variance within a small range is increased and more detail is obtained in the desired features without changing the information.

In order to reduce the amount of information of an image, pixel averaging routines may be used on each band. This process makes a large image more manageable when working with an extensive area not requiring much detail. The scale of an image may also be reduced when using routines which correct the image geometrically.

The ratioing technique is an information manipulation and extraction process obtained by dividing the pixel value in one band by the corresponding pixel value in another band. In a ratio image the extreme black-white tones of the grey-scale represent the maximum difference in spectral reflectivity between the two MSS bands.

These ratio images show the variations in slopes of the spectral reflectivity curves (see 1.2.5) between the two wavelength bands. These variations are useful for distinguishing between active vegetation, soil and water. Another advantage of this technique is that a feature has the same ratio value, regardless of variations in illumination and therefore the effects of topography are removed.

1.2.5 Reflectance characteristics of surface features

The quantity of reflected electromagnetic energy detected by LANDSAT is determined partially by atmospheric conditions and the physical characteristics of the biotic components of the ground-cover under surveillance. The variability of atmospheric factors may be minimized on clear days. The physical surface features such as texture, shape, moisture content and colour of individual components of the ground-cover affect the quantity and intensity of their spectral reflectance. These effects are displayed in the frequency of wavelength of the radiation concerned. The generalised reflectance curves for three basic land surface features (water, healthy green vegetation and soil) in the spectral region covered by the LANDSAT MSS are illustrated in

Figure 1.1 (Lane 1980). Bands 4 and 5 measuring reflectance between 0,5 and 0,7 μm are useful in detecting bare areas due to high reflectance values. Bands 6 and 7 (0,7 - 1,1 μm) represent high reflectance values from active vegetation and bare areas and total absorption by water.

1.3 UCT SYSTEM CAPABILITIES

The UCT Image Processing System (CATNIPS) allows analysis of remotely sensed images. The system, written mainly in Fortran on the UCT UNIVAC 1100 / 80 computer, is designed to cater for images from a variety of sources, namely LANDSAT 1, 2 & 3 satellites, NOAA 4 and NOAA 5 weather satellites, and the CZCS (Nimbus-G) oceanographic satellite. The use of any of a large selection of processing modules to produce output allows the user to better understand and analyse the required area. The output can be either on a line printer or on a photographic negative.

The CATNIPS manual provides users of the UCT Image Processing System with an overview of the working and capability of the system. Selected routines used in this project are listed below:

<u>Load Module</u>

INTAPE : To input selected bands from a LANDSAT 1, 2 or LANDSAT 3 tape and convert to internal file format for future processing.

<u>Spatial Manipulation Module</u>

SKEW : Corrects images for pixel aspect ratio and earth rotation.

CLSKEW : Corrects a classified image for earth rotation, pixel aspect ratio, line printer format and scale.

<u>Image Manipulation Module</u>

AVERAG : Reduces the size of an image by pixel averaging.

<u>Radiometric Manipulation Module</u>

RATIO : Calculates the ratio of images.

STRECH : Enables the picture to be stretched over the range 0-255.

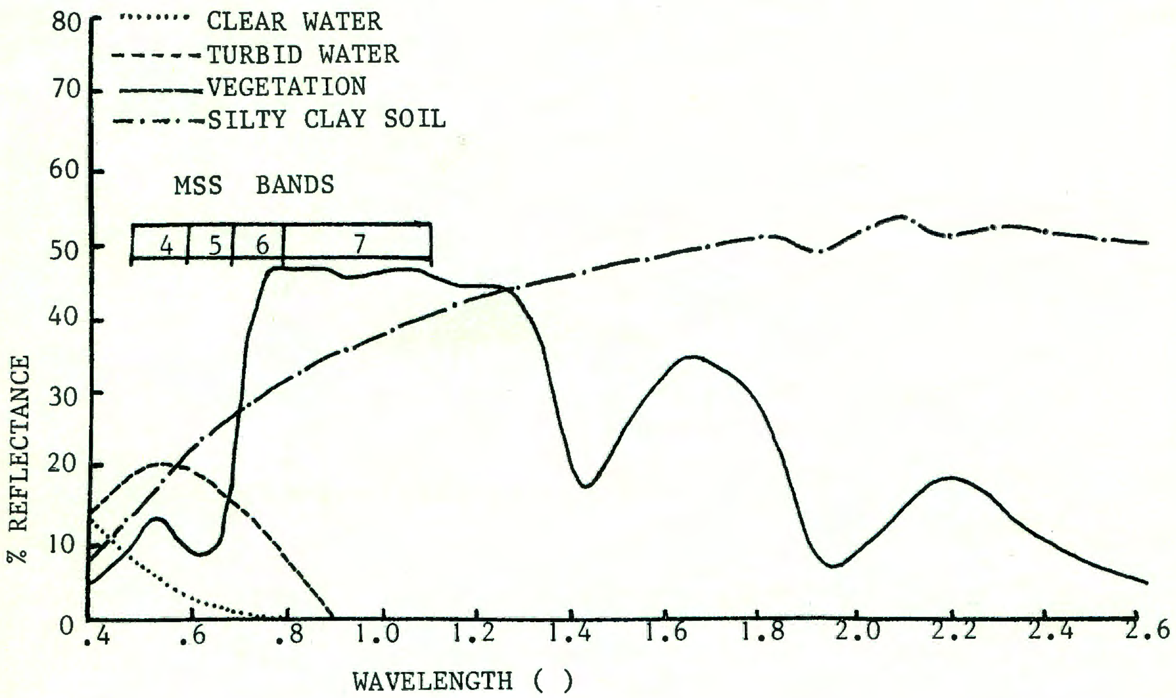


Figure 1.1 Spectral reflectance of basic cover types (After Lane 1980)

Classification Module

MAXLIK : To obtain the maximum likelihood classification of a multispectral image.

ITCLUS : Iterative clustering of an image.

EDTSIG : To select chosen class signatures from input signature files.

Image Display Module

DISPLY : Displays an image or part of an image on the printer, using various characters to denote grey-scale levels.

LIST : Provides frequency counts, percentages and a decimal printout of a picture.

MAPCLS : Prints a classified image.

1.4 AVAILABILITY OF IMAGERY

The availability of imagery in the form of CCTs to achieve the objectives of the project has been a problem.

There has been a shortage of suitable CCTs at UCT for the following reasons:

(1) Repetitive images unavailable at Satellite Remote Sensing Centre.

(2) Cloud cover over the land surface of the images.

(3) Many of the recent CCTs available have one or more bands recorded in high gain mode which is designed to emphasize oceanographic features. Although these can be used in classifications the results are not directly comparable to those using standard LANDSAT CCTs.

As a result of the shortage of suitable CCTs, investigations into the capabilities of the UCT IPU system have been carried out mainly on images recorded in 1972 and 1973. These have been fully adequate for investigating the capabilities of the image processing system available at UCT but it has not yet been possible to fully investigate seasonality or short-term changes in vegetation and it has also not been feasible to undertake mapping of the whole fynbos area at this stage.

With direct reception from the LANDSAT satellite in 1981, however, many of these problems of image accessibility are likely to be minimized and the overall objectives of the Fynbos programme will then become feasible.

1.5 DISCUSSION

The need for a Biome wide mapping of land cover categories for management and conservation purposes has been identified. Available land-use maps are either of too small a scale for these purposes (Acock's 1953) or are based on data collected over a period of time of 5-6 years (Davies and Cook 1980). Mapping using LANDSAT imagery could update available information on land use categories and furthermore can provide valuable information on short-term habitat changes and complex gradual changes which would not be readily apparent using classical survey techniques.

A point which is often difficult to convey is the reason for preferring to use computer classification routines for land use or vegetation mapping. Topographic features, such as are of use in geological or urban applications of remote sensing imagery, are often best illustrated following computer enhancement techniques. But analysis of vegetation and habitat requires considerable simplification of the data, and furthermore it is often difficult if not impossible to class hundreds of colour hues into similar categories. A computer classification routine such as we have described above allows the data to be classified relatively simply on a basis of the actual values of spectral reflectance.

The feasibility study was designed to show the greater versatility of the LANDSAT imagery compared to standard air photos. If LANDSAT products could be shown to be useful at a range of scales, the advantages of acquiring one type of imagery which could be used for a variety of purposes becomes important to a management orientated user agency.

Methods used in the feasibility study are consistent with those used in standard air photo interpretation, that is: choice of representative areas and extrapolation of the knowledge and experience gained working in those areas, throughout a particular study area. As we have become more familiar with the computer classification technique we have become aware of the fact that a "hybrid" approach to classification is the best one to adopt. The choice of an area to run an "unsupervised classification" on should be "supervised". The map planning stage becomes very important. Map classification units should be designed before instigation of the survey, and such units should be real units in terms of landscape features.

The use of preclassification data manipulation has been found to be helpful in locating test areas. In this type of processing certain features are reduced/simplified while others are enhanced. This enables the user to investigate various features of interest more thoroughly. However, it has been decided that unprocessed data should be used in the classification maps at this stage, as they represent the true spectral reflectivity of an area without introducing a bias into the classification.

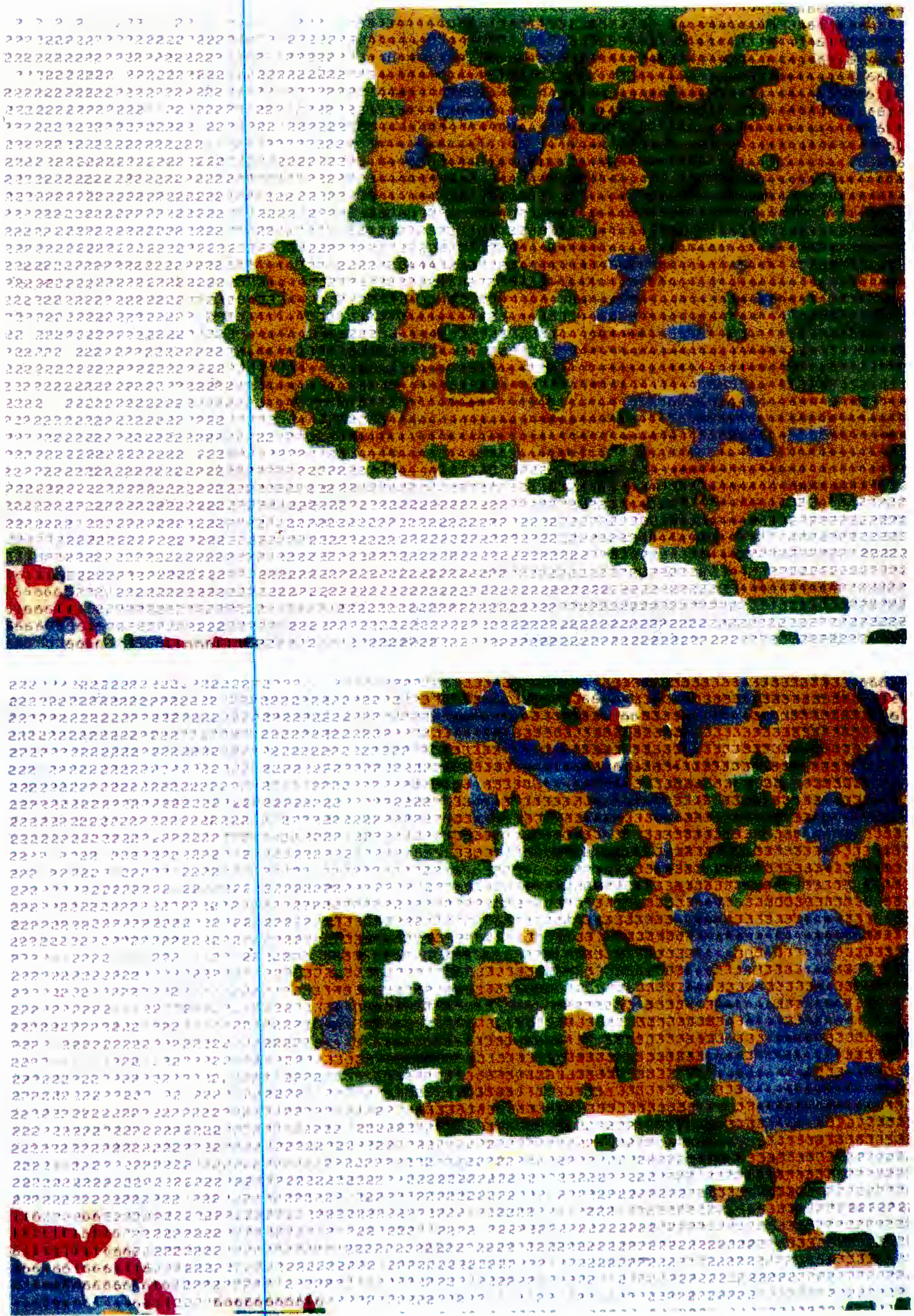


Figure 3.1 Classification of the Langebaan lagoon marsh areas carried out at 1:10 000 scale from CCT 10055 - 08064 16 September 1972 and CCT 10145 - 08073 15 December 1972.

The classified map at the top is the September image and below it is the December image. The dark green communities are the very moist Spartina-Triglochin (Nb) and Typha capensis (Mc) forms of the marsh communities (Boucher and Jarman 1977). Note the more extensive area of dark green in the September image when there is more surface water present.

The UCT CATNIPS system contains many more image processing routines which are used in different applications but have not been investigated. Research into the applications of those routines is needed in order to develop the full potential of the Image Processing Unit at UCT.

2. CATNIPS ROUTINES USED TO GENERATE A CLASSIFIED MAP

A procedure has been developed during the course of this study which uses available CATNIPS routines to generate a classified map. This can be applied, regardless of the scale of mapping operation. A stepwise summary of the procedure follows:

(a) Identify and extract area for study (INTAPE)

The catalogue of CCT's available to users in this country is distributed by the Satellite Remote Sensing Centre at Hartebeeshoek. It lists the CCT's with the World Reference System (WRS) numbering. These numbers correspond to those on an accompanying index map.

We have found that a "visual" picture of the CCT is essential for orientation. Black and white negatives or prints of wave bands 5 and 6 (for vegetation purposes) at 1:1 000 000 scale appear to be the most useful for this purpose. These and other photographic products are also obtainable from Hartebeeshoek.

If only a portion of the CCT is to be used, it can be located on the photographic image, and its position on the CCT identified by measurement, in terms of start pixel number and start line number. A complete LANDSAT CCT is 3240 pixels horizontally by 2340 lines vertically. The top left-hand corner of an image corresponds to position 0 pixel number, 0 line number.

The CCT data is then copied from the NASA tape onto the users computer system using the routine INTAPE, thus generating a tape containing 4 files of the 4 bands of information.

(b) Frequency counts (LIST) and Stretch routines (STRECH)

A histogram of the distribution of spectral reflectance values for the area to be investigated is then listed for each wave band. This enables the user to decide whether to do any stretching routines on the data (STRECH) (see Section 1.2.4).

(c) Display routines (DISPLY)

Single wave band map print-outs are then generated. These enable the user to decide on test areas to be used within the total area under investigation. (See Section 3.2).

(d) Classification routines and map displays (ITCLUS and MAPCLS)

The Ball and Hall (1965) Isodata, iterative clustering routine (see section 1.2.3) is then applied to the test areas followed by a printing out of the classification of these areas.

(e) Choice of final map classes (EDTSIG)

The cluster classes to be used in the final map of the study area are then selected. This can either be from one test area, or from a number of test areas. An editing programme is employed to select the statistics of the cluster classes to be used for the final classification process (see section 1.3).

(f) Final pixel allocation to map classes and display of map (MAKLIK and MAPCLS)

A Bayesian maximum likelihood classifier is then used to obtain the final allocation of all pixels for the whole study area into the cluster classes that they closest represent. This is again followed by a printing out of the final classification of the study area.

Sections (d), (e) and (f) above can be repeated until the user is satisfied with the product.

(g) Final processing, scale corrections (SKEW and CLSKEW)

The data can then be processed for scale and geometric corrections to be used in the production of a classified map at the desired scale (see section 1.3).

3. PROCEDURES USED IN FEASIBILITY STUDY

3.1 MAPPING AT DIFFERENT SCALES

Table 3.1 gives a breakdown of selected scales of mapping based on recommendations by the Botanical Research Institute (Edwards and Jarman 1972), the minimum size of map unit recognized at each scale, and what this means in terms of the number of pixels involved in classification in each instance.

It was decided to limit investigation to four scales of operation; namely

(1) detailed (1:10 000)

(2) semi-detailed (1:20 000)

(3) semi-detailed (1:50 000)

(4) reconnaissance (1:250 000)

Table 3.1 Relationship between map scale, smallest recognizable map unit (in ha) and number of pixels used in classification.

Map scale	Smallest map unit recognized = 2 print characters		Units used in classification	
	No of pixels	(ha)	No of pixels	(ha)
General and General Reconnaissance >1:1 000 000	3200	1408,0	1600 (40 x 40)	704,0
Reconnaissance 1:250 000	200	88,0	100 (10 x 10)	44,0
Semi-detailed 1:50 000	8	3,5	4 (2 x 2)	1,8
1:20 000	2	0,8	1	0,4
Detailed 1:10 000	1	0,4	1	0,4
Ultra-detailed <1:500	Beyond the limits of resolution of current LANDSAT series			

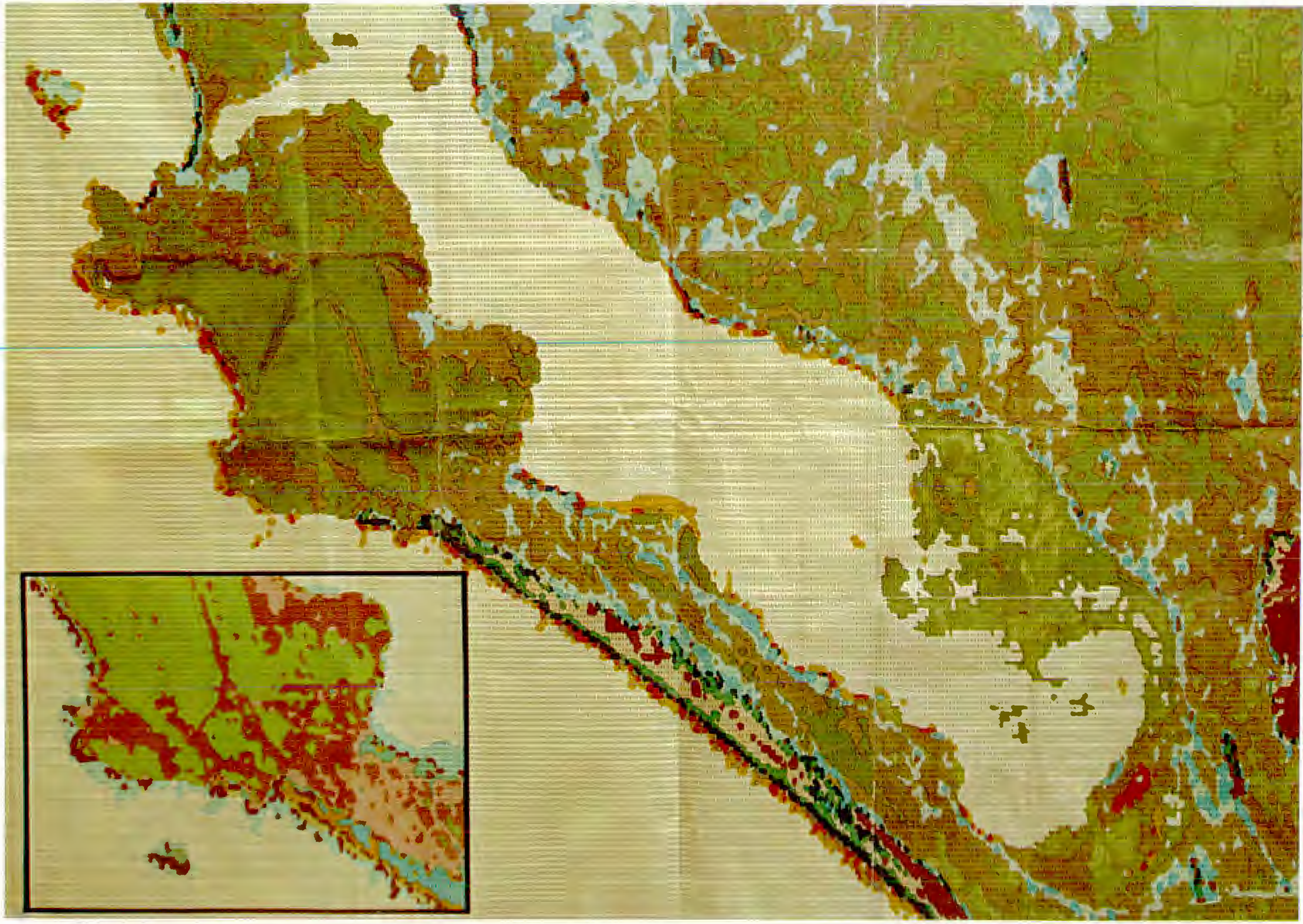


Figure 3.2 Classification of the Langebaan-Saldanha area carried out at 1:20 000 scale using statistics generated from one "representative test area" from CCT 10055 - 08064, 16 September 1972.

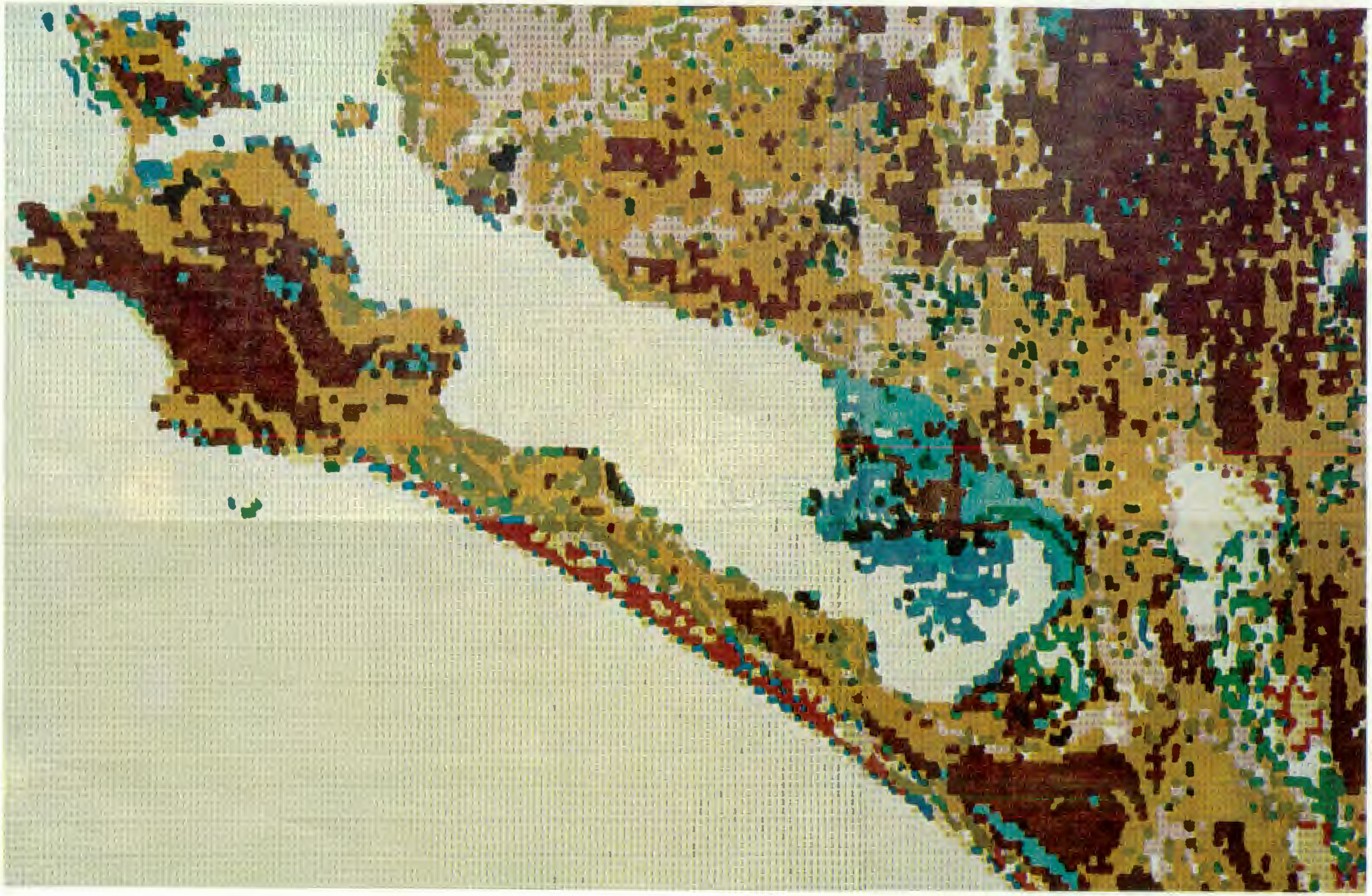


Figure 3.3 Classification of the Langebaan-Saldanha area carried out at 1:50 000 scale from CCT 10055 - 08064, 16 September 1972, using statistics generated from a number of test areas.

The application of classification techniques to LANDSAT data at the remaining two mapping scales would not be suitable. Condensing information into 40 x 40 pixel blocks at 1:1 000 000 general and general-reconnaissance scale of operation would lose too much information; and the ultra-detailed level of mapping was beyond the limits of resolution of the present LANDSAT series. The 4 scales of operation were also selected because of the availability of maps, standard air photo products, and orthophoto products at these scales.

3.1.1 Detailed - final mapping 1:10 000 scale

Classification routines applied at this scale of operation use single pixels as units for classification. This is approaching the lower limits of resolution of the technique. However, the marsh community area of the CCT 10055-08064, 16 September, 1972 Langebaan-Saldanha study area (see 3.1.3) was classified into a large number of classes to show the detail it is possible to extract from a CCT (see figure 3.1). The routines INTAPE, LIST, DISPLY, ITCLUS and MAPCLS, MAKLIK and MAPCLS were used in this instance. This was checked against available 1:10 000 scale orthophoto maps, colour air photographs at 1:10 000 scale, and Boucher and Jarman's (1977) map and report on the vegetation of the area. Single pixels were accepted as the smallest unit recognized as map units at this scale.

3.1.2 Semi-detailed - final mapping 1:20 000 scale

This was the scale of operation at which a large amount of the initial work was carried out. During the course of the feasibility study the routines AVERAG and EDTSIG were written for the CATNIPS suite. At a 1:20 000 scale of operation classification routines are applied to single pixel units, with no AVERAG routine being necessary.

(a) The first approach used the routines INTAPE, LIST, DISPLY, ITCLUS and MAPCLS, MAKLIK and MAPCLS for the whole area of study in each case, or used the cluster class statistics generated from one representative test area.

The following study areas in the SW Cape were investigated:

Study Area	WRS	Scene ID		Date
Table Mountain	187-084	10180-08015	of	19.1.73 (Jarman 1979)
Cape Point	187-084	10180-08015	of	19.1.73 (Ripp 1978)
Ysterfontein	188-083	10055-08064	of	16.9.72 (Bossi 1979)
Verlorenvlei	188-082	10181-08065	of	20.1.73 (Lane 1980)

(b) The second approach used the routines INTAPE, LIST, DISPLY, ITCLUS and MAPCLS, EDTSIG, MAKLIK and MAPCLS, SKEW. In this approach test areas are selected, the ITCLUS routine applied to these areas, and the routine EDTSIG used to combine the statistics of a number of classes from different test areas if necessary. This represents a major advance in the versatility of the UCT CATNIPS system in applications of classification procedures.

The following area was studied (see Figure 3.2):

Langebaan-Saldanha 188-083 10055-08064 of 16.9.72 (Jarman and Jackson in prep)

3.1.3 Semi-detailed - final mapping 1:50 000 scale

The availability of 1:50 000 Topocadastral series of maps produced by Trigonometrical Survey Office made this a logical choice of final mapping scale. The original scale of operation for the Fynbos Biome Project Landuse project (Davies and Cook 1980) was also carried out using the information on the 1:50 000 Topocadastral Series as a data base.

CCT WRS 188-083 Scene ID 10055-08064, 16 September 1972, was used for this investigation.

Three different procedures were adopted, and comparisons of the final map products in each case were carried out. In each instance the Langebaan Peninsula area was extracted from the whole tape (INTAPE) (33°04'S to 33°13'S and 17°56'E to 18°10'E). This is an area approximately 20 x 20 km in extent.

(a) In the first instance the sequence INTAPE, LIST, DISPLY, ITCLUS and MAPCLS, EDTSIG, AVERAG, MAKLIK and MAPCLS was used. This classification was carried out by obtaining the chosen spectral classes from test areas at a single pixel level. The whole study area was then reduced to a 1:50 000 scale by using a 2 x 2 average routine. A maximum likelihood classification was then applied based on the statistics of the larger-scaled test areas (see figure 3.3).

(b) Secondly the sequence INTAPE, LIST, DISPLY, ITCLUS and MAPCLS, EDTSIG, MAKLIK, CLSKEW and MAPCLS was used. In this instance both the generation of classes from test areas and final classification of the study area was carried out at a single pixel level (1:20 000 scale).

(c) Thirdly the sequence INTAPE, LIST, DISPLY, ITCLUS and MAPCLS, EDTSIG, MAKLIK, AVERAG and MAPCLS was used. The same classification procedure as that in section (b) was used but the final scale adjustment from 1:20 000 to 1:50 000 was carried out by using the 2 x 2 averaging routine.

3.1.4 Reconnaissance - final mapping 1:250 000 scale

A 1:250 000 final mapping scale was decided upon due both to the availability of a base map series at that scale for the Fynbos Biome with accompanying Acocks Veld Types overlays, already produced by another Fynbos Biome Project Landuse investigation (Davies and Cook 1980)

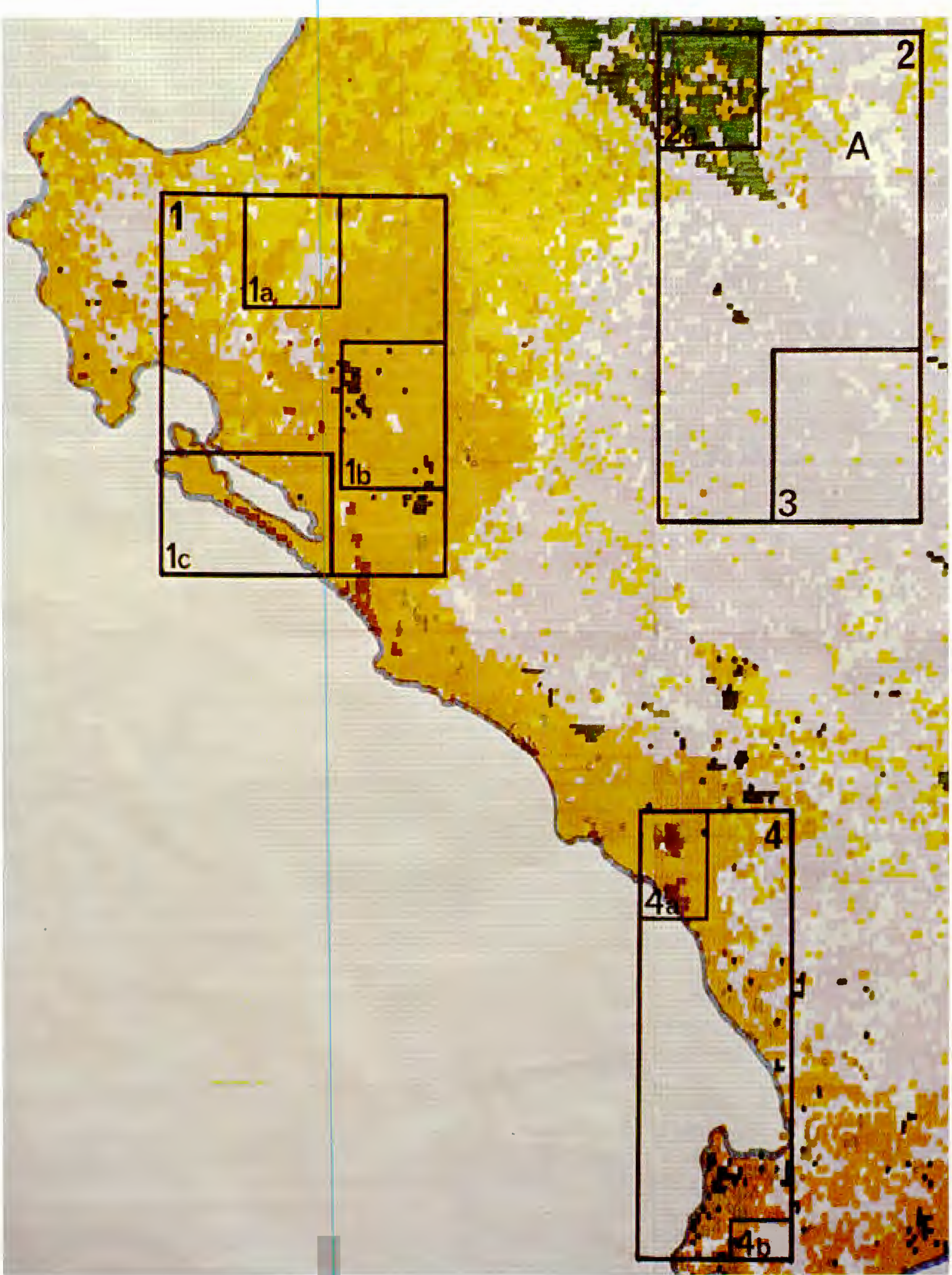


Figure 3.4 Classification of CCT 10055-08064 16 September 1972 carried out at 1:250 000 scale, showing test areas used in classification (7 map classes).

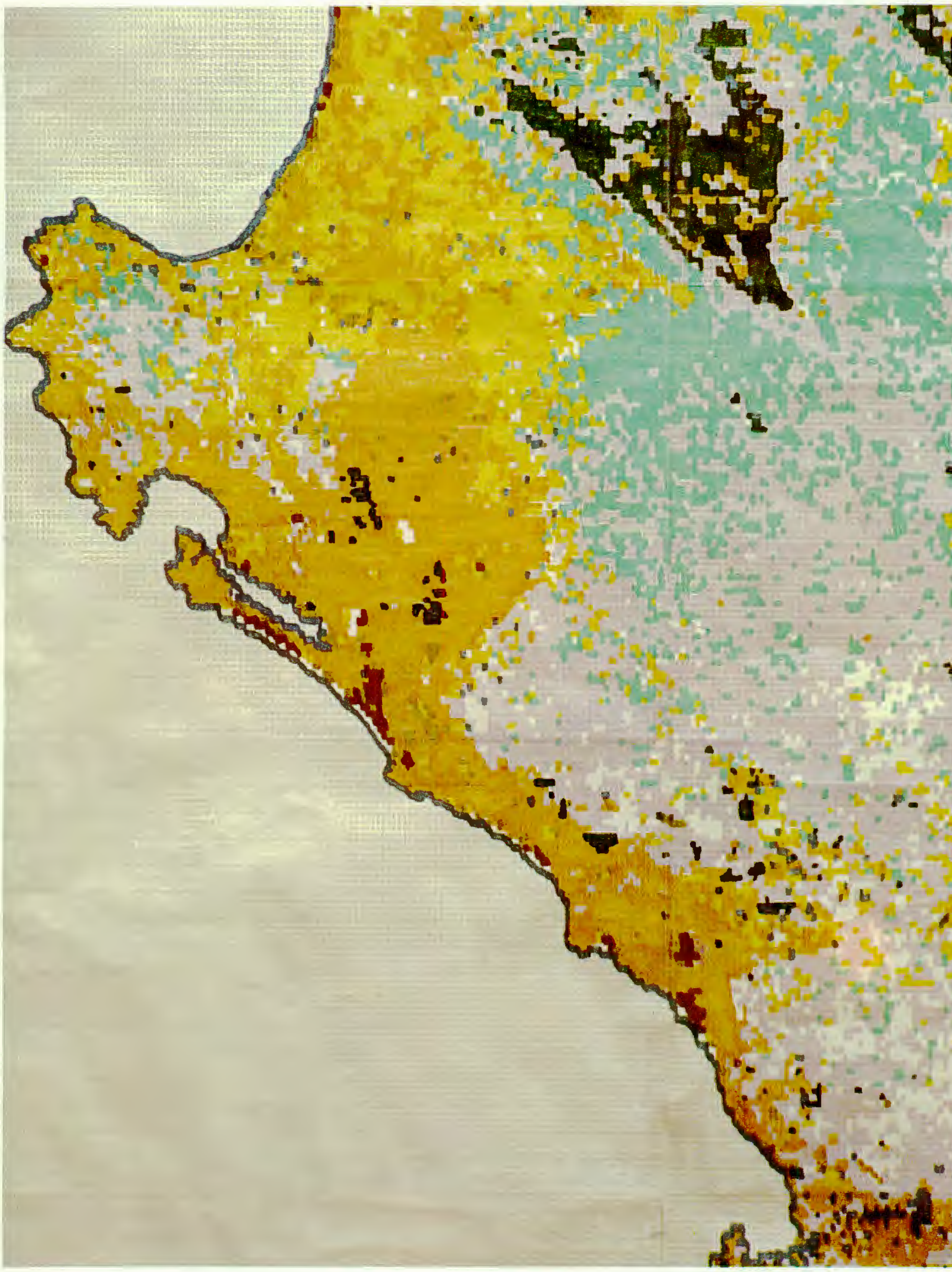


Figure 3.5 Classification of CCT 10055 - 08064 16 September 1972 carried out at 1:250 000 scale. This is an eight class classification.

and the availability to all potential users of 1:250 000 Topographic and Topocadastral series produced by Trigonometrical Survey for the whole of South Africa.

CCT's used at this scale were:

CCT	WRS	Scene ID	Date
(a)	188-083	10055-08064	16 September 1972
(b)	188-083	10145-08073	15 December 1972
(c)	187-084	30271-07511	1 December 1978
(d)	187-084	10180-08015	19 January 1973

The basic procedure described in Section 2 was followed with all 4 CCT's. The whole CCT (185 km x 185 km) was extracted in each instance. A step was included between stages (a) INTAPE and (b) LIST of the described procedure. This comprised the averaging routine AVERAG (see section 1.2.4), which reduced the spectral information to a 10 x 10 pixel matrix, with each unit used in subsequent processing then being 44,0 ha in extent.

The remaining steps of the procedure (c) DISPLY, (d) ITCLUS and MAPCLS, (e) EDTSIG, (f) MAXLIK and MAPCLS were then carried out, with successive refinements (see Figures 3.4 and 3.5). Once the desired classifications had been obtained, they were checked against available soil and geology (Coertze 1970 and Theron 1971) and vegetation maps (Acocks 1953) (see Figure 3.6) for confirmation of the broad landscape classes. They were also compared with the map and report produced by Taylor and Boucher (1973), as part of the Section III, Plant Ecological Surveys - B - "Vegetation boundaries of the south western Cape" (see Figure 3.7). They had used visual identification of features off the 1:500 000 photolitho prints of the 16 September 1972, Scene ID 10055-08064 Langebaan image and the 19 January 1973, Scene ID 10180-08015, Cape Peninsula image. These two researchers also had good field working experience of the area covered.

3.2 CHOICE OF TEST AREA

It is both expensive in terms of computer time, and inefficient in terms of having to handle the confusion of unnecessary added spectral map classes, to run the iterative clustering routine on a whole area of investigation. It appears better to use a "hybrid" approach to the application of classification techniques to mapping of vegetation surface features. This means "supervising" the classification to the extent of selecting the areas which contain the classes which are to be used in the final map classification.

To investigate the effect of choice of test area on the resulting clssification, data from LANDSAT CCT 10055-08064 of 16 September 1972 were subjected to the following treatments.

3.2.1 Semi-detailed investigations at 1:20 000 scale

(a) Data for the previously defined Langebaan-Saldanha area (see Section 3.1.3) were extracted from the tape (INTAPE), histograms of frequency distributions obtained (LIST), stretching of data was carried out (STRECH) and single waveband printouts generated (DISPLY); The single waveband printouts have a range of symbols representing a grey-scale of categories of spectral reflectance. Test areas were selected on the basis of these printouts. The iterative clustering routine was run on all test areas (ITCLUS and MAPCLS), followed by printing out of the map classes for each area. Programme parameters (see Section 3.5) were kept constant for all test areas. The results obtained were examined (Figure 3.8).

In some test areas, where either insufficient or too many classes had been generated, the parameters (T_1 and T_2) were adjusted to rectify this (see Section 3.5).

A final selection of cluster classes from all eleven test areas was made, and the remaining procedures, EDTSIG, MAXLIK and MAPCLS, and SKEW were run to generate the final map (see Figure 3.9)

(b) The same data were used, and one test area selected (see Figure 3.2) in an attempt to choose an area which contained all the representative map units required. The map generated by this approach was compared with that generated using the first approach.

3.2.2 Semi-detailed investigations at 1:50 000 scale

The test areas and statistics of the classes obtained at the 1:20 000 level of investigation were used to generate the map at 1:50 000 scale (see Figure 3.3).

3.2.3 Reconnaissance investigations at 1:250 000 scale

The routines used to select test areas were INTAPE, AVERAG, LIST, STRECH and DISPLY. This produced 10 x 10 averaged pixel single wave band printouts. Test areas were chosen on the basis of the distribution of the range of grey-scale categories of spectral reflectance values on these printouts. The iterative clustering routine was run on all test areas (ITCLUS and MAPCLS), followed by printing out of the map classes for each area. Classes on these printouts were selected on the basis of the iterative clustering classes generated in these test areas considered to be representative of the study area. After the first classification map obtained was

Figure 3.6 Acocks' Veld Types of South Western Cape -- at 1:250 000 scale.

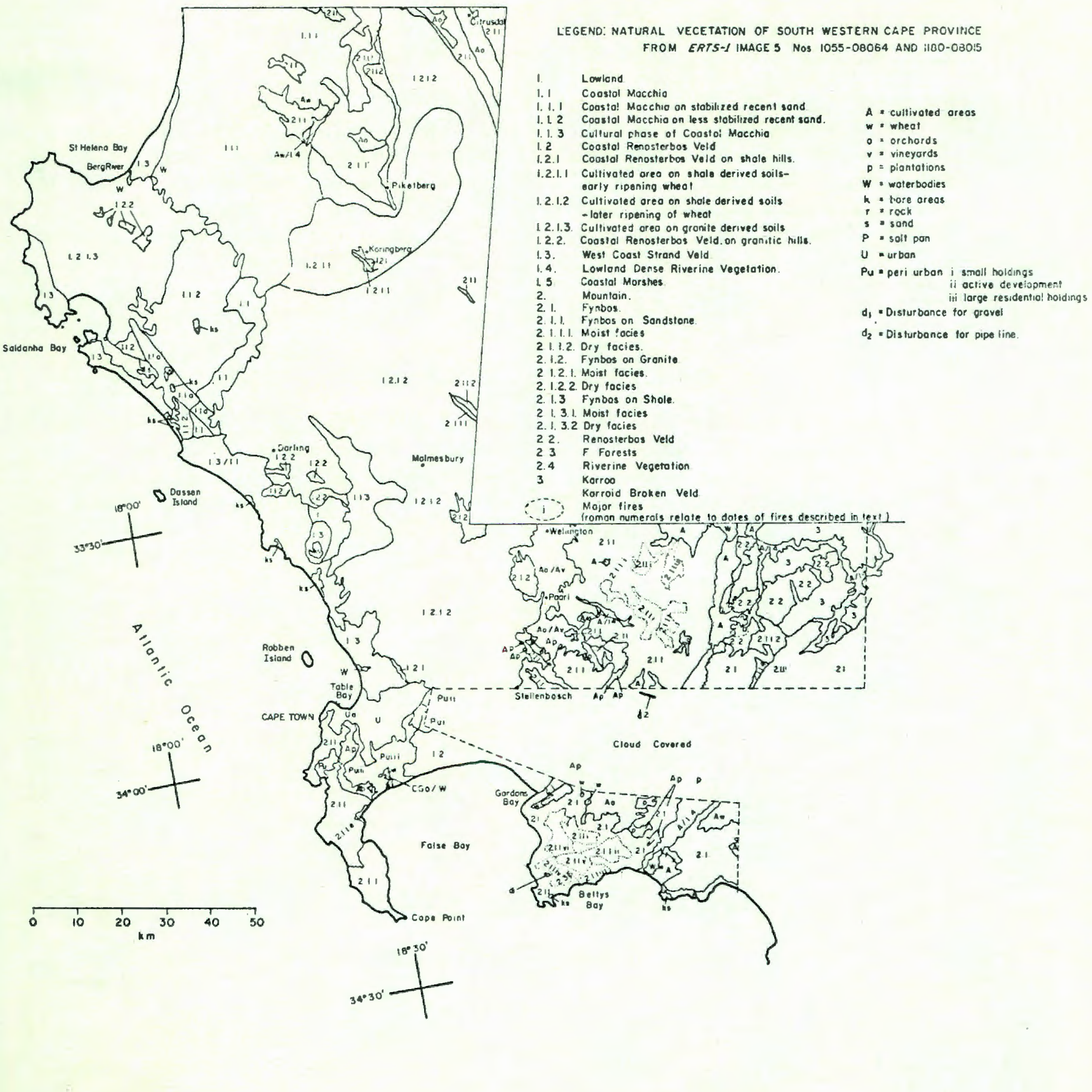


Figure 3.7 Natural vegetation of south western Cape Province from LANDSAT No's 10055 - 08064 and 10180 - 08015 (Taylor and Boucher 1973).

examined carefully (Figure 3.4) a further selection of classes was made, and a second classification map generated (see Figure 3.5). Refinements of this nature can be continued until the user is satisfied that the map meets its particular objective.

3.3 SIZE OF TEST AREA

3.3.1 Semi-detailed investigations at 1:20 000 scale

An investigation was carried out on test area 2A of the Langebaan-Saldanha study area (see Figure 3.8). The Langebaan peninsula area in this study area is particularly convenient to use, because from sea to lagoon there is a gradient of soil, geological substrate and vegetation community types, which is consistent over a wide area. Strips across this gradient of varying numbers of pixels were examined (see Table 3.2) and two sets of T_1 and T_2 (see Section 3.5.1) values were used.

3.3.2 Reconnaissance investigations at 1:250 000 scale

An investigation was carried out on the whole CCT of scene 10055-08064, 16 September 1972. Small test areas were selected as shown in Figure 3.4 (1a, 1b, 1c, 2a, 3, 4a, 5b). The iterative clustering routine was run on these areas, and they were found to be too small. The test areas were extended to the size shown on Figure 3.4 (1, 2 and 4).

3.4 DEGREE OF TOPOGRAPHIC VARIATION

3.4.1 Semi-detailed investigations at 1:20 000 scale

CCT 10180-08015 of 19 January 1973, was used to illustrate the problems of working with an area with marked topographic variation, at this scale of operation. The Table Mountain Area was investigated. The procedure INTAPE, LIST, DISPLY, ITCLUS and MAPCLS, was used. The classification map, illustrated in Figure 3.10 was obtained.

3.4.2 Reconnaissance investigations at 1:250 000 scale

In Section 3.1 where mapping was carried out at different scales, the effect of topographic variation was investigated at 1:250 000 scale (see Figure 3.5).

3.5 ALTERATION OF PROGRAMME PARAMETERS

3.5.1 Langebaan land vegetation communities at 1:20 000 scale

In an attempt to investigate the effect of alteration of the programme cluster splitting/combining threshold parameters (T_1 and T_2) on the

Table 3.2 Varying the size of a test area to see the effect on the number of useful map classes produced in a classification at a particular scale

		T_1	T_2	No. of Pixels	No. of Classes	Useful map categories
A	1	16,0	11,0	352	4	3
	2	16,0	11,0	792	4	3
	3	16,0	11,0	1056	6	4
	4	16,0	11,0	1540	6	4
	5	16,0	11,0	2376	4	3
	6	16,0	11,0	3168	4	3
	7	16,0	11,0	7400	5	4
B	8	10,5	7,0	352	5	4
	9	10,5	7,0	792	8	6
	10	10,5	7,0	1056	10	6
	11	10,5	7,0	1540	10	6
	12	10,5	7,0	2376	9	6
	13	10,5	7,0	3168	10	6
	14	10,5	7,0	7400	12	6

NB. A Minimum size 1056 pixels i.e. 34 x 34

B Minimum size 792 pixels i.e. 30 x 30

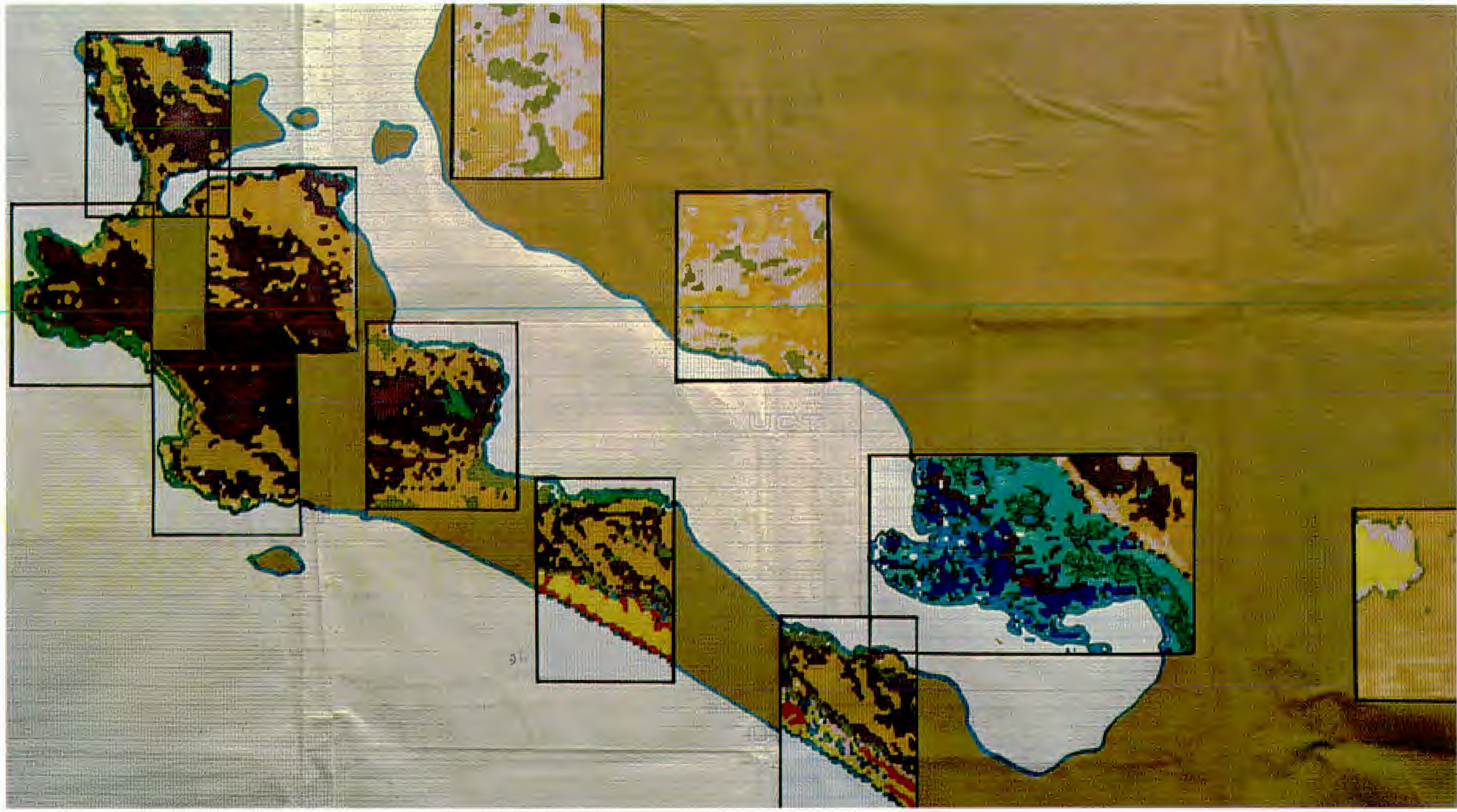


Figure 3.8 Single wave band printout at 1:20 000 scale showing test areas used in classification of Langebaan-Saldanha area of CCT 10055-08064, 16 September 1972.

The classifications of the test areas have been superimposed onto the single waveband printout to demonstrate the way in which the final map classes are selected. Classes with similar reflectance values in different test areas are shown as the same colour.

Figure 3.9 Classification of the Langebaan-Saldanha area carried out at 1:20 000 scale using combined statistics generated from a number of test areas from CCT 10055-08064, 16 September 1972.

This figure shows the marsh communities present in the eastern edge of the Langebaan Lagoon system, which were not distinguishable in Figure 3.2.

number of classes generated, data from test area 2A (see Figure 3.8) from the previously specified Langebaan peninsula area were again utilized.

The optimum number of vegetation community map unit classes for that area was known to be 6, at a semi-detailed level of investigation from available ground truth. Table 3.3 shows the effect of altering T_1 and T_2 values on the number of cluster classes generated, and the meaningful map classes in each case.

3.5.2 Langebaan marsh vegetation communities at 1:10 000 scale

Alteration of T_1 and T_2 threshold parameter values was carried out on the marsh community area of Langebaan lagoon from CCT 10055-08064. Figure 3.11 shows the results.

3.6 SEASONAL IMAGERY DIFFERENCES

Problems of lack of suitable repetitive imagery have made it difficult to examine the effect of this at a reconnaissance level of investigation

Examples of seasonal differences at a 1:20 000 semi-detailed level of operation are presented here. Three dates of CCTs for the Langebaan-Saldanha area exist, namely: Scene 10055-08064 of 16 Septembe 1972, scene 10145-08073 of 15 December 1972 and scene 30110-07552 of June 1978.

3.6.1 Langebaan land vegetation communities at 1:20 000 scale

The three CCT's were used in an investigation by Jarman, Bossi and Sommerville (1980) to show seasonal variation in extent of vegetation communities. An area on the Langebaan peninsula was chosen, and classifications were carried out for each date. These classifications were compared with one another and existing knowledge of vegetation seasonality in the area.

3.6.2 Langebaan marsh communities at 1:10 000 scale

Classification of the salt marsh area of the lagoon for two different dates of imagery were compared for seasonal variation (see Figure 3.1).

3.7 MONITORING SHORT TERM HABITAT CHANGE

Again the lack of suitable repetitive imagery to date has made this a difficult point to consider. The examples of seasonal variation given in section 3.6 are also examples of short-term habitat change.

3.8 DISCUSSION

The procedure outlined at the beginning of section 2 is one which has been developed to meet the particular mapping objective envisaged. A particular iterative clustering classification routine has been adopted for use throughout. Other techniques such as a principle component analysis (PCTRAN), also available in the UCT CATNIPS system could well prove useful. However, it was felt that once an approach had been tried and tested and found usable in one area, it should be applied to a wider mapping project in order to see its general applicability. Experimentation with different classification routines would involve whole new areas of research, not within the scope of this project.

4. RESULTS AND CONCLUSIONS

4.1 MAPPING AT DIFFERENT SCALES

4.1.1 Detailed - final mapping - 1:10 000 scale

Figure 3.1 shows 3 different map classifications of the salt marsh area in Langebaan Lagoon, namely: a 6 class, 10 class and 15 class classification. By increasing the number of classes, more detail with regard to descrimination of marsh communities was obtained. Small areas can be mapped in detail using these classificatory techniques. However, it should be pointed out that not all areas will be suitable for this approach. Marsh communities tend to grow in single specie stands, giving a greater degree of homogeneity within types. The marsh area is also flat and featureless. There was thus no confusing spectral information introduced due to topographic features.

4.1.2 Semi-detailed - final mapping - 1:20 000 scale

(a) The Table Mountain area has been classified and correlation with Moll and Campbell's (1976) map of the area has been carried out (Jarman 1979). The area is complex with a range of topographic and aspect variations. Classes obtained have meaning as regards surface vegetation features but these are not being consistently identified throughout the area.

The Cape Point Nature Reserve (Ripp 1978) has been successfully classified producing 14 vegetation classes which have been correlated with units on Taylor's (1969) vegetation map of the area.

A comparison of computer generated classes of the Ysterfontain area (Bossi 1979) with the adjacent Langebaan-Saldanha area (Jarman and Jackson in prep) was successfully completed (Table 4.1). The same September 1972 image was used in both

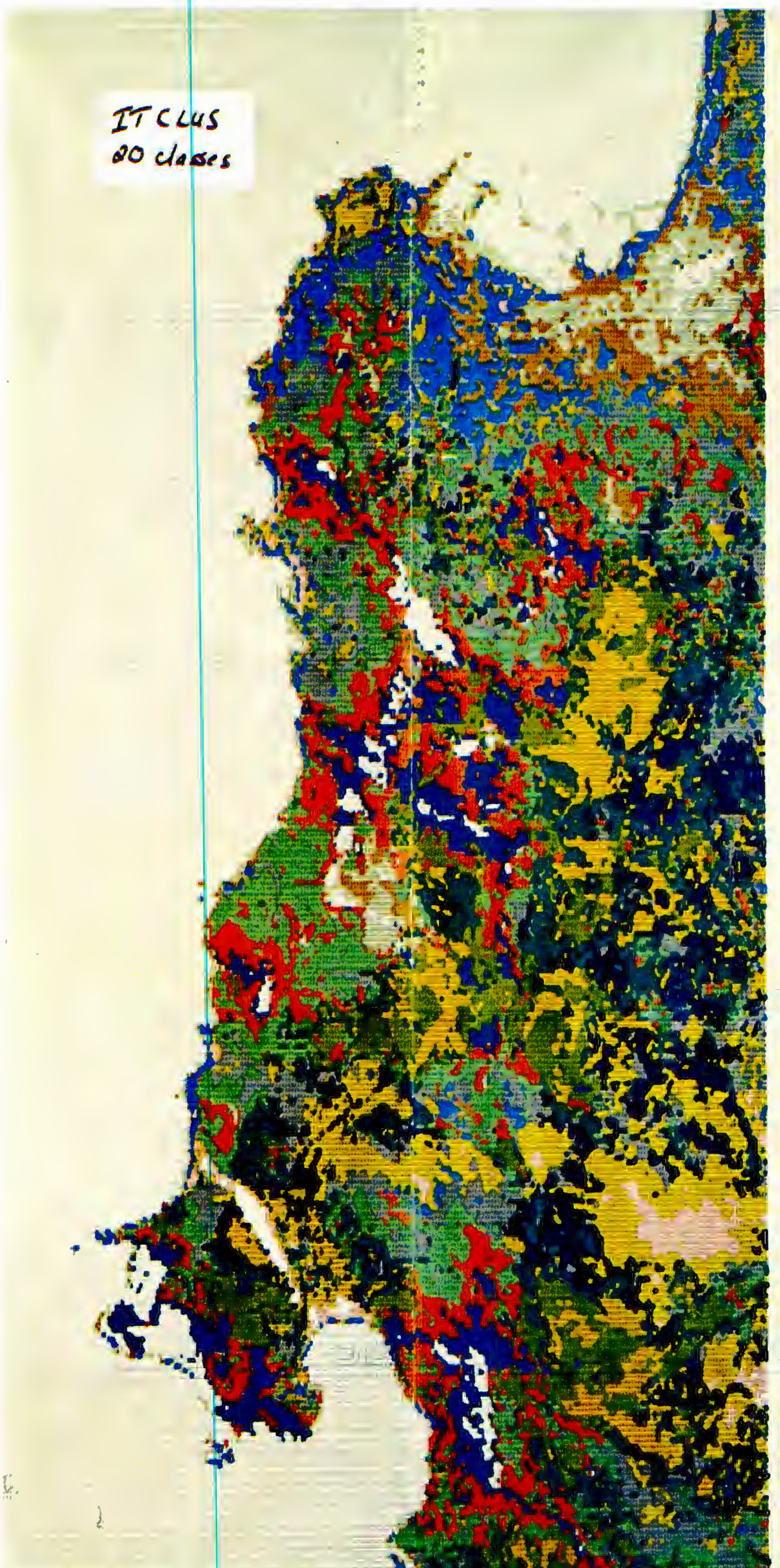
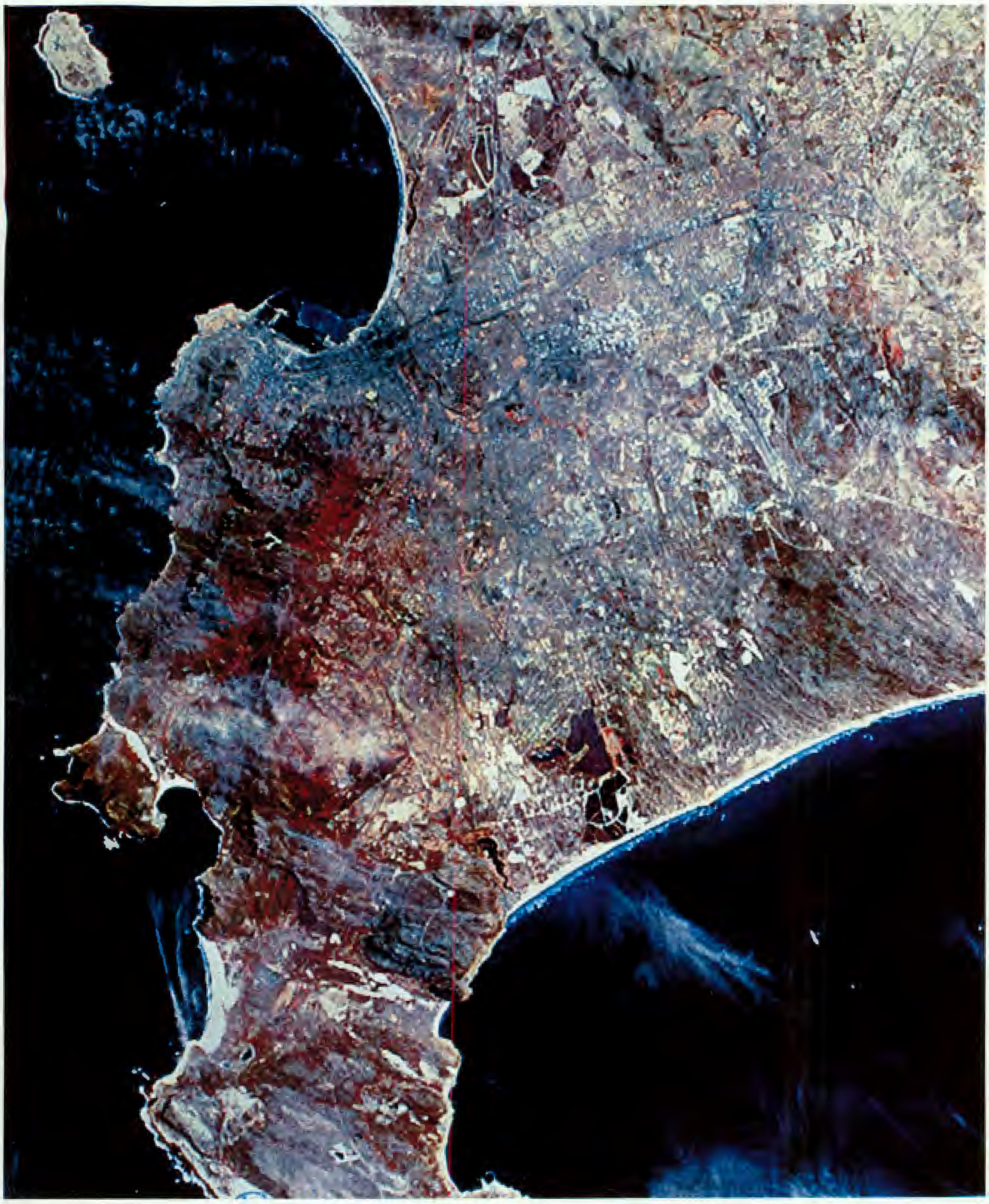


Figure 3.10 Classification of the Table Mountain area carried out at 1:20 000 scale from CCT 10180 - 08015 of 19 January 1973.



Three band colour composite of the raw data for portion of CCT 10180 - 08015 of the Table Mountain and Cape Flats area, south west Cape Province.

Table 3.3 Effect of varying T_1 and T_2 parameters in Test Area 2A - Langebaan Peninsula

Map No.	T_1	T_2	No. of cluster classes	Meaningful vegetation community map classes at 1:20 000 (optimum number 6)
1	18,0	12,0	4	3
2	17,8	13,0	4	3
3	17,5	11,8	6	4
4	17,2	11,7	6	4
5	17,0	11,5	6	4
6	16,0	11,0	6	
7	14,0	10,3	7	4
8	13,5	9,7	7	4
9	13,5	9,5	7	4
10	13,0	9,2	9	5
11	12,0	8,2	9	5
12	10,5	7,0	10	6
13	9,0	5,5	12	6
14	7,5	4,0	13	6
15	6,0	4,0	15	6
16	5,0	3,5	18	6

Table 4.1 A comparison of computer generated map classes in the Ysterfontein and Langebaan areas (Bossi 1979)

Ysterfontein Computer Generated Classes	Langebaan Computer Generated Classes	Total Area in hectares	Map unit type
1,3,5,7,11,13	1,6,7,11	2261,2	Dune communities
6	3	11573,2	Disturbed limestone and consolidated dune communities
2,14	5,15	7342,0	Disturbed sandy areas
3	8	5656,0	Undisturbed WCS communities
10	13	2222,4	Aliens/rocky outcrops
	16,17	935,2	Salt marsh communities

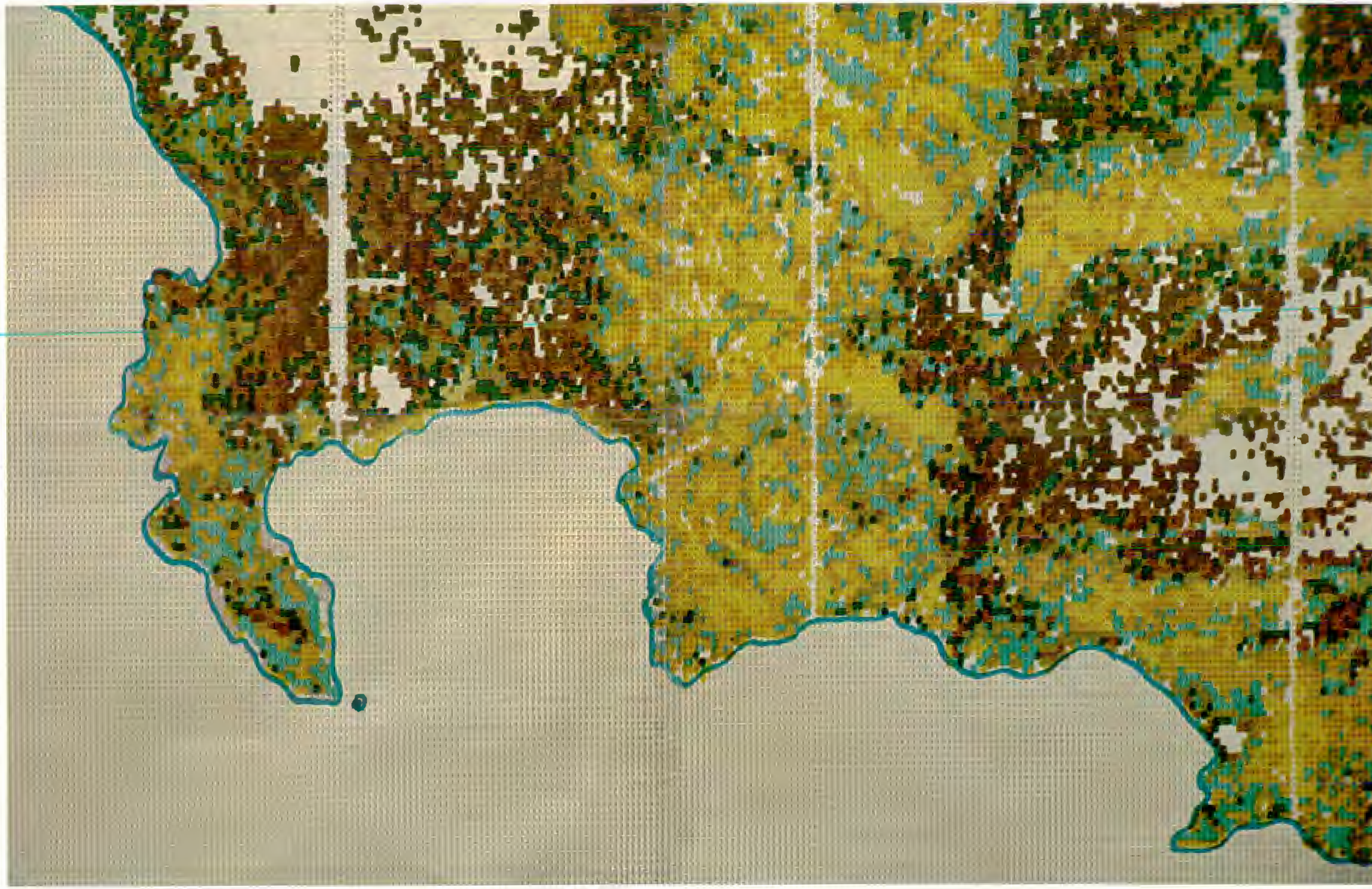


Figure 4.1 Classification of CCT 30271 - 07511 of 1 December 1978 carried out at 1:250 000 scale. Band 5 on this CCT was recorded in high gain mode. This is a ten class classification.

Three band colour composite of the raw data from CCT 30271 - 07511 of 1 December 1978, of the south west Cape Province.

classifications. The classes generated in the overlap area in both cases are identical in location and extent.

A study concerned with interpreting computer processed LANDSAT MSS data of Verlorenvlei (south western Cape) in order to determine the potential use of the data for constructing a meaningful land-cover classification of the area, was carried out. A method of ground-truth data collection and processing enabling significant physical characteristics to be recorded and correlated with spectral classes distinguished in the LANDSAT image was designed (Lane 1980). The area concerned was of a semi-arid nature with sparse vegetation cover and heavy disturbance by land use. For these reasons the classified spectral classes obtained were highly fragmented and no satisfactory classification was obtained. The techniques used in the project did not provide a highly geometrically corrected map which created problems in correlating the field collected ground-truth with satellite data. There were no intermediate photo or map products available to the researcher for orientation. The routine EDTSIG which allows different classes to be combined from a number of test areas was not available at the time. Use of this routine, together with classifying at a smaller scale using the routine AVERAG would possibly have reduced the fragmentation.

(b) Table 4.2 illustrates a comparison of computer generated classes with ground-truth communities in the Langebaan area (Jarman and Jackson in prep). The approach used in this example provided good results as classes could be selected from a number of test areas distributed throughout the study area (see Figure 3.9). In the examples in section 4.1.2 (a) above, classes from only one test area could be used as the necessary computer routines were not available to combine statistics from a number of test areas. It was thus difficult to find a test area that was representative of the whole study area.

4.1.3 <u>Semi-detailed - final mapping - 1:50 000 scale</u>

(a) The classes obtained in this classification correlated well with the vegetation communities mapped by Boucher and Jarman (1977), but the map still contained geometric distortion.

(b) Figure 3.3 is a classified map of the Langebaan Peninsula area at 1:50 000 scale. This reduction of a 1:20 000 scale classification was the most successful of the 1:50 000 trials.

(c) The classes obtained in this process were not as satisfactory. The averaging routine (AVERAG) should not be used to reduce scale after a classification.

In all three examples the statistics for the map classes were obtained at a single pixel level. This is consistent with standard air photo interpretation where map class categories are chosen at a more detailed

Table 4.2 A comparison of computer generated classes with ground-truth communities in the Langebaan area (Jarman and Jackson in prep)

Computer generated Class No.	Class name	Vegetation communities included+
1	Loose dune sand	K (open sand areas)
2	Shallow water	
3	Disturbed limestone and consolidated dune communities	(E, F, H, I)
4	Deep water	
5	Littoral dune communities Old lands/cultivated areas	J
6	Grassed dune ridges	K-*Eragrostis cyperoides* dominant
7	Dune pioneers (low cover)	K-*Didelta-Psoralea* dominants
8	Undisturbed WCS communities	A, G (B,D,D)
9	Beach sand/Urban concrete	
10 (A)	Cloud/Surf	
11 (B)	Grassed dune fringes	K
12 (C)	Wet beach sand	
13 (D)	Aliens/Rocky outcrops	
14 (E)	'Pans'	
15 (F)	Disturbed areas	J
16 (G)	Sedge-type marsh	Ma, Mb, Mc, Md and Nb
17 (H)	Dwarf succulent marsh community	Na

+ As mapped by Boucher and Jarman (1977)

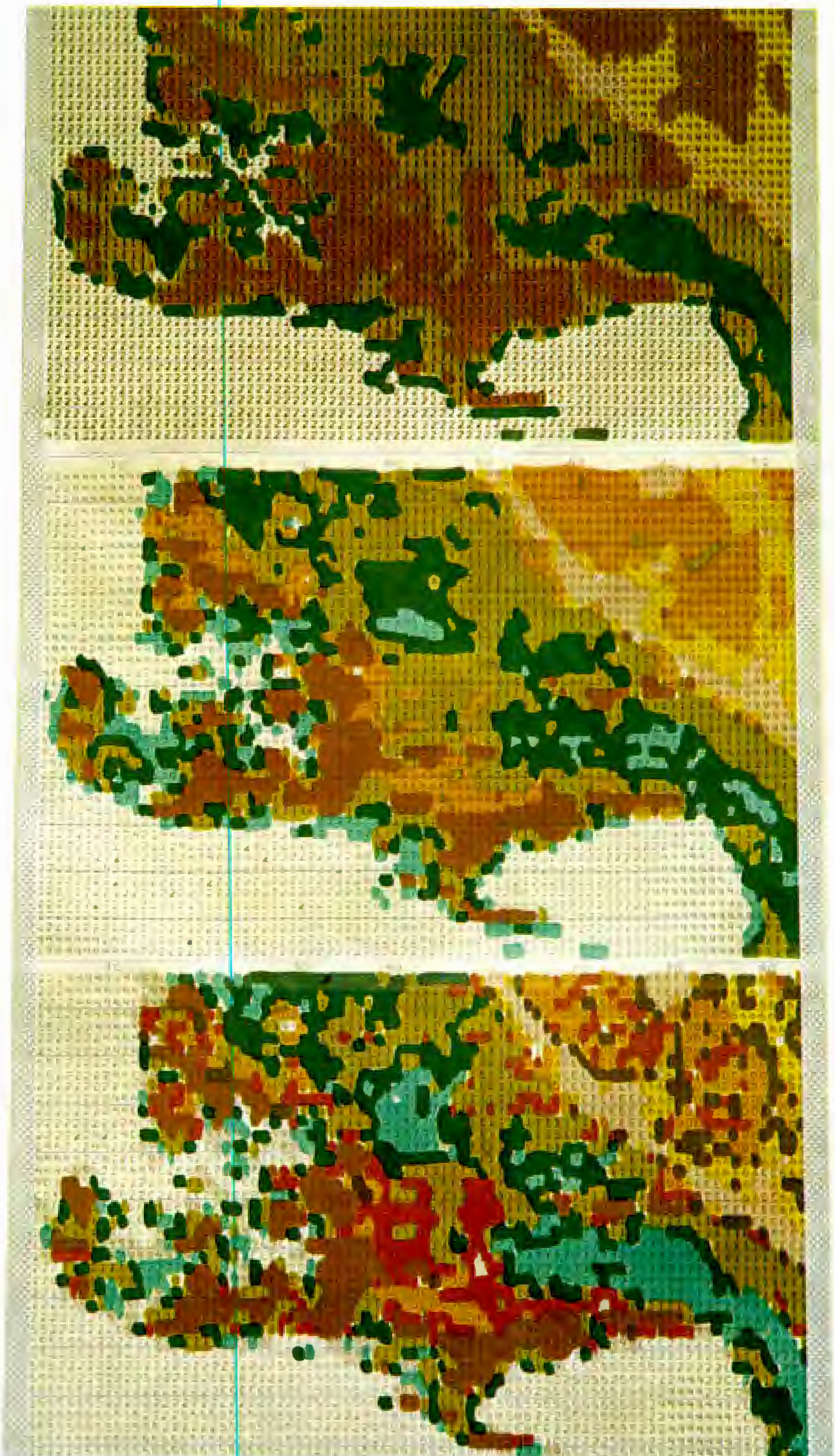


Figure 3.11 6, 10 and 15 class classifications of the marsh area, Langebaan Lagoon from CCT 10055 - 08064 16 September 1972, carried out at 1:10 000 scale.

level than the final map.

These examples have also shown that the averaging routine should only be used to reduce the basic spectral information, in order to make processing more manageable at smaller mapping scale. It should not be used to reduce scale after classification of spectral information.

4.1.4 Reconnaissance - final mapping - 1:250 000 scale

(a) CCT 10055-08064, 16 September 1972

A classified map of the area is shown in Figure 3.5.

Table 4.3 shows the comparison between existing mapped soil, geological and vegetation boundaries and those obtained by the computer classification. Comparison with Taylor and Boucher's map (1973) (Figure 3.7) showed that all the classes recognized by these two researchers were also identified in the 8 class classification.

The emphasis in their approach was identification of all recognizable vegetation surface features, including land use categories such as "early and late ripening wheat".

Figure 3.4, which is a 7 class classification of the same area, excludes the distinction between cultural phases of wheat cultivation, and actually gives a closer approximation to Acocks Veld Types Map than does the 8 class classification.

The classification maps of this area confirm Taylor and Boucher's (1973) statement that the tongue of coastal Renosterbosveld up to the east coast of Saldanha Bay is not correct.

(b) CCT 10145-08073, 15 December 1972

This CCT had 40% cloud cover over the land mass making the area east of 18^{o} 15'E unusable. It was impossible to map at a 1:250 000 scale using this scene.

(c) Cape Peninsula. Scene ID 30271-07511, 1 December 1978

Black and white prints of the single wave bands for the area showed the marked differences in band 5 between cultivated and non-cultivated areas. This CCT had band 5 recorded in high gain mode specifically designed for recording oceanographic features. Figure 4.1 is a 2-band classified map using bands 5 and 6. The iterative clustering routine was applied to the whole area at a 1:250 000 scale using units of 10 x 10 pixels. The classified map distinguishes clearly the cultivated areas from the natural fynbos areas. Map class boundaries correspond well to existing vegetation and geological maps (see Figure 3.6).

Table 4.3 Comparison between existing mapped soil, geologic and vegetation boundaries with computer classified categories (CCT 10055-08064, 16 September 1972)

Computer Class No.	Description	Geologic (Theron[1]) 1:125 000	Geologic (Coertze et al [2])	Acocks' Veld Types[3]	Taylor and Boucher[4] Categories
1 Olive Green	Dry mountain shrub and heath communities on shale hills and sandstone	CQ Sandstone TM Series Sandstone with minor grit, conglomerate and shale	C_1 TMS - quartzite, shale, tillite	69 - Macchia (Mountain Fynbos)	2.1.1.2 Mountain Fynbos on sandstone dry facies
				34 W C Strandveld	1.3 West Coast Strandveld - only the bare sand margins
				46 Coastal Renosterveld	1.2.1 Coastal Renosterveld on shale hills
2 Brown	Bare sand	Q5 Dune sand in places highly calcareous		34 W Coast Strandveld	ks Bare sand areas
3 Orange	Lowland heath and shrub communities on unconsolidated sand	QC Consolidated to unconsolidated limestone and lime-rich sand	Unconsolidated superficial deposits, conglomerate, limestone, sandstone, marl, high-level gravel	47 Coastal Macchia - Coastal Fynbos 34 West Coast Strandveld	1.1.2 Coastal Macchia on less stabilized recent sand 1.3 West Coast Strandveld
4 White	Water				
5 Yellow	Lowland heath and shrub communities on consolidated sand	Q_2 sand and sandy loam of hillocky veld Q_1 light to white reddish sandy soil	Unconsolidated superficial deposits, conglomerate, limestone, sandstone, marl, high-level gravel	47 Coastal Macchia - Coastal Fynbos 34 West Coast Strandveld	1.1.1 Coastal Macchia on stabilized recent sand 1.3 West Coast Strandveld
6 Lilac	Green wheatlands on shale derived soils	Ma Malmesbury Formation Phyllilic shale greywacke and sandstone with minor impure limestone	N Quartzite, arkose, limestone, shale, phyllic, tillite, lava, tuff (Malmesbury system)	46 Coastal Renosterveld	1.2.1.2 Cultivated area on shale derived soils - later ripening of wheat
7 Dark Green	Moist mountain heath communities on sandstone	CQ Sandstone with minor grit, conglomerate and shale	C_1 TMS - quartzite shale, tillite	69 Macchia - Mountain Fynbos	2.1.1.1 Mountain Fynbos on sandstone moist facies
Mosaic 3, 5 & 7	Mixed agriculture on sandy? soils	G_1 coarse porphyritic granite G_{1b} contaminated granite Gd Hybrid granodiorite	N Quartzite, arkose, limestone, shale, phyllic, tillite, lava, tuff	47 Coastal Macchia = Coastal Fynbos	1.1.3 Cultural phase of Coastal Macchia (Fynbos)
6 & 8 Lilac & Turquoise Mosaic	Mixed agriculture on granite derived soils	G_3 coarsely porphyritic granite G_4 even grained granite	AG_9 Granite, syenitic rocks, quartz porphyry	46 Coastal Renosterveld	1.2.1.3 Cultivated area on granite derived soils
6, 3 Lilac & Orange Mosaic	Mixed agriculture on unconsolidated sand	Q_1 white to light reddish sandy soil		47 Coastal Macchia - Coastal Fynbos	AW/14 Cultivated area, wheat and lowland dense woodland
5, 6, 8 Yellow, Lilac & Turquoise Mosaic	Wheatlands on consolidated sand	Q_2 sand and sandy loam of hillocky veld Q_1 light to white reddish sandy soil	Unconsolidated superficial deposits, conglomerate, limestone, sandstone, marl, high-level gravel	34 West Coast Strandveld	AW Cultivated areas - wheat
8 Turquoise	Wheatlands on shale derived soils	Ma Malmesbury Formation Phyllilic shale greywacke and sandstone with minor impure limestone	N Quartzite, arkose, limestone, shale, phyllic, tillite, lava, tuff (Malmesbury system)	46 Coastal Renosterveld	1.2.1.1 Cultivated area on shale derived soils - early ripening phase of wheat

1 Theron (1971)
2 Coertze, Schifano and van Eeden (1970)
3 Acocks (1953)
4 Taylor & Boucher (1973)

(d) Cape Peninsula. Scene ID 10180-08015, January 1973

A figure of 20% cloud cover over the land made use of this CCT not entirely satisfactory for producing a map. However, areas within the whole scene could be discriminated well, and major land use categories such as wheat farming and viticulture were distinguished. The major natural vegetation formation, Acocks Veld Types - Karoo, was also distinguished readily from Coastal and Mountain Fynbos.

4.2 CHOICE OF TEST AREA

The CCT used for these investigations was 10055-08064 of 16 September 1972.

4.2.1 Semi-detailed investigations at 1:20 000 scale

(a) Figure 3.8 shows the single wave band printout for band 7, with the classified maps of small test areas superimposed on it.

Figure 3.9 shows the classification of the whole Langebaan-Saldanha area produced from the combined statistics from test areas in Figure 3.8. The classes correspond to those described in Table 4.2.

(b) Figure 3.2 shows a classification of the whole Langebaan-Saldanha area produced from the statistics generated from one "representative" test area. A comparison of the two classifications (Figure 3.9 and Figure 3.2) illustrates the difficulty of choosing one totally representative test area in any given study area. The classification shown in Figure 3.2 completely eliminated the marsh communities and 2 of the land-based communities. These were either not present at all or covered too small a portion of the test area chosen to be separated out as a spectral class.

4.2.2 Semi-detailed investigations at 1:50 000 scale

Figure 3.3 shows a classified map generated from the statistics from a number of test areas at a 1:20 000 scale.

4.2.3 Reconnaissance investigations at 1:250 000 scale

Figures 3.5 and 3.4 and Table 4.3 illustrate the results obtained after selecting test areas on which to run the iterative clustering routine, and using the statistical classes from these areas to generate the final classified map.

With no prior knowledge of the area, and on careful examination of band 5 and band 6 single wave band map printouts in particular, it is possible to locate test areas for detailed investigation purely by making sure that all grey-scale categories of reflectance values have more or less equal representation.

Using this as a basis for operation, it was first attempted to run iterative clustering routines on small test areas, as shown in Figure 3.4. (Small test areas 1a, 1b, 1c, 2a, 3, 4a and 5b). No classification was achieved. The test areas were extended to the larger sizes shown in Figure 3.4, namely 1, 2 and 4. These areas classified successfully, and of the total number of classes generated in all 3 test areas, 7 and 8 classes were chosen to generate classified maps shown in Figures 3.4 and 3.5 respectively.

Examination of Figure 3.4, the first classified map generated, using a 7 class classification showed that an extensive area in test area 2 (marked as (A)) had been classified as class zero, and that we had not used it in the final map classification. The statistics for class zero were then included with the other 7, and a new classified map generated, i.e. Figure 3.5. On comparison with the map drawn by Taylor and Boucher (1973) we found that this was a category representing early ripening wheat on shale soils. It is of considerable importance to decide whether land-use categories of this nature are to be recognized or not in a final map classification.

4.3 SIZE OF TEST AREA

4.3.1 Semi-detailed investigations at 1:20 000 scale

Table 3.2 illustrates the effect of varying the size of test area on the number of classes generated. Two different combinations of the cluster splitting/combining threshold parameters (T_1/T_2) were used, namely 16,0/11,0 (section A on Table 3.2) and 1,5/7,0 (section B on Table 3.2).

Using T_1 and T_2 values of 16,0 and 11,0, both the maximum number of classes generated, and the maximum number of useful map categories was achieved with a test area of 1056 pixels in extent (34 x 34). The second set of T_1 and T_2 values (10,5 and 7,0) showed 792 (29 x 29) pixels to be the minimum size necessary for a test area when taking only useful map categories into consideration.

A minimum test area size would appear to be 1000 pixels. This is not necessarily consistent in all land cover types. It would be necessary to establish the minimum test area size at the start of any mapping operation. These findings are in accordance with the recommendations by Boyd and Linderlaub (1979), with respect to the best test area size for optimum returns on computer time and effectiveness of classification. They recommend units 50 x 50 to 100 x 100 pixels in extent.

4.3.2 Reconnaissance investigations at 1:250 000 scale

The initial size of test areas chosen as representative of spectral classes at the 1:250 000 scale on the basis of their grey-scale levels, was too small. Sizes selected had ranged from blocks of 10 x 10 to 20 x 20 pixels. This exercise had confirmed the need to choose test areas which contain relatively few spectrally distinct classes, but which are a minimum size of 35 x 35 pixels (see Section 4.3.1).

4.4 DEGREE OF TOPOGRAPHIC VARIATION

4.4.1 Semi-detailed investigations at 1:20 000 scale

The Table Mountain area of the Cape Peninsula was processed without the benefit of using the EDTSIG programme. Figure 3.10 shows a classified map of the Table Mountain area which gives map units which are meaningful in terms of surface vegetation feature identification, but which have not been consistently identified throughout the area (Jarman 1979). The range of topographic variation in the area has caused this.

4.4.2 Reconnaissance investigations at 1:250 000 scale

Figure 3.5 shows clearly the 2 areas with marked topographic variation, namely Table Mountain area of Cape Peninsula and the Piketberg in the north of the map. At this scale of operation, topographic features aid orientation and do not appear to cause classification problems due to shadow effects.

4.5 ALTERATION OF PROGRAMME PARAMETERS

4.5.1 Langebaan land vegetation communities at 1:20 000

Table 3.3 shows a range of T_1 and T_2 values in test area 2A of the Langebaan Peninsula. T_1 and T_2 values of 10,5 and 7,0 respectively produced the optimum number of vegetation community map classes for the area. Decreasing these threshold parameters further to increase the number of cluster classes did not give any more vegetation community information. For this particular test area and this vegetation type (West Coast Strandveld) threshold parameters of 10,5 and 7,0 were the most effective. Users should determine the number of map classes desired at the outset of an investigation and alter the threshold parameters accordingly.

4.5.2 Langebaan marsh vegetation communities at 1:10 000 scale

The marsh community classifications shown in Figure 3.11 further illustrate the effects of altering threshold parameters.

At the level of vegetation community mapping used in a 1:10 000 scale operation, the ten class classification using T_1 and T_2 values of 6,5 and 4,0 was more accurate than the six class classification using T_1 and T_2 values of 10,5 and 7,1.

4.6 SEASONAL IMAGERY DIFFERENCES

4.6.1 Langebaan land communities at 1:20 000 scale

Results of the investigation by Jarman, Bossi and Sommerville (1980) showed an increase in the extent of a dense cover west coast Strandveld vegetation community between June and September. There was a decrease in the extent of the same vegetation cover class between September and December. The first increase was due to the development of an annual component in an adjoining intermediate cover community. The subsequent decrease could be attributed to the drought deciduous component of the dense cover class losing its leaves during this period. This seasonal variation in extent of the dense cover community ranges between 14 (6,2 ha) and 49 pixels (21,6 ha).

4.6.2 Langebaan marsh communities at 1:10 000 scale

Figure 3.1 shows six class classifications of the marsh area for September and December 1972. The extent of the water-logged marsh area (dark green) in the September example is greater than the corresponding water-logged area in the December example. This seasonal variation in extent of a ground cover class again illustrates the necessity to choose optimum seasons for carrying out map operations.

4.7 MONITORING SHORT-TERM HABITAT CHANGE

No examples of short-term habitat change other than those described in section 4.6 have been investigated, due to lack of suitable repetitive imagery.

It is expected that surface features with distinct spectral characteristics such as burnt areas would be easily identified.

4.8 DISCUSSION

Examining the results in relation to key question (a); is it possible to recognize and map vegetation types with consistency at various scales? - the following observations can be made:

(1) The results showed the versatility of the product over that of standard air photo products in that a range of map classifications from 1:10 000 to 1:250 000 were achieved from the same basic data. This represents a tremendous saving to any potential user agency.

(2) At the detailed and semi-detailed levels of operation, successful classifications were achieved. Good and detailed ground-truth is necessary, throughout the area under

investigation. This is consistent with the guidelines laid down by the Botanical Research Institute (Edwards and Jarman 1972), where they describe the field work suitable for these scales as being:

detailed - intensive quantitative sampling
semi-detailed - moderately high density plot samples

This scale is therefore best suited to individuals carrying out surveys whose objectives are to produce detailed community information.

(3) The reconnaissance level is the scale suited to meeting the particular objectives of this study. It best utilizes the satellite data, as the classification routines involved condense the spectral information into manageable proportions. The returns on time and the amount of field control work necessary to produce a satisfactory classification, are very good. It is the level at which potentially the technique can be manipulated to produce the desired result - and this is precisely what is required.

Application of a land ecological system such as that reported on by Tupper (1980), as proposed by Driscol et al, which has four components: vegetation, soil, landform and aquatic (see Table 4.4), with careful consideration of the relevant local categories at a 1:250 000 scale operation, will produce suitable map units. The best examples of these broad landscape units can be identified, and the spectral signatures generated for them. A refined map classification can thus be obtained - suited to the objectives of the user.

5. GENERAL CONCLUSIONS

The feasibility stage of this project has shown that at this stage of development in local expertise it has been possible to map specific study areas (185 x 185 km in extent) at 1:250 000 scale. The map categories produced are land cover classes combining geological/soil/major vegetation formations and land use features.

It is felt that we are now in a position to map the whole Fynbos Biome area at a 1:250 000 scale, using the relatively unsophisticated approach described in section 2. The feasibility project has contributed to the UCT Image Processing Unit becoming fully operational at the level which we need to meet this mapping objective. Direct satellite reception expected in 1981, will ensure availability of suitable repetitive imagery. It has been impossible to investigate the effect of seasonal variation in imagery at this level of operation to date. However, the mapping could be carried out on imagery obtained during one season, preferably summer; provided the imagery becomes available.

Table 4.4 Basic categories of the Recommended National Classification System for Renewable Resources (Driscoll et al 1978)

Vegetation system	Soil system	Landform system	Aquatic system
Formation Class	Order	Realm	Order
Formation Subclass	Suborder	Major Division	Class
Formation Group	Great Group	Province	Family
Formation	Subgroup	Section	Type association
Subformation	Family	Region	Type
Series	Series	District	.
			.
Association	Phase	Area	.
			Others as needed
.	.	Zone	
.	.		
.	.	Locale	
Others as needed	Others as needed	.	
		.	
		.	
		Others as needed	

from : Tupper 1980, page 30

There has been an added stimulus to co-operative research due to activities within the Fynbos Biome Project. At present there are a number of research workers involved in field based, vegetation classification projects throughout the area. Their cooperation and expertise will aid in the selection of representative test areas for the development of map categories. All available maps, reports, air photos and satellite photographic products will be used to aid this selection process. Interaction with the Durban University Land Survey Department will ensure uniformity of technique and critical selection of routines developed due to exchange of software.

Since the start of the LANDSAT series there has been sporadic interest in satellite imagery for vegetation and land use interpretation. It is felt that the production of a map product useful to "user" agencies, would stimulate interest in the further exploitation of this technique.

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7. APPENDIX : EXPANDED CONTENTS PAGES

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8. ACKNOWLEDGEMENTS

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PART VI GENERAL CONCLUSIONS AND RECOMMENDATIONS

In considering the three basic steps involved in producing a vegetation map, namely; data collection, interpretation and product generation (Fleming and Hoffer 1977), either an image orientated approach incorporating visual interpretation of photo products, or a numerically orientated approach incorporating computer analysis of digital data (Landgrebe 1973) can be utilized.

Experimentation within the Fynbos Biome remote sensing vegetation mapping programme with the branch of digital image processing which incorporates "information processes designed to utilize the decision making capability of computers to identify and extract specific groups of information" (Sabins 1978) has resulted in some significant findings and developments. These should be examined in the context of developments and findings elsewhere.

6.1 RESEARCH INTO THE USE OF DIFFERENT CLASSIFICATION ALGORITHMS

Applications utilizing computer analysis of Landsat MSS digital data for vegetation analysis carried out elsewhere centred initially around research into the the usefulness of the various classification algorithms being produced. Considerable effort went into comparing and evaluating various classification algorithms. Wacker and Landgrebe (1972) showed that the use of a parametric classifier assuming a multi-variate normal density function offered the best compromise between classification performance (accuracy) and cost (speed and complexity). Generally the maximum likelihood algorithm based on the Gaussian assumption was used extensively (Hoffer 1972).

It has been possible to capitalize on the early research into classifiers done elsewhere, and local research effort has not concentrated on that aspect. The algorithms used locally are an iterative clustering algorithm based on the ISODATA technique of Ball and Hall (1975) and a Bayesian (Maximum Likelihood) classifier using a multivariate normal assumption (Shlein and Goodenough 1973).

6.2 RESEARCH INTO EVALUATION OF SUPERVISED VERSUS UNSUPERVISED APPROACHES

There are two major methods of obtaining training spectral classes for use in computer classification of digital data in vegetation mapping. The first, referred to as the supervised approach, involves locating individual pure areas of pixels on the image which represent a single cover type of interest to the user. This selection is based entirely on ground truth. These areas are used to obtain statistical training classes and the pixels in the image would be associated with one of the specific classes. In this way only the data describing the classes of interest is classified thus providing a final map of informational value. The disadvantage with this approach lies in misclassification of pixels as a result of overlap in spectral characteristics obtained from the natural variations in ground-cover.

In the second method, the unsupervised approach, an algorithm is used to deliniate groups of pixels within the sample that are spectrally similar in a representative sample from the image.

Ground truth data is then used to relate these spectral classes to features on the ground. This method is particularly useful in a heterogeneous scene in which the likelihood of observing several adjacent pixels of the same cover type is low.

Elsewhere, initially, various computer-aided analyses of aircraft MSS digital data using supervised approaches were carried out, including: mapping of agricultural lands (LARS 1968); analysis of forest lands (Smedes et al 1970); analysis of forest tree species (Rhode and Olsen 1972); detection of forest tree stress (Weber and Polcyn 1972); vegetation mapping in California (Lent 1969); and analysis of cover type classes (Coggeshall and Hoffer 1973).

The general conclusion was that for small flat areas the supervised techniques worked well.

Investigations into unsupervised techniques (Wacker and Landgrebe 1970) at aircraft levels were carried out successfully by Hoffer, Anuta and Phillips (1972).

There has been no local experimentation with classifications of digital MSS data derived from aircraft borne systems. Elsewhere, workers appear to have experimented with such data prior to the Landsat MSS digital data being generally available. The computer analysis procedures utilized for aircraft derived data are the same as those which have been used in South African applications utilizing Landsat digital data. Research should be initiated in this country into the aquisition of and analysis of digital MSS data derived from aircraft borne sensors to compliment that being done on Landsat digital data.

Subsequent to the general availability of Landsat digital data, numerous investigations were carried out utilizing computer-aided analysis techniques in attempting to map renewable natural resources, with varying degrees of success. They include work by Weber, Roberts and Waite (1975); Driscoll and Francis (1975); Lawrence and Herzog (1975); Aldrich, Norick and Greentree (1974); Hoffer, Flemming and Kneb (1974); Dodge and Bryant (1976); Sayn-Wittgenstein and Wightman (1975); Kalensky and Scherk (1975). The majority of these applications utilized the supervised approach; in the more successful cases a maximum likelihood classifier assuming a Gaussian distribution was used.

A typical conclusion reached was that the supervised approaches produced acceptable results at a regional broad level; but not at the more detailed level. Topography effects created problems in the application of the supervised classification routines.

Application of unsupervised computer classification routines at both the regional (reconnaissance) and semi-detailed /detailed levels of investigation in the Fynbos Biome applications produced acceptable results. In addition to this, topography effects appeared to be minimized by using unsupervised procedures, particularly at the regional (reconnaissance level).

A comparative study carried out by Fleming, Berkebile and Hoffer (1975) between supervised and unsupervised procedures increased overall classification accuracy from 70,0 percent with the supervised approach to 76,6 percent with the unsupervised approach.

The majority of the investigations into applications of supervised procedures were based on assumptions of the quality of ground-truth available and the distribution of the pixels in a given class in the 4-dimensional space defined by the reflectances in the four spectral bands. Although widely used because of the mathematical simplicity and computational convenience of the method, the validity of the procedure was questioned on both procedural and statistical grounds (Nagy, Shelton and Tolaba 1971; Armstrong 1975).

One of the major problems with the analysis of Landsat digital data, using supervised procedures, is the definition of homogeneous areas which represent a specific ground target. A second problem is ensuring that the selected areas include features which can be discriminated in the MSS data. The use of unsupervised techniques avoids both of these problems. However, although unsupervised techniques ensure identification of homogeneous and discriminable land surface features, such techniques do not guarantee that the classes formed are meaningful to the user. Thus, instead of completely removing subjective interpretation from the process, these techniques move the interpretation to a different level.

As a result of the comparatively lower success of supervised techniques elsewhere and because most of the Fynbos Biome has inadequate ground control to utilize supervised procedures, it was decided from the outset of the overall Fynbos Biome project vegetation mapping programme to use unsupervised procedures in order to establish signatures and training sets. Consequently no research effort has been expended on comparisons between supervised and unsupervised techniques in the south west Cape applications.

6.3 RESEARCH INTO THE DEVELOPMENT OF A VEGETATION MAPPING PROCEDURE

6.3.1 Development of sequence of routines

As a result of the difficulties entailed in using supervised and unsupervised approaches for mapping cover classes in areas of rugged terrain, an approach called the modified cluster was developed and tested by Fleming, Berkebile and Hoffer (1975). Subsequently Fleming and Hoffer (1977) refined the "multi-cluster blocks" system (see PART IV page D19). This procedure is analogous to the procedure being utilized in vegetation mapping in the south west Cape which was developed completely independently.

The procedure used in applications reported on here is equivalent to the processes one goes through in carrying out visual interpretation of photo products. Figure 4.1 on page D 4 is a flow chart showing the suggested sequence of use of routines available in the UCT, CATNIPS manual for computer-aided analysis of digital MSS data in vegetation mapping. This amounts to:-

(i) Identification and extraction of the area for study from the whole Landsat tape, which covers an area 185 x 185 km^2.

(ii) Preprocessing of the digital data in order to identify test areas containing the training signatures or photo units to be used in the final classification.

(iii) Actual feature extraction (classification), or identification of the training signatures from each test area, which are to be used in the final classification or identification of photo units.

(iv) Employment of an editing programme which then combines the training signatures from a number of test areas into one set for use in the final classification process. This is equivalent to compiling a final map classification in visual interpretation through combining the units in annotations of representative photo units into an acceptable map classification.

(v) Classification of the whole study area and display in line printer map form. This is comparible to the tedious extrapolation/annotation phase in a visual interpretation operation.

(vi) Generation of the final map product. This can be in line printer form, corrected to scale through use of available software routines, or in photo product form from computer optronics processing. The equivalent operation in visual interpretation of photo products would be the transferring of annotated photo unit boundaries from photos by means of photogrammetry techniques, onto base maps at the required scale.

This sequence of routines applies regardless of the scale of operation. In the case of operating at smaller scales of mapping (ie 1:20 000 to 1: 3 000 000 and smaller), an additional step is introduced into the procedure which uses an averaging routine to compress the data into units which are more manageable .

6.3.2 Technicalities investigated

In development of the procedure used locally, various technicalities were investigated at the same time.

6.3.2.1 Choice of test area

On selecting test areas on which to run the iterative clustering algorithms for extracting training signatures, it is necessary to ensure covering the full range of spectral information existing in a scene. The generation of line printer map print outs of single wave bands of both stretched and unstretched data aids in this process. These print outs are equivalent to black and white negatives of separate MSS bands in that symbols on the print out correspond to grey scale categories on normal black and white air photo products. By ensuring that the full range of grey scale categories present in a scene are represented in the range of test areas selected for further analysis one can be reasonably sure of having chosen a representative sample.

6.3.2.2 Size of test area

As a result of investigations into the effect of altering the size of test area on the number of map classes generated in various classifications, the minimum test area size would appear to be 1000 pixels. This was established for West Coast Strandveld and Coastal Fynbos (Acocks 1953) communities on the south west coast of South Africa. It is not necessarily consistent in all land cover types. It would be necessary perhaps to establish the minimum test area size at the start of any mapping operation. These findings are in accordance however with the recommendations by Boyd and Linderlaub (1979). They recommend units 50 x 50 to 100 x 100 pixels in extent.

6.3.2.3 Alteration of programme cluster splitting/combining threshold parameters

Work done in the Langebaan area showed that by altering the cluster splitting/combining threshold parameters (T_1/T_2) which control the number of classes obtained in a classificatio processing of digital data for a specific test area produced classifications of from four to eighteen classes. Careful ground checking, and checking of air photographs showed that most of these classifications were meaningless in terms of ground cover categories. In fact the ten class classification, with T_1/T_2 of 10,5 and 7,0 respectively was the one which produced closest agreement with the ground cover situation. This is a very important factor in applying the classification algorithms. Usually the computer routines are operated at 'default' parameter values or alternatively are set to produce a pre-determined number of classes, which need not necessarily be real spectrally distinguishable classes.

It is strongly recommended that some experimentation with altering T_1/T_2 values should be carried out at the beginning of the operation.

6.4 RESEARCH INTO SPECIFIC APPLICATIONS

With the emphasis having moved generally away from experimentation into various classifiers, and procedures becoming more standardized, more recent vegetation science endeavours in this field have been aimed at the effectiveness of utilizing various forms of image processing in specific applications. They include:

6.4.1 Attempts to discriminate forest types (eg Hoffer, Anuta and Phillips 1972; Fleming and Hoffer 1977; Hoffer et al 1979; Beaubien 1979). Attempts are being made in South Africa to discriminate forest types using these computer-aided procedures, but no significant results have yet been achieved.

6.4.2 Attempts to discriminate agricultural crops (eg Hoffer and Swain 1980; Misra and Wheeler 1978; Bauer et al 1979; Lemme and Westin 1979 (testing the reliability of a Landsat-simulating ground-based spectral radiometer); Welch et al 1979 (determining agricultural developments in China); Hlavka et al 1980 (discrimination of winter wheat); Colwell et al 1977 (wheat yield forecasts); Bauer et al 1978.

An experiment in the Highveld Region in South Africa into discrimination of crops has been initiated.

6.4.3 Attempts to assess rangeland resources (eg Hoffer and Swain 1980; McKloy 1980 (Australian rangelands); Tupper 1981 (Australian range condition)).

No specific applications into assessment of 'rangeland resources' have been embarked upon in South Africa.

6.4.4 Attempts at vegetation mapping (eg Sweet et al 1980; Johnson and Howarth 1980 (using image enhamcement techniques); and Richardson and Wiegand 1977).

The south west Cape applications reported on here fall within this category of attempts at vegetation mapping. Some fairly significant findings can be reported on, other than those already mentioned in sections 6.1 to 6.4.2 above.

6.4.4.1 Computer classification algorithms were used because these best suited the approach of classical vegetation mapping using standard air photos and visual interpretation techniques.

6.4.4.2 Vegetation classifications have been achieved at a range of scales from 1:10 000 to 1:250 000 using the same basic digital data, thus demonstrating the tremendous versatility of the product over that of standard air photo products. A routine called AVERAG was developed during the course of the research carried out locally, to accommodate compressing spectral data into manageable units for automatic computer processing at the smaller scales of operation. Generally the 1:250 000 reconnaissance scale appears best suited to computer-aided analysis. (See Part V, Section 4.8).

6.4.4.3 Vegetation has, however, also been mapped at a semi-detailed scale (1:50 000 final map scale) in the Langebaan area, South Africa, and the result compared favourably with an existing vegetation map at the same scale. The existing map had been produced from visual interpretation of standard air photo products backed by intensive field sampling.

The vegetation map classes produced in this operation, however, matched well with vegetation structural categories, rather than floristic categories. The visual interpretation of standard air photographs used for the existing map had readily identified floristic types. Therefore, although vegetation can be mapped at a semi-detailed level using Landsat digital data, the resolution is not sufficient to detect species differences. The maps produced are structural maps.

The ground truth support necessary for verification of the units produced at this scale of operation proved to be consistent with the recommendations of Edwards and Jarman (1972), that semi-detailed studies should be backed by field information collected from defined samples of a moderately high density, recording structural types and total floristics.

Because both structural and floristic site information existed for the Langebaan area, it was possible to sub-divide the computer derived spectral units, which were equivalent to vegetation structural units, into structural and floristic units. It is suggested therefore that field sampling to back automatic processing of data at this scale of operation should be carried out as recommended by Edwards and Jarman (1972). That is, record total floristics, name dominants in each stratum and classify the structural type using a scheme such as that designed by Campbell et al (1981) for vegetation in the Fynbos Biome. The computer produced map will 'reflect' vegetation structural types; the precisely located field samples will make it possible to break these structural types down into floristic groupings if it is deemed necessary.

6.4.4.4 Season of imagery and timing of photography can either enhance or mask vegetation features. As a result of the work carried out in the Langebaan and Verlorenvlei areas in the south west Cape it is clear that in well vegetated areas the season of maximum contrast between the dominant elements is the best season for imagery. In low cover areas, the season of maximum leaf standing crop is the best season to mask soil effects. (See Part IV, section 4.5 page D 21).

6.4.4.5 For the Verlorenvlei area Lane (1980) found canopy cover to be the single most important factor in relating spectral reflectance to vegetation factors.

work done in the Langebaan area, however, showed height of dominant strata as well as canopy cover to be important in distinguishing plant communities at this scale of resolution. This would appear to be a function of ground cover, in that in the higher cover areas (50 per cent), height of dominant strata becomes an important factor, whereas in lower cover areas (50 per cent) canopy cover remains of prime importance.

6.4.4.6 Computer processing of digital data has the advantage of the map production being part and parcel of the whole automated process. Soft-ware is continually being refined to cope with the scale adjustments and corrections necessary to produce correctly scaled final products. The majority of the work reported on here was carried out before the local image processing system had the necessary software to cope with these adjustments. This meant that the problem of orientation on the computer products was considerable.

6.5 RESEARCH INTO CHANGE DETECTION

This has been concentrated on the advantages of obtaining repetitive coverage of an area provided by the Landsat MSS data. For example a study carried out by Welch et al (1979) to determine new agrictural land developments and cropping patterns in north east China utilized visual and classification processing of Landsat data. The workers had twenty-seven Landsat scenes to work from spanning a period from 1972 to 1976, and were able to benefit from the use of multi-temporal data.

The use of Landsat multi-temporal data elsewhere has more recently been made possible because of the capability of registering multi-date data. In South Africa no multi-date data has been analyzed using computer-aided classification techniques as yet. This is an area which should be investigated as other investigators have reported increases in classification accuracy using this approach (Hlavka et al 1980).

The monitoring potential of these techniques has also been demonstrated elsewhere in that Hall and Ormsby (1980) monitored the recovery of areas after fire, using digital classification techniques.

Detecting damage such as insect damage to forest trees has mainly been limited to techniques such as visual interpretation of aerial photography, risk rating vegetation, multi-stage sampling and double-sampling. It appears that Landsat wave bands are too broad to help the vegetation damage analyst (Heller 1978).

There was a shortage of suitable CCTs for carrying out change detection analysis during the course of the work reported on here. Repetitive images were either simply not available (early investigations were carried out on images recorded in 1972 and 1973) or where they were available had considerable areas under cloud cover. The available images were adequate for investigating the capabilities of the image processing system available at the University of Cape Town, but it was not possible to fully investigate seasonal or short-term changes in vegetation cover. This was particularly the case for any attempts to investigate seasonal effects on vegetation distribution at the reconnaissance level of resolution, where whole Landsat scenes are utilized.

Three dates of CCTs were available for the Langebaan-Saldanha area and it was possible to extract a small area for investigation which was cloud free (2 x 3 km^2). Results of the investigation showed an increase in the extent of a dense cover west coast Strandveld vegetation community between June and September, and a decrease in extent of the same community between September and December. These changes in extent could be attributed to seasonal changes in the dominant plant species occurring in these communities (see Part V, section 4.6 page 44).

With direct reception of Landsat imagery now a reality in this country, many of the problems of image accessibility are likely to be minimized, and seasonal effects can be more extensively investigated.

6.6 ACCURACY OF MAPPING

In order to achieve wider acceptance among users of land use mapping from remote sensing data, the interpreter must be able to specify the 'accuracy' of his product (van Genderen and Lock 1977). Stratified random sampling techniques have been accepted as the most appropriate method of sampling in land use studies using remote sensing imagery, so that small areas can be satisfactorily represented (Rudd 1971; Zonneveld 1972). Hay (1979) recommends a minimum sample size of fifty field checked sample sites per mapped category. South African workers are very aware of the need to determine the accuracy of their mapping. So far no investigation including work reported on here, has carried an accuracy rating.

Sweet et al (1980) carried out a successful exercise in mapping the distribution of six vegetational complexes in Central Florids's east coast. They used an approach similar to that reported on in Part IV of this report, and distinguished vegetation structural types. They state in conclusion that "expression of the computer classification techniques full potential depends on the intimate participation of trained botanists". It is essential that this is borne in mind for local research effort.

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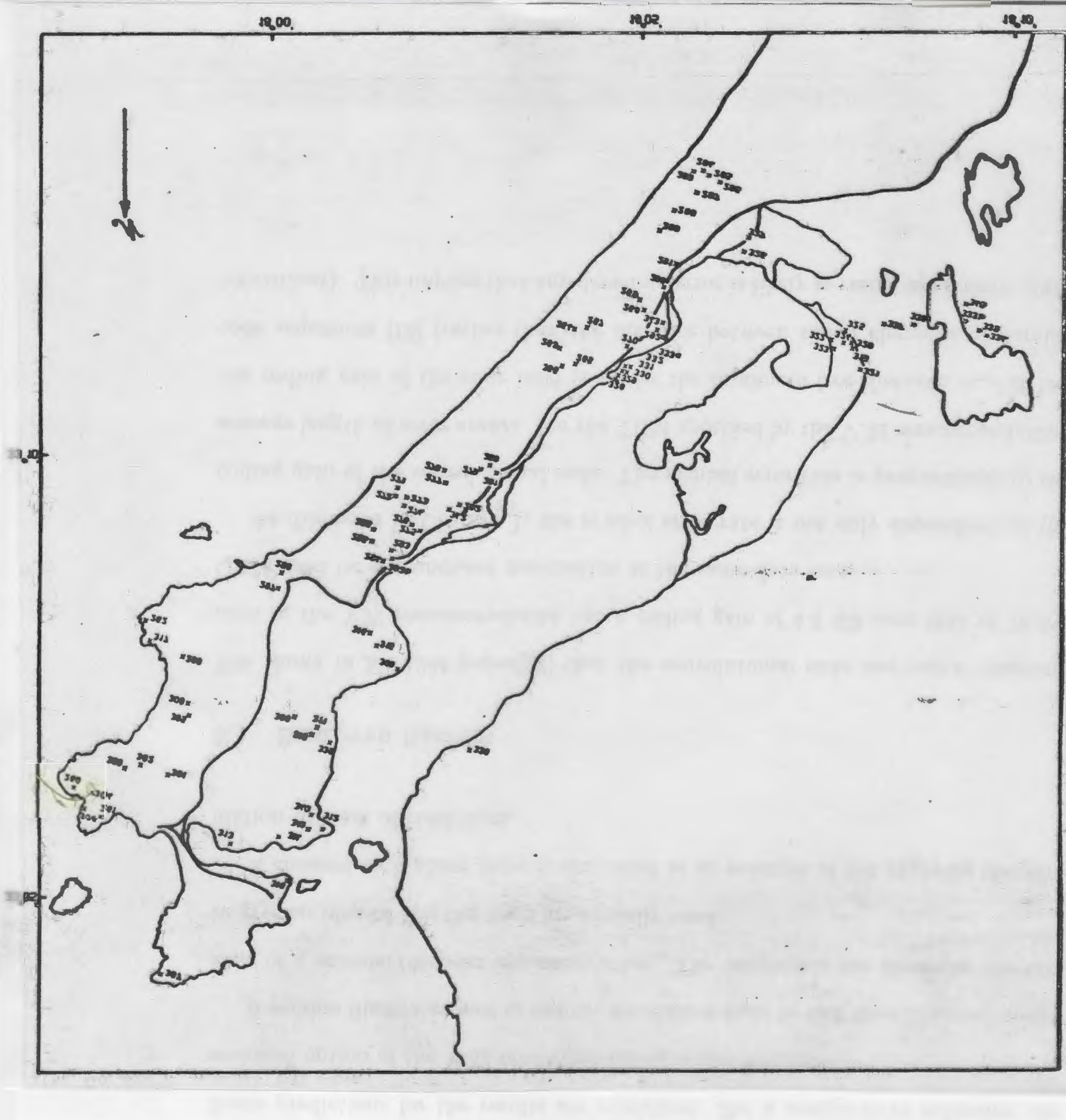

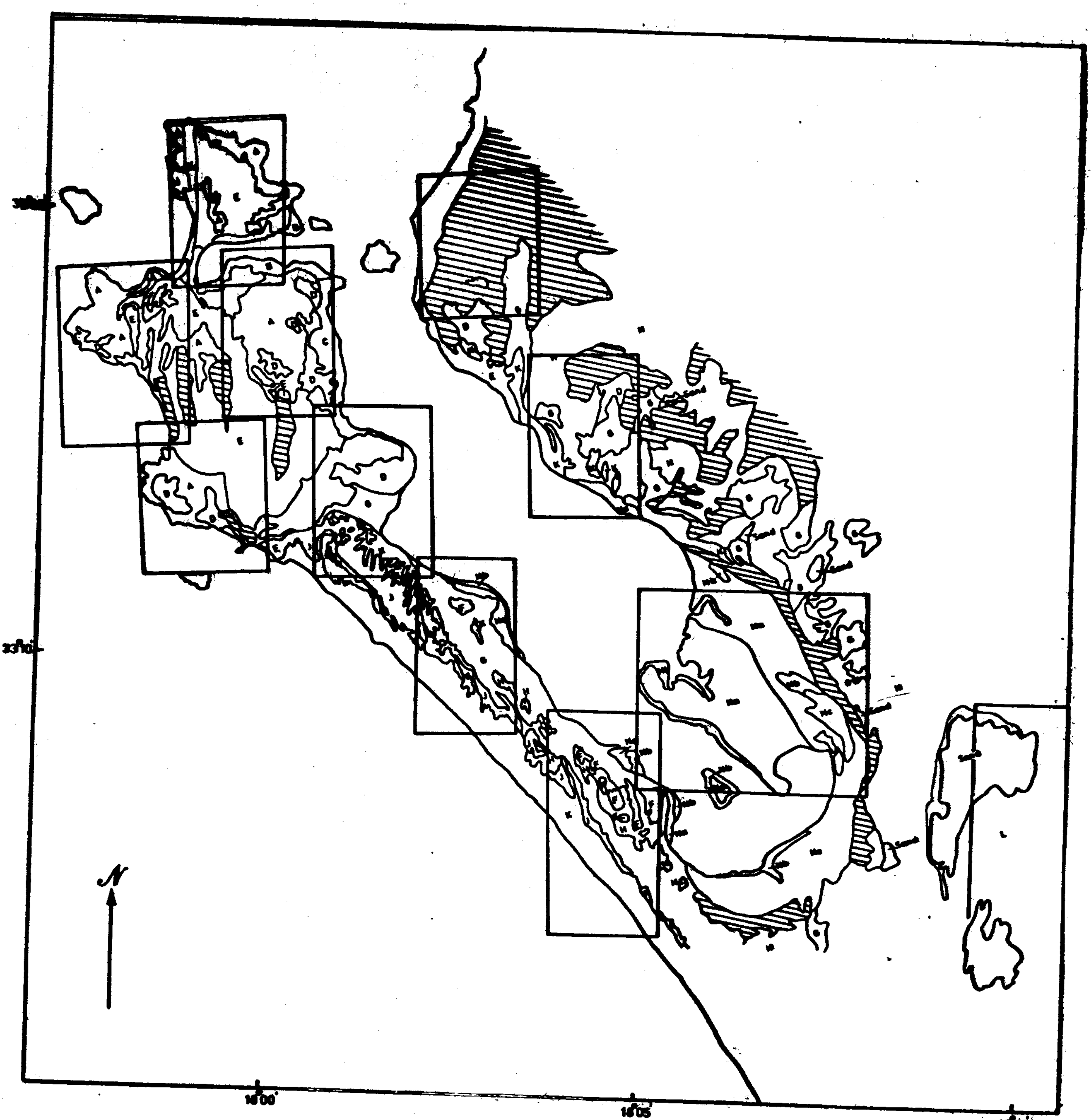
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