MAPPING THE VEGETATION OF THE FYNBOS BIOME WITH THE AID OF LANDSAT IMAGERY

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It really is a question
of teaming man with machine,
and learning which tasks man
or the machine can do better.

After Landgrebe 1978

ABSTRACT

Fourteen Landsat II photographic and digital images were used to map the vegetation of the fynbos biome. Landsat images were chosen as the best suited remote sensing products for mapping the fynbos vegetation. This was concluded after investigations which are presented in a report appearing in Appendix 1.

A preliminary mapping attempt using visual interpretation techniques on Landsat photographic prints at 1 : 250 000 scale is described in the first paper. It was found that the use of Acocks' Veld Types did not satisfactorily represent the range of vegetation of the fynbos biome.

A scheme of vegetation categories that is a second approximation to Acocks' work and a description of the production of the final map using these categories is presented in the second paper. A discussion on the mapping of the vegetation categories is also provided. The use of a combination of standard 1 : 1 000 000 scale false colour transparencies and 1 : 250 000 black and white photographic prints of band 6 for visual interpretation purposes, was successful. Computer-aided analysis of the digital data was not very successful.

The third paper describes the computer-aided analysis techniques used at 1 : 250 000 scale. Supervised training area selection, in combination with unsupervised classification techniques were used to produce computer classified maps. Only broad fynbos classes were distinguished. The distinction between classes appeared to be mainly due to vegetation canopy cover and density.

The spectral reflectance values resulting from computer classified classes are presented as spectral curves in the fourth paper. The characteristics for the fynbos and adjacent vegetation are described. The fynbos reflectance curves are shown to be very different from adjacent vegetation types such as forests, karroid shrublands and bare sandy areas.

It is concluded that Landsat images were useful and economical remote sensing products in mapping the vegetation of the fynbos biome.

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PART I GENERAL INTRODUCTION

BACKGROUND

The objective of mapping the fynbos biome vegetation was to define the geographical distribution and extent of the major vegetation types. The geographic area of the fynbos biome extends from roughly 31°S to 35°S and 18°E to 27°E, covering approximately 74 500 km^2 of the southwestern, southern and southeastern Cape. Fynbos is a broad category of vegetation formations consisting mainly of sclerophyllous shrublands of the Cape Folded mountains and their foothills, and the coastal forelands (South African National Scientific Programmes Report No 28). The dominant fynbos formations vary considerably in structure. The heathland component is characterised by growth forms of the restioid, ericoid and proteoid types (Taylor 1978), while Renosterveld is characterised by small-leafed, evergreen, sclerophyllous shrubs, notably Elytropappus rhinocerotis, a cupressoid shrub, and Strandveld by small- and broad-leafed evergreen and deciduous shrubs and scattered succulents (Moll et al, Part III in this report). The fynbos biome is one of the six world floristic kingdoms with a floral diversity of 8 550 species, of which 6 252 are endemic (Goldblatt 1978). It is not only of scientific and aesthetic interest but also economically important. The fynbos ecosystems have been fairly well conserved in the mountains but greatly reduced on the lowlands, calling for urgent conservation management plans.

The only available vegetation map and description of the fynbos biome is by Acocks (1953) and forms part of his Veld Types map of South Africa. Acocks' map was initially drawn at 1 : 500 000 scale and then reduced to 1 : 1 500 000 scale. The Veld Types, which represent units of similar farming potential and occur within the geographic limits of the fynbos biome, include Knysna Forest, Strandveld, Coastal Renosterveld, Mountain Renosterveld, Coastal Macchia, Macchia and False Macchia (Veld Types 4, 34, 43, 46, 47, 69 and 70 respectively). Although these Veld Types have been used by a number of authors to variously interpret the limits of the fynbos biome (for example Boucher and Moll 1981; Goldblatt 1978; Kruger 1979; Moll and Bossi, Part III in this report; Taylor 1978 and Werger 1978), they have been unable to agree on an accepted definition of the limits of the biome. It has become clear that the use of Acocks' Veld Types (1953) in describing the biome is not adequate.

The use of Acocks' map for conservation purposes is also not practical as the map delineates potential Veld Types and not just areas of remaining natural vegetation. Thus a remote sensing project was initiated to map those remaining areas of natural vegetation using Landsat satellite images.

A preliminary investigation into the usefulness of various remote sensing techniques for studying and mapping the fynbos biome was started in 1980 (Jarman, Bossi and Moll 1981, Appendix 1 in this report). Various remote sensing products were used, in particular Landsat I and II satellite images obtained from NASA. This investigation was motivated as a result of experience gained in the application of computer classification techniques to Landsat data in mapping vegetation in the Langebaan area (Jarman and Jackson 1981) and in the Ysterfontein area (Bossi 1979) of the southwestern Cape. Two other projects involving vegetation interpretation of digital Landsat I imagery in the Verlorenvlei area (Lane 1980) and the southern Cape Peninsula (Ripp 1978) had also been completed. All these projects were carried out at a semi-detailed scale of operation. Therefore drawing from the results of the projects mentioned above and from experimentation with computer classifications of Landsat data of fynbos vegetation at various scales (Jarman, Bossi and Moll 1981, Appendix I in this report), it was decided that a reconnaissance level of operation was most suitable to meet the mapping objective of the Fynbos Biome Programme. A mapping scale at 1 : 250 000 and the production of a final map at 1 : 1 000 000 scale was selected to be the most appropriate scales due to the extent of the biome and the suitability of operating at this scale with Landsat images. Landsat digital and photographic images were chosen to be the main remote sensing products for this project for several reasons. Firstly there would be direct reception of satellite data at the Satellite Remote Sensing Centre, Hartebeeshoek as from late 1980 (the start of the mapping project) which would ensure availability of suitable up-to-date imagery. Delay here had previously proved to be a problem in dealing with NASA. Secondly, the extensive coverage (185 x 185 km per image) provided by the Landsat images, at a relatively low cost and as manageable products, were favourable aspects. Similar coverage by aircraft would have been very expensive. Thirdly, the processing of the Landsat data at suitable scales for mapping the fynbos biome was possible. Data compression techniques were available for the digital data processing and the photographic images were also supplied at convenient scales. Fourthly, a digital image processing system, PIPS, was available and in operation at the University and there were facilities for visual interpretation of the photographic images.

THE LANDSAT SYSTEM

Landsat is in a sun-synchronous, near-polar orbit at an altitude of 917 km. The sun-synchronous nature of its orbit means that it passes over all locations at the same local sun time (09h45). It circles the globe 14 times a day and covers the entire land surface and selected ocean areas of the earth every 18 days meaning that data can potentially be collected 20 times a year for any given location. The ground scene of each image covers an area of 185 x 185 km. Each image has stereo sidelap viewing of 85% near the poles to 14% at the equator.

The main sensor system on Landsat is a multispectral scanner (MSS) which functions basically as follows:-

Reflected and emitted electromagnetic radiation (EMR) from a point on the ground is transmitted through the atmosphere and strikes an oscillating mirror in the lower part of the scanner. The mirror deflects the radiation to a set of optics that separate it into four distinct spectral bands. Radiation in each spectral band strikes a different electro-optical detector which transforms the EMR into an electrical signal (digital number) that can be recorded on magnetic tape when the satellite is beyond the line - of - sight of any ground receiving stations. The spectral bands, which include two visible and two near-infrared bands, are:

Band 4 : 0,5 - 0,6 μm (green)
Band 5 : 0,6 - 0,7 μm (red)
Band 6 : 0,7 - 0,8 μm (near IR)
Band 7 : 0,8 - 1,1 μm (near IR)

Because the responses in all four spectral bands are detected simultaneously, the recorded data is four-dimensional in nature and is often referred to as multispectral data.

As the satellite passes over the surface of the earth, the scanner mirror traces out a scan path perpendicular to the motion of the spacecraft. This is depicted in Figure 1. Six lines are scanned and recorded simultaneously.

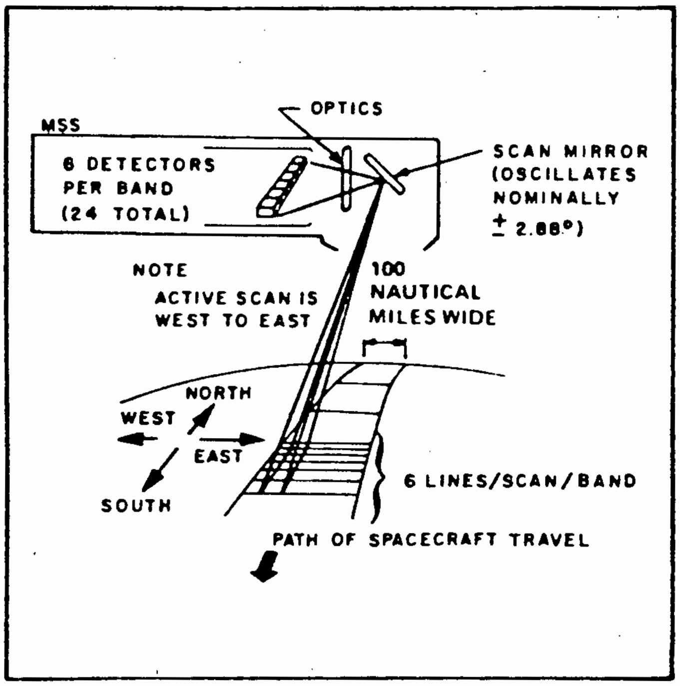

Figure 1. Schematic of LANDSAT MSS scan pattern (after NASA, 1972).

At a given instant of time the scanner views an element in each line which has the nominal dimensions of 80 x 80 m on the earth's surface. There are approximately 3 240 such elements (pixels) per line and one complete image contains 2 340 scan lines. The Landsat MSS data is received from the satellite by NASA or another ground receiving station, processed and delivered to the users in the form of computer compatible tapes (CCT's) and photographic images.

APPROACHES TO LANDSAT DATA ANALYSIS

This sophisticated technology developed to gather multispectral scanner (MSS) imagery of the entire earth's surface from spacecraft altitudes, has greatly improved mapping prospects. The capability to gather data has been increased in terms of area covered, speed of collection and repetitiveness of coverage. With this increased quantity of data, the technology for interpreting the data on an operational basis has also had to be developed. As part of this new technology, a numerically orientated approach to mapping has been introduced. This approach involves processing of the digital data gathered by the multispectral scanner by means of computer-aided analysis techniques. These techniques present an unbiased, repetitive form of information extraction.

The inherently quantitative nature of digital MSS data lends itself to numerical treatment. In remote sensing applications, two major types of numerical treatment of the data are commonly utilized: image (1) enhancement and (2) multispectral classification. Image enhancement is a numerical processing method applied to an image to emphasize or suppress certain features in the image, for example emphasizing boundaries between different ground cover types or suppressing undesired features such as noise. The output is a transformed image which can be more effectively analysed and classified through conventional visual interpretation methods. Multispectral classification is another numerical processing method which analyses the MSS data and classifies it into specific classes. This method implies the definition of a decision criterion that can be used by a computer to assign a certain object in the scene into a specific class on the basis of a given classification rule. The computer therefore has to be provided with characteristics of a number of spectral (training) classes. There are two approaches to determine these spectral characteristics which are in fact sets of statistics. The supervised approach defines the statistics of training classes through the selection of homogeneous and informationally pure fields of known cover types. In the unsupervised approach the statistics that define the training classes are determined through the selection of heterogeneous fields containing as many different spectral responses as possible. A clustering algorithm is then used to automatically group pixels of similar spectral characteristics into a number of spectrally separable spectral classes. However, regardless of the approach used, the usefulness and accuracy of the classification is dependent on the choice of the optimum set of training classes by the analyst. In other words, the best results are obtained through computer-aided analysis techniques in contrast to automatic data processing techniques. There are also a number of pre-classification procedures which may be performed on data to correct for known geometric and radiometric distortions.

Visual interpretations of Landsat imagery, particularly the 1 : 250 000 scale false colour composite, provides adequate information for mapping broad categories of land cover at a reconnaissance level (Bartolucci 1979). However, the Landsat data in digital format contain a great deal more information, useful for mapping at more detailed scales. The digital data provides the analyst with a larger number of gray scales (256) with which to work, in contrast to the 16 differentiable gray levels that are distinguishable in a Landsat photographic product. More efficient handling of the large quantities of digital data have been made possible by the development of computer-aided analysis. Furthermore, these techniques are able to operate simultaneously with data from several bands, which further increases the capabilities of spectrally discriminating objects that in individual spectral bands would not be possible (Landgrebe 1978).

Many studies have however found Landsat photographic images very useful (for example Kalensky et al 1980, Kratky 1974, Nelson and Hoffer 1979).
In South Africa Landsat photographic products were first introduced many years ago when the value of early poor quality 3rd and 4th generation positives and negatives from NASA were assessed for resource inventory in South Africa (Malan 1973).
In this survey it was found that "major veld types, physiognomic-structural and ecological classes of vegetation could be mapped with at least a fair degree of accuracy and most often with a generally high degree of accuracy by various investigators, on the basis of existing knowledge and with only a minimum of ground control". Satellite imagery was used for small scale mapping in England and Scotland and it was found that false colour composites were adequate for interpreting vegetation (Mott and Chisman 1975). Landsat imagery was also found to be suitable in Australia to produce a map at 1 : 1 000 000 scale showing features such as topography, soils and vegetation (Story et al 1976).

Much less common has been the use of digital image processing of Landsat data for mapping areas of natural vegetation. Jarman and Jackson (1982) and Sweet et al (1980) present examples of vegetation maps prepared at a semi-detailed scale. Research concerning the use of computer processing techniques has been more exhaustive in providing reliable crop production information (Bauer et al 1979) and in mapping agricultural lands (Welch and Lo 1979) where in both cases a high degree of accuracy has been attained. This has been possible as agricultural lands have large areas of relatively uniform spectral reflectance characteristics compared to the areas of natural vegetation where there is often a large mixture of vegetation communities, each with different spectral reflectance characteristics. This feature tends to lead to unsatisfactory results from the computer processing of data from natural vegetation (Bossi, Part IV in this report).

THE MAPPING PROCEDURE

Landsat II photographic and digital imagery was used in mapping the fynbos biome vegetation at a reconnaissance scale of 1 : 250 000. The final map was reduced to 1 : 1 000 000 scale. Nine 1 : 250 000 map sheets from the Trigonometrical Survey series were used as base maps and fourteen Landsat images were needed for complete coverage of this area (Moll et al, Part III in this report).

The initial attempt at mapping and calculating the extent of the remaining natural vegetation of the fynbos biome is described in Moll and Bossi (Part II in this report). This attempt was completed using visual interpretation techniques on false colour composite transparencies and waveband 6 black and white photographic prints. The investigation found that 34% of the natural vegetation had been removed. It was also reported that the Acocks Veld Types (1953) which had been used to delineate the vegetation types did not satisfactorily represent the range of types in the fynbos biome. Results from recent intensive research activity within the Fynbos Biome Programme have also emphasised this shortcoming. Therefore a new scheme of vegetation categories for the biome has been developed as a second approximation to Acocks' work (Moll et al, Part III in this report). This scheme includes the major categories occurring in or adjacent to the fynbos biome and is the one used for the final map of the biome.

A description of the mapping method used is given in Moll et al (Part III in this report). Visual interpretation and digital image processing techniques were utilized in producing the final maps. Paper copies of the nine 1 : 250 000 final map sheets, and colour prints of the 1 : 250 000 Worcester sheet and the 1 : 1 000 000 final map delineating the fynbos vegetation are included in this report as Appendix 2. The computer generated maps were not as useful as it was originally hoped because the spectral categories (computer generated) did not always correspond with the vegetation classes as defined by botanists. Other difficulties in categorizing certain parts of biome are discussed in the paper by Moll et al (Part III in this report). However, field surveys and comments from botanists confirmed that the final vegetation boundaries drawn were good.

The computer processing of each of the fourteen images covering the biome is presented in the paper by Bossi (Part IV in this report). Using supervised training area selection in combination with unsupervised classification techniques, produced only broad fynbos vegetation classes. The distinction between the spectral classes was based mainly on differences in vegetation canopy cover and density.

The spectral reflectance values of the spectral classes are presented as spectral curves in the paper by Bossi (Part V in this report). These curves are examined and the characteristics for the fynbos and adjacent vegetation are described. The spectral reflectance characteristics show that there is a variation within the fynbos classes from different geographical and environmental areas. It is also seen from the curves that the fynbos reflectance characteristics are very different from adjacent vegetation types.

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NB

PART II. FIRST PAPER: A CURRENT ASSESSMENT OF THE EXTENT OF THE NATURAL VEGETATION OF THE FYNBOS BIOME

E J Moll and L Bossi

ABSTRACT

The natural vegetation of the fynbos biome was mapped by using visual interpretation techniques on Landsat satellite imagery. Vegetation categories were delineated using Acocks' Veld Types occurring in the fynbos biome, namely Knysna Forest, Strandveld, Mountain Renosterveld, Coastal Renosterveld, Coastal Macchia, Macchia and False Macchia (Veld Types 4, 34, 43, 46, 47, 69 and 70 respectively). The extent of the map categories occurring on Acocks' map and our map were measured, highlighting areas cleared by human activities. During the mapping operation it was found that Acocks' Veld Types did not satisfactorily represent the range of vegetation of the fynbos biome.

INTRODUCTION

The region comprising the fynbos biome has been interpreted differently by various authors and currently there is no unanimously accepted definition. In the preliminary synthesis of the Fynbos Biome Programme (Day et al 1979), Kruger (1979a) followed Werger's (1978) delimitation of the "Capensis" Region in his description of the biome. This was characterized by Acocks' (1953) Strandveld, Coastal Renosterveld, Coastal Macchia, Macchia and False Macchia (Veld Types 34, 46, 47, 69 and 70 respectively). Goldblatt's (1978) interpretation was similar to Kruger's except he excluded Strandveld from the Cape Floristic Region. Boucher and Moll (1981) in their account of Mediterranean climate shrublands, which omitted the heathland components (Kruger 1979b), included Mountain Renosterveld (Veld Type 43).

In this present study we have attempted to satisfy as wide a spectrum of views as possible and have included Knysna Forest (Veld Type 4) in addition to Strandveld, Mountain Renosterveld, Coastal Renosterveld, Coastal Macchia, Macchia and False Macchia. The reason for including Knysna Forest is that there are many relic Afromontane Forest patches (White 1978) distributed throughout the Cape Folded Mountains in which a number of Cape endemics occur. On the other hand true Karoo types belonging to the Karoo-Namib Region and bushveld types belonging to the Sudano-Zambezian Region (Werger 1978) on nutrient-rich clays and clay-loams have been excluded as these have never been considered part of the Capensis Region/ Cape Floral Kingdom/fynbos biome.

METHODS

Visual interpretation techniques were used on Landsat satellite imagery to map the remaining areas of natural vegetation in the fynbos biome. The images were acquired during February 1981 so the information is reasonably up-to-date. Summer images were chosen to allow for maximum discrimination between the fynbos vegetation and the agricultural land.

The vegetation of the fynbos biome was mapped at 1 : 250 000 scale and then reduced to 1 : 1 000 000 scale to produce a final map. Fourteen Landsat images were required to cover the entire biome (Table 1). The type of imagery used was false colour composite transparencies (wavebands 4, 5 and 7) at 1 : 1 000 000 scale and black and white photographic prints at 1 : 250 000 scale. Using a hand lens, the colour transparencies were interpreted and the vegetation boundaries were then delineated on a transparent overlay on the waveband 6 photographic image. Supporting sources of information, in particular the Geological Survey maps (1970) and personal field experience were used to aid the interpretation.

Table 1. Listing of the 14 Landsat images which cover the fynbos biome

WRS	SCENE - ID	DATE	AREA DESCRIPTION
188-082	22229-07533	81-02-28	Verlorenvlei
188-083	22211-07535	81-02-10	Langebaan
187-082	22228-07474	81-02-27	Calvinia
187-083	22228-07481	81-02-27	Ceres
187-084	22228-07483	81-02-27	Cape Town
186-083	22209-07422	81-02-08	Laingsburg
186-084	22209-07424	81-02-08	Bredasdorp
185-084	22208-07370	81-02-07	Mossel Bay
185-083	22208-07363	81-02-07	Oudtshoorn
184-083	22243-07305	81-03-14	Uniondale
184-084	22243-07312	81-03-14	Plettenberg Bay
183-083	22224-07251	81-02-23	Port Elizabeth
183-084	22224-07254	81-02-23	Humansdorp
182-083	22169-07195	80-12-30	Grahamstown

A set of nine map sheets at 1 : 250 000 scale were drawn in this manner and then photographically reduced to 1 : 1 000 000 scale. The extent of each map category was measured after the reduction by using a digitizer and these data are given in Figure 1.

A map of Acocks'(1953) Veld Types in the fynbos biome was also reproduced and the extent of each map category measured. By comparing the Acocks (1953) map with our map, the areas cleared by human activities could be delineated and measured.

In his work Acocks (1953) recognized Veld Types as units of "farming potential" and did not excise areas where the natural vegetation had been cleared. In our delineation we endeavoured to map only areas of natural vegetation but recognize that some areas densely or partially infested by alien vegetation, or fallow areas recolonized with shrubby vegetation, have been included as "natural".

The imagery available in this study did not include all the areas mapped by Acocks (1953); specifically the Roggeveld and Kamieskroon mountains covered by Mountain Renosterveld were missing. These areas have therefore been excluded from our map and from the reproduction of the Acocks map.

RESULTS AND DISCUSSION

A reproduction of the map of the area comprising the fynbos biome as mapped by Acocks (1953) is shown in Figure 1. Comparative figures of the extent of Veld Types represented on Acocks' map and the estimated extent of the remaining vegetation are given in Table 2. Because Acocks mapped units of "farming potential" without excising areas where the natural vegetation had been cleared, a comparison of these figures represents the extent of natural vegetation cleared by man, primarily since 1652.

Our map of the existing natural vegetation of the fynbos biome is shown in Figure 2. The boundaries between natural vegetation and the agricultural regions were mainly derived from the Landsat images, whereas the drawing of the boundaries between the various types of natural vegetation was greatly assisted by the Geological Survey maps (Figure 3) and field experience.

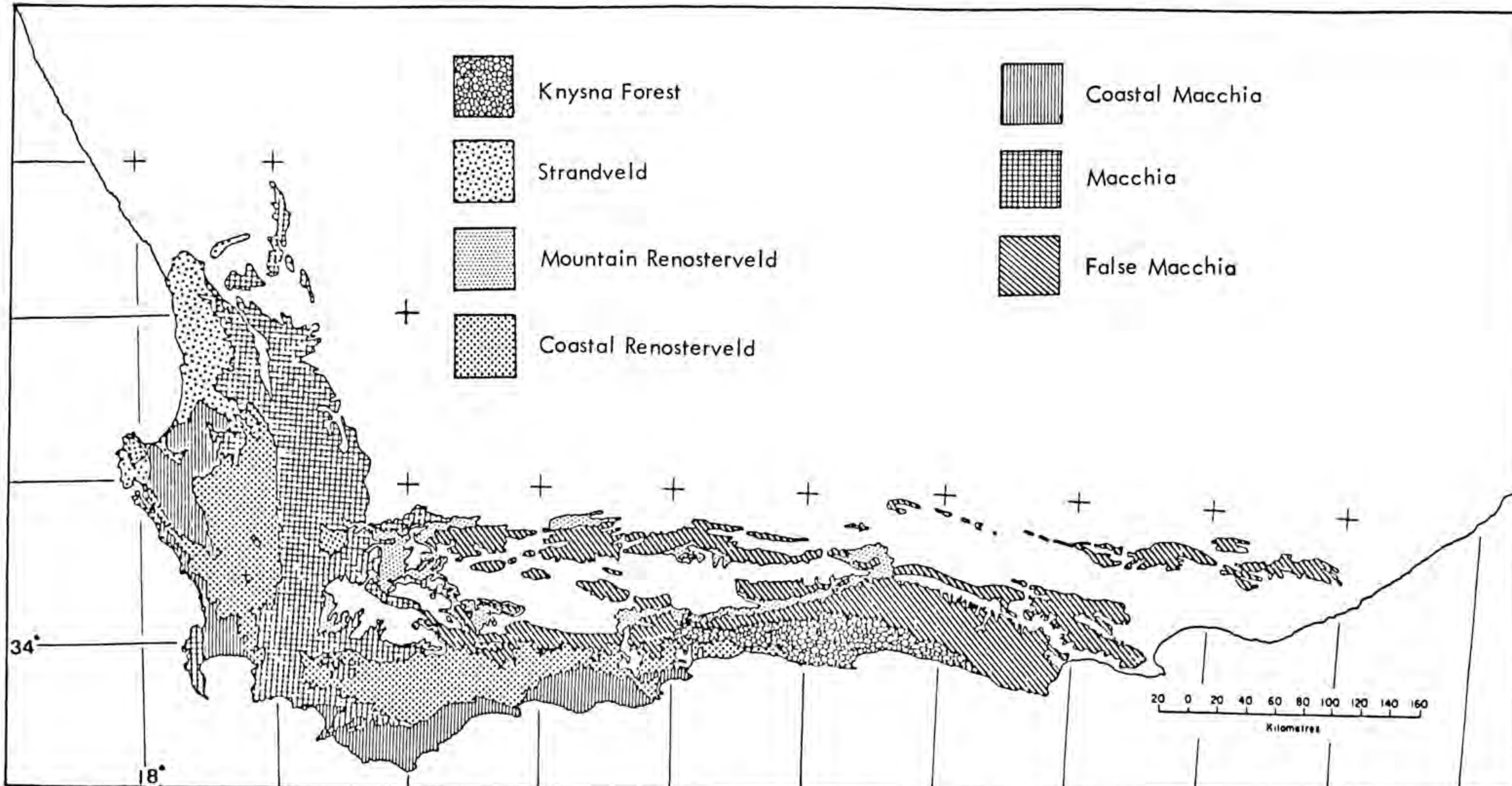

Figure 1. Map of the fynbos biome based on part of Acocks' Veld Type map of South Africa (1953).

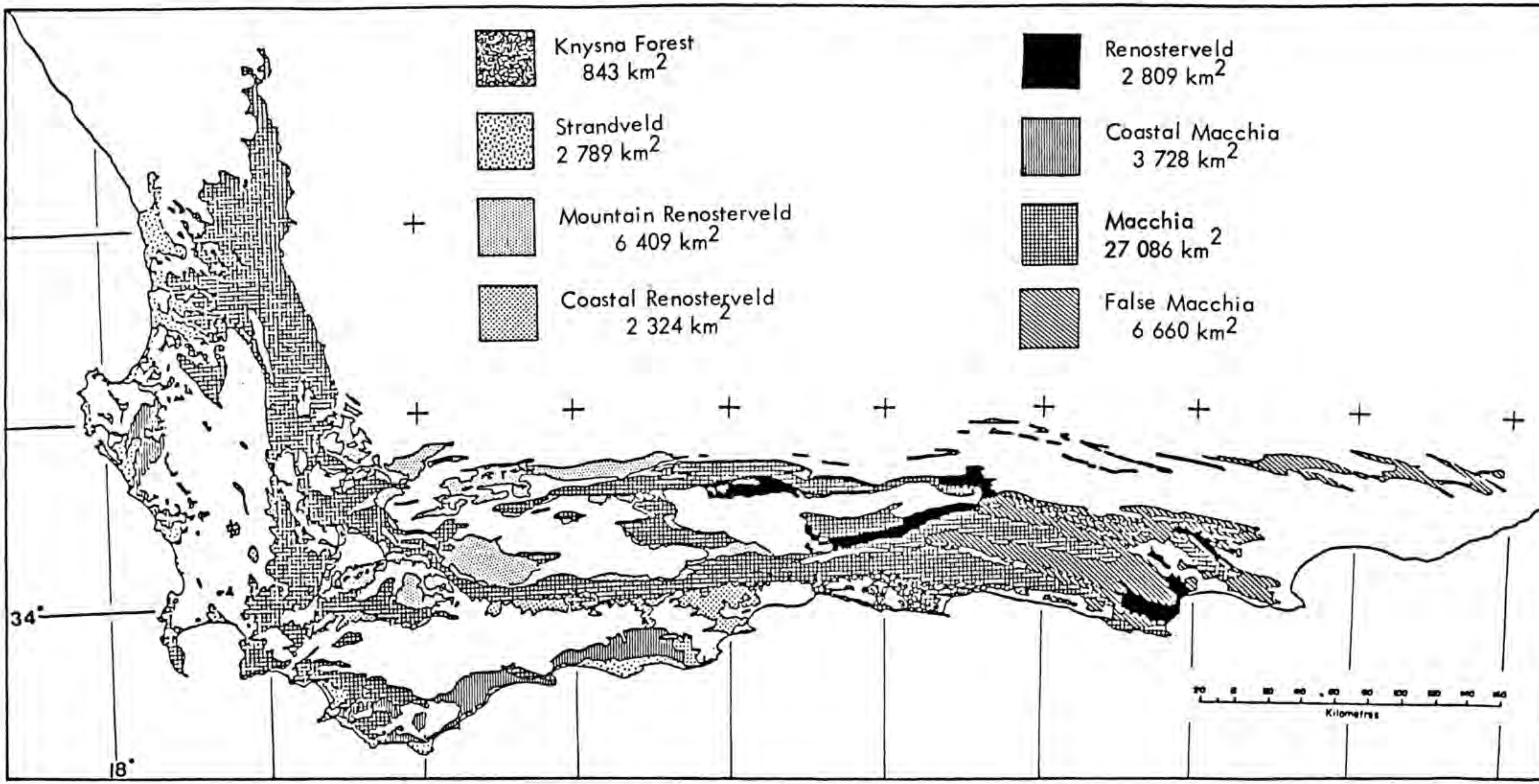

Figure 2. Remaining natural vegetation of the fynbos biome as mapped from the 1981 Landsat images. The area for each type is given in the legend.

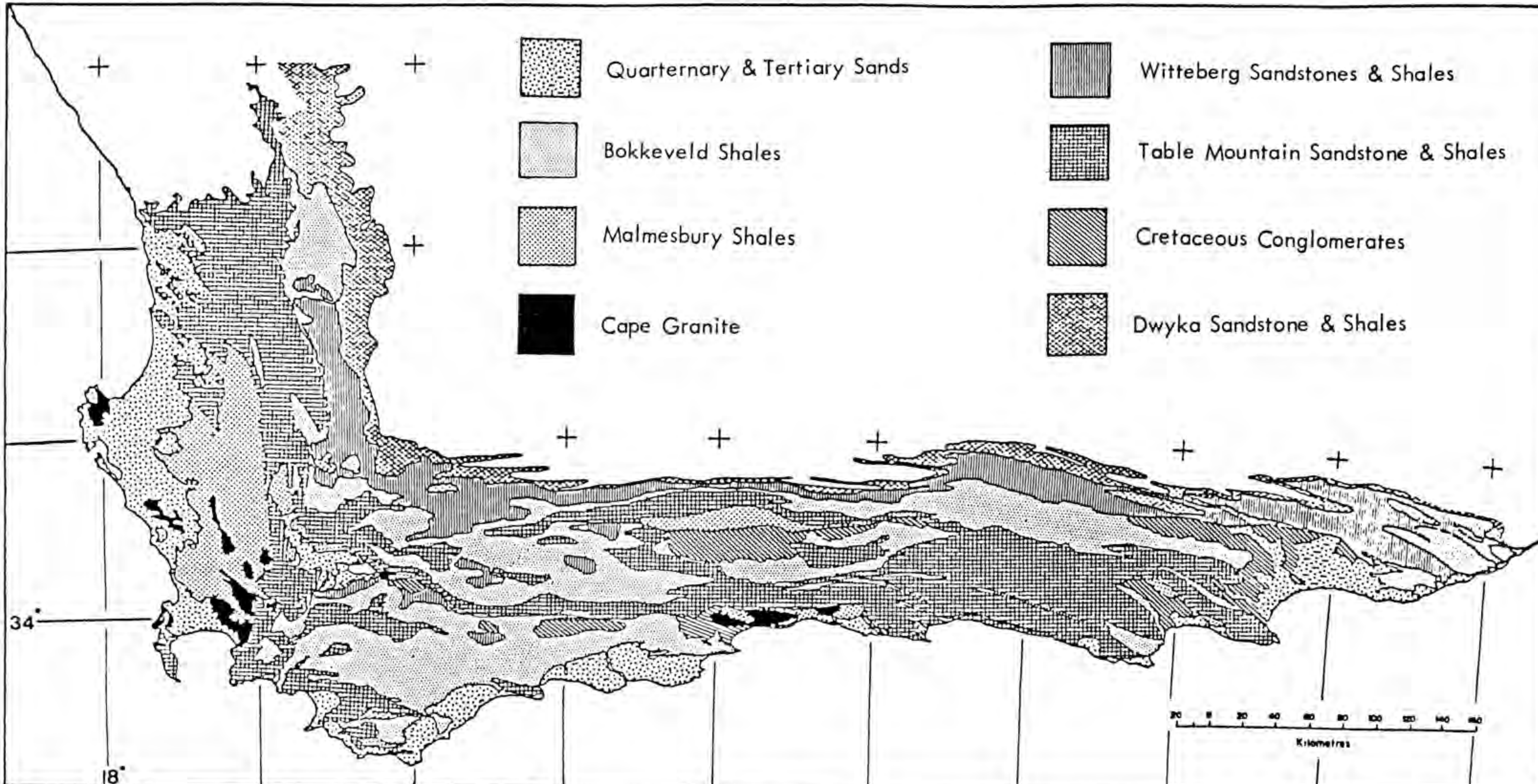

Figure 3. Major geological formations of the southwestern and southern Cape (after Geological Survey maps 1970)

Table 2. The extent of natural vegatation as mapped by Acocks (1953) and that remaining as interpreted from the 1981 Landsat imagery

Veld Type N°	Name	Area (km^2)	Remaining area (km^2)	Natural Vegetation lost %
4	Knysna Forest	3 844	2 930	24
34	Strandveld *	4 453	2 072	53
43	Mountain Renosterveld	4 754	3 448	27
46	Coastal Renosterveld	15 285	2 256	85
47	Coastal Macchia	8 770	4 627	47
69	Macchia	18 345	16 305	11
70	False Macchia	18 965	18 347	3

* excluding northern coastal portion

In our work we have endeavoured to follow Acocks' (1953) Veld Types, but since we used modern remote sensing techniques our map and interpretations are not always compatible. The major differences between the vegetation boundaries of the two maps are as follows:

(a) Knysna Forest (Veld Type 4). We were more conservative in the recognition of this type and have mapped essentially high forest and not "potential" Knysna Forest areas.

(b) Mountain Renosterveld (Veld Type 43). Two forms of Mountain Renosterveld have been distinguished. One form (Mountain Renosterveld) is restricted to the winter-rainfall region in the west and the other form (Renosterveld) to the all-year-rainfall to summer-rainfall area. There are two reasons for this; firstly, two types of Mountain Renosterveld could be distinguished on the Landsat images, and secondly the debate about the whole controversy of whether Mountain Renosterveld should be included in the fynbos biome made us more aware of differences while interpreting this type. Also field experience indicated that the eastern form has more grassy elements and merges into Sudano-Zambezian types compared to the western form which merges into Karoo-Namib types (Werger 1978).

(c) Strandveld (Veld Type 34). Acocks only recognized this Veld Type along the West Coast. Our interpretation of this type on the West Coast was essentially the same. However, we also distinguished limited areas of Strandveld on the south coast.

(d) Coastal Renosterveld (Veld Type 46). Most of this Veld Type as mapped by Acocks has been cleared for agricultural purposes but the map boundaries of what little natural vegetation remains were well matched between the two maps.

(e) Coastal Macchia (Veld Type 47). For simplicity we adhered to Acocks' delineation for this Veld Type (except for recognizing some Strandveld on the south coast). However, we could distinguish different fynbos types along the south coast, notably on limestone and lateritic substrates.

(f) Macchia (Veld Type 69). Our map boundaries for this Veld Type extended further towards the east because much of what Acocks recognized as a more grassy and useful agricultural type was interpreted as true Macchia.

(g) False Macchia (Veld Type 70). Our interpretation of Veld Type 70 was that it only occurred in the all-year-rainfall to summer-rainfall areas. Some of the areas mapped as False Macchia by Acocks were recognized as Renosterveld on our map, possibly due to the encroachment of Elytropappus into the False Macchia.

CONCLUSIONS

In this study we have undertaken to improve the vegetation map of the fynbos biome as given by Day et al (1979) and to provide data on the extent of the remaining natural vegetation.

We calculated that 34% of the natural vegetation has been removed. This figure is lower than expected when compared to the estimate of 61% obtained by Hall (1978). However, it is not known how much of the fynbos biome area was included in Hall's estimate and possibly a comparison between these two figures is not valid.

During the mapping operation it was found that the Acocks' Veld Types did not satisfactorily represent the range of vegetation of the fynbos biome. Thus a more detailed description and map of the biome are in preparation.

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PART III. SECOND PAPER: A DESCRIPTION OF MAPPED MAJOR VEGETATION CATEGORIES IN AND ADJACENT TO THE CAPE FLORAL KINGDOM

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ABSTRACT

A scheme of major categories of the vegetation in and adjacent to the Cape Floral Kingdom is given as a second approximation after Acock's Veld Types (1953). A fan tier hierarchy is presented with nineteen categories of vegetation. The major sub-divisions recognized on the basis of their structural, environmental and floristic characteristics are: Cape Fynbos Shrublands; a mosaic of Cape Fynbos Shrublands and Sub-tropibal Elements; Cape Transitional Shrublands; Sub-tropical Thicket; Afromontane Forest; and Karroid Shrublands.

In addition a vegetation map on which these categories were recognized was produced using Landsat imagery.

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INTRODUCTION

The fynbos biome, which closely approximates the geographic area of the Cape Floristic Kingdom (Goldblatt 1978, Kruger 1979a), has received little syntaxonomic treatment, and Acocks' (1953) treatment has had to suffice as an overall vegetation classification of the biome. Over the years it has become clear that Acocks' treatment is inadequate and Acocks himself stated that the subdivision of mountain fynbos into Macchia and False Macchia was like "dividing the tropical vegetation of South Africa into grassveld and bushveld". Apart from the problems of an inadequate classification, a precise and generally acceptable definition of 'fynbos' has so far eluded botanists; and this has led to confusion amongst other environmentalists (see Moll & Jarman 1983).

Since 1978, concomitant with the emergence of the Fynbos Biome Project, there has been an upsurge of research activity in the biome. As part of the initial baseline study phase of the project many workers have undertaken descriptive studies aimed at mapping, classification and characterization of biome vegetation both on an intensive and extensive scale. Up to date regional phytosociological and structural data are now available from Bond (1981) (structure and floristics in the southern Cape mountains), Boucher (in prep) (floristics in the west coast lowlands), Campbell (1984a, 1984b) (structure in the mountains) and Cowling (1983a) (floristics in the eastern Cape). In addition the major vegetation types have been mapped at 1:250 000 scale from Landsat imagery (Jarman, Bossi & Moll 1981, Jarman, Bossi & Moll 1983, Moll & Bossi in press, Bossi in prep).

As a result of these research activities the time is ripe to present a synthesis of the findings; a scheme of vegetation categories that is a second approximation to Acocks' work. Unfortunately the available regional data are of various types (structure in some cases; floristics in others), and there are large areas of the biome not covered in the regional surveys. Because of these limitations, a limited hierarchy is suggested here and the applicable map scales are those of about 1:250 000 or smaller. Controversies still remain, and even within the present authorship there are some divergent views.

MAPPING METHOD USED

Fourteen Landsat images were required for coverage of the whole Fynbos Biome (Table 1). Landsat products, available from the Satellite Remote Sensing Centre in South Africa, were assessed to determine which date and what type of images would best be suited for identifying the fynbos vegetation at the hierarchical level presented here (Table 2).

Two scenes, WRS 187-84 and WRS 188-83 (Cape Town and Langebaan scenes), were chosen for this assessment. Two sets of photographic images of each scene, a summer and a winter set, were examined. Each set of images consisted of black and white transparencies of wavebands 4, 5, 6 and 7, and a false colour composite transparency (a combination of wavebands 4, 5 and 7). These images are standard product transparencies at 1:1 000 000 scale and were not enhanced. Summer images displayed greater contrast between major categories of fynbos vegetation and surrounding agricultural land. The false colour composite transparencies and waveband 6 black and white transparencies were found to be the most useful for identifying fynbos. From these evaluations it was decided to use a combination of images in the visual interpretation process.

TABLE 1. LISTING OF THE 14 LANDSAT IMAGES WHICH COVER THE FYNBOS BIOME

WRS	SCENE - ID	DATE	AREA DESCRIPTION
188-082	22229-07533	81-02-28	Verlorenvlei
188-083	22211-07535	81-02-10	Langebaan
187-082	22228-07474	81-02-27	Calvinia
187-083	22228-07481	81-02-27	Ceres
187-084	22228-07483	81-02-27	Cape Town
186-083	22209-07422	81-02-08	Laingsburg
186-084	22209-07424	81-02-08	Bredasdorp
185-084	22208-07370	81-02-07	Mossel Bay
185-083	22208-07363	81-02-07	Oudtshoorn
184-083	22243-07305	81-03-14	Uniondale
184-084	22243-07312	81-03-14	Plettenberg Bay
183-083	22224-07251	81-02-23	Port Elizabeth
183-084	22224-07254	81-02-23	Humansdorp
182-082	22169-07195	80-12-30	Grahamstown

The false colour composite transparencies were used at the original 1:1 000 000 scale. The waveband 6 transparencies were enlarged to a 1:250 000 scale and photographic prints were produced at that scale. Transparent base maps at 1 250 000 scale (from the Trigonometrical Survey series) were placed over the waveband 6 images. Visual analysis of the images, based on standard air photo interpretation techniques were carried out by placing each false colour composite on a light table and interpreting them with the aid of a hand-lens. The interpreted features were then located on the waveband 6 images and delineated on the transparent base maps. This procedure was repeated until all the images were interpreted.

Throughout the process reference was made to available literature and maps (in particular the Geological Survey maps (1970) and Acocks' Veld Type Map 1953). Many field checks were made and the extensive reservoir of field experience amongst local botanists was drawn upon to assist in interpretations. A first draft of the nine 1:250 000 maps were then widely circulated for comment and criticism. These are; 3118 Calvinia, 3218 Clanwilliam, 3318 Cape Town, 3319 Worcester, 3420 Riversdale, 3320 Ladismith, 3322 Oudtshoorn, 3324 Port Elizabeth and 3326 Grahamstown.

Digital image processing techniques were also applied to the fourteen Landsat computer compatible tapes (CCTs) to produce computer classification in map form of the whole biome. This procedure is described in detail in another paper (Bossi, in prep). These computer generated maps were used to assist in finalising the 1:250 000 maps. The boundaries of the computer generated vegetation categories were compared with visually interpreted boundaries in areas where there was confusion or indecision.

The final set of nine map sheets at 1:250 000 scale were photographically reduced to 1:1 000 000 scale for the final map production.

TABLE 2 : MAJOR CATEGORIES RECOGNIZED IN MAPPING VEGETATION IN AND ADJACENT TO THE CAPE FLORAL KINGDOM

MAPPED VEGETATION CATEGORIES	STRUCTURAL ENVIRONMENTAL DESCRIPTIONS	BIOGEOGRAPHIC AFFINITIES	FLORAL KINGDOM DIVISIONS
AREAS OF NATURAL VEGETATION			
CAPE FYNBOS SHRUBLANDS			
Mountain Fynbos			
Wet Mountain Fynbos Mesic Mountain Fynbos Dry Mountain Fynbos	Heathlands on sandstone and quartzite mountains	Cape Communities	Cape Floral Kingdom
Grassy Fynbos			
Mesic Grassy Fynbos Dry Grassy Fynbos	Grassy heathlands on sandstone, quartzites and conglomerates		
Lowland Fynbos			
Sand Fynbos	Heathlands on lowland acid sands		
Elim Fynbos	Heathlands on lowland laterites		
Limestone Fynbos	Heathlands on lowland limestone		
MOSAIC OF CAPE FYNBOS SHRUBLANDS AND SUBTROPICAL ELEMENTS			
Dune Fynbos	Shrublands on coast dunes	Cape/Sudano-Zambezian Communities	Elements of Cape and Palaeotropic Floral Kingdoms
CAPE TRANSITIONAL SHRUBLANDS			
Renosterveld			
West Coast Renosterveld	Small-leafed shrublands mainly on Malmesbury shales and Cape Granite	Cape/Karoo/Namib/Afromontane Communities	
South Coast Renosterveld	Small-leafed shrublands on Bokkeveld shales and Cretaceous conglomerates		
Central Mountain Renosterveld	Small-leafed shrublands mainly on Bokkeveld and Witteberg shales		
Eastern Renosterveld	Small-leafed shrublands mainly on Bokkeveld and Cango shales	Cape/Karoo-Namib/Sudano-Zambezian Communities	
Strandveld			
West Coast Strandveld South Coast Strandveld	Broad-leafed shrublands on coastal, calcareous sands	Sudano-Zambezian/Tongaland-Pondoland/Cape Communities	
SUBTROPICAL TRANSITIONAL THICKET AND FOREST			
Kaffrarian Thicket	Tongaland-Pondoland Regional mosaic communities mainly on coastal sands	Tongaland-Pondoland Communities	Palaeotropic Floral Kingdom
Valley Bushveld (undifferentiated)	Zambezian Domain communities on shales and conglomerates	Sudano-Zambezisan/Tongoland-Pondoland Communities	
AFROMONTANE FOREST			
Afromontane Forest Communities (undifferentiated)		Afromontane Communities	
KARROID SHRUBLANDS			
Karroid Shrublands on shales and mudstones (undifferentiated)		Karoo-Namib Communities	

Ecotones

Mosaic of Dry Mountain Fynbos and Karroid Shrublands
Mosaic of Sand Lowland Fynbos and West Coast Strandveld
Mosaic of Dune Fynbos and Dune Thicket

AREAS PARTIALLY CLEARED OF NATURAL VEGETATION

Mosaic of Eastern Renosterveld and agriculture

AREAS CLEARED OF NATURAL VEGETATION

Cultivated land, plantations, dense alien communities and open sandy areas
Reservoirs, pans and lakes
Cities and towns

AZONAL COMMUNITIES (not mapped or described in detail)

Riverine Communities
Wetland Communities
Littoral Communities

THE PROPOSED SCHEME

Table 2 shows the major categories that we recognize. These have been used in mapping the vegetation at a final scale of 1:1 000 000. The two higher tiers of the four tier hierarchy are phytochorological units; being based on the world floristic kingdoms (Takhatjan 1969) and the system of White (1982) in his UNESCO map of the vegetation of Africa. These have been included to assist readers to gain an overall perspective, particularly those who are unfamiliar with how our mapped categories relate to recognised African and world schemes.

The third tier in the four tier hierarchy consists of structural/environmental descriptions of mapped vegetation units. It should be noted that at this level, although we use units such as heathlands on sandstone and quartzite mountains, we do recognize that the geological-vegetation relationships are far from perfect (e.g. fynbos can occur on many geological formations throughout the biome provided that rainfall is at least above 600 mm, and non-fynbos can occur on sandstone provided that rainfall is at least below 400 mm (Campbell 1984b)).

At the scale of mapping (the fourth tier in the hierarchy) not all the categories are at the same floristic hierarchical level. For instance future detailed structural environmental descriptions may sub-divide a category such as 'Sand Fynbos' into specific xeric, mesic and wet types. Also at a floristic level of recognition our mapped categories may consist of a number of types.

1. CAPE FLORAL KINGDOM

All the fynbos communities (sensu heathlands, concept Specht 1979, and Specht & Moll 1983) of the fynbos biome are placed in the "Cape Floral Kingdom".

1.1 CAPE FYNBOS SHRUBLANDS

The term "Cape" is used to differentiate this fynbos type from the fynbos which occurs in the Afromontane and Afro-alpine regions (eg Killick 1979, and White 1978). This non-Cape fynbos we term Afromontane Fynbos following the proposals of Campbell (1984a) and Cowling (1983a). The term fynbos has been previously used in two very different ways. Bews (1925), who probably coined the term in the botanical literature, applied it to the fine-leaved shrublands of the Cape and non-Cape regions. On the other hand Kruger (1979b) and Taylor (1978) use fynbos to denote only those shrublands of the Cape. We follow the former tradition.

Cape Fynbos shrublands are identified by Cowling (1983a) as having:

(i) Sample floras with a phytochorological spectrum in which more than 50% of the species are restricted to the Cape phytochorion as delimited by Werger (1978) and Goldblatt (1978). The majority of the remaining species are largely Cape linking taxa.

(ii) A high incidence of regional endemism (cf Weimarck 1941). Regional endemics are mostly of Cape affinity.

(iii) Communities ecologically restricted to areas receiving a substantial proportion of winter rainfall on infertile soils derived from quartzite, sandstones, laterites and limestones.

Campbell (1984a) provides an operational structural definition for the fynbos of the mountains, which from personal observation is also applicable to the lowland areas (see Table 3).

MOUNTAIN FYNBOS

Mountain Fynbos is the general term used by Taylor (1978) and Kruger (1979b) to replace Acocks' (1953) Macchia (69) and False Macchia (70). Campbell and Cowling exclude Grassy Fynbos (occurring in Acocks' False Macchia Veld Type) from their concept of Mountain Fynbos, and we have adopted this distinction in the present scheme. We recognize and map as Mountain Fynbos those communities occurring on sandstones and quartzites of the Cape Folded Belt; from the Cedarberg in the north west to the Groot Winterhoek mountains in the south east. Communities of limited extent, too small to map at this scale on Cape granites in the foothills of the Hottentots Holland and Bainskloof Mountains (Bossi in prep).

In our scheme we recognize three sub-divisions of Mountain Fynbos based on a moisture gradient from wet to dry sites, which is physiognomically expressed by the vegetation, and thus has been recognized on satellite imagery*. These three sub-divisions are the units that can satisfactorily be mapped from the Landsat images. However, we do recognise that they can be structurally heterogeneous e.g. Wet Mountain Fynbos varies from tall proteoid shrublands (almost low forest in some cases) to low ericaceous shrublands. These sub-divisions are perhaps best described as landscape units which have a certain specified set of communities. In Campbell's (1984a) recent classification of the mountain vegetation he recognises six major series of fynbos (Table 3) and these six structural units do largely not correspond with our mapped sub-divisions. His communities are not mapable at 1:1 000 000. For this very reason he also provides a map of community complexes (see Figure 1).

FOOTNOTE: *All structural terminology and definitions used in the report are from here on based on those of Campbell et al (1981).

1.1.1 Wet Mountain Fynbos

This comprises closed (75% canopy cover) Mountain Fynbos on annually, and even perennially water-logged sites, usually on southern slopes of the Langeberg, Outeniqua and Tsitsikamma mountains. These communities which are sometimes seral to forest, or either almost entirely mid-high to tall restioid communities, or mid-high to tall ericoid or proteoid shrublands (examples from Campbell (1984a) are: Mesic Proteoid Fynbos, Wet Proteoid Fynbos and Ericaceous Fynbos).

1.1.2 Mesic Mountain Fynbos

This comprises open to closed (±40 - 90% canopy cover) Mountain Fynbos on seasonally water-logged, mesic sites. The plant communities are mixtures of the three primary elements; namely restioid, ericoid and

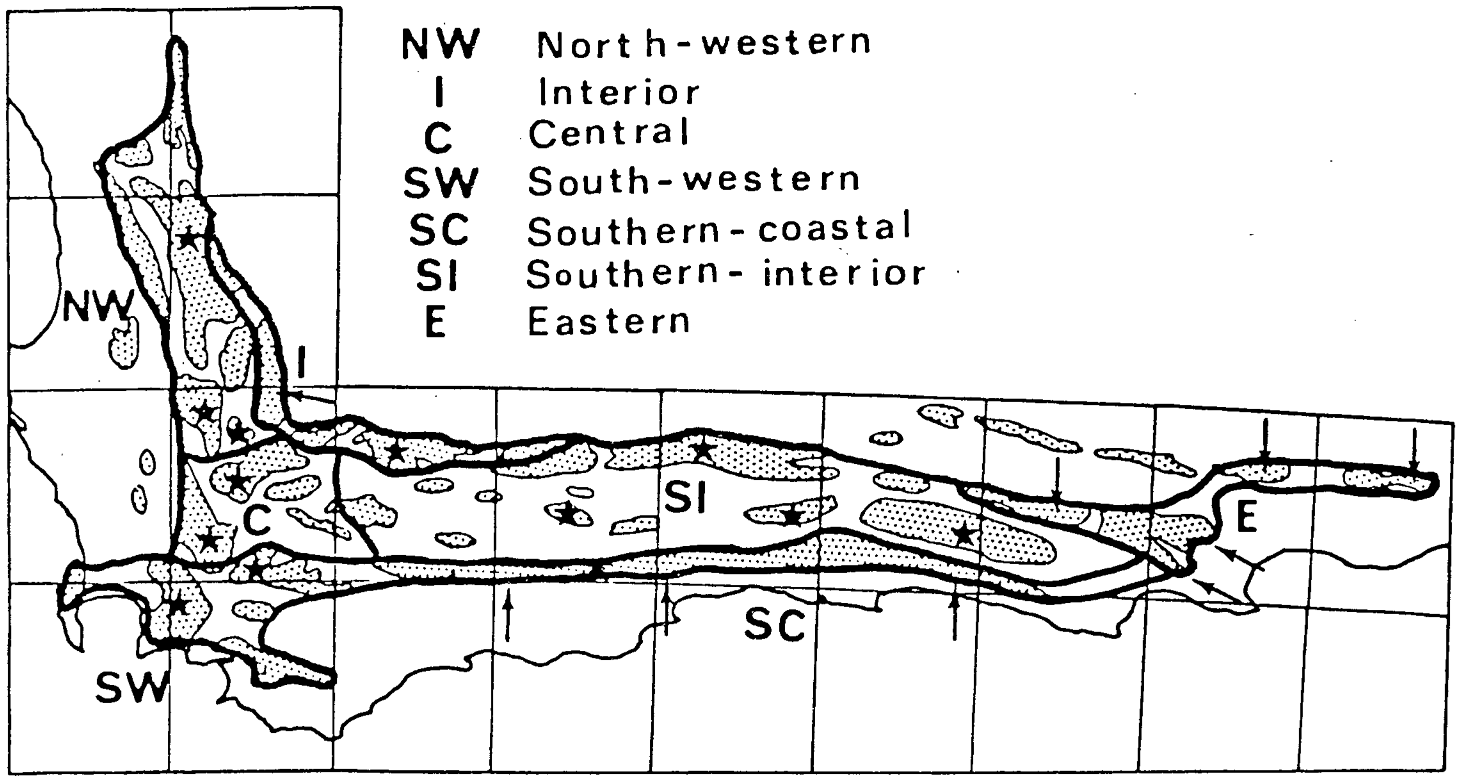

FIGURE 1 The seven mountain regions of the Fynbos Biome. The regions recognized only apply to the mountains within the designated area, and the boundaries are somewhat arbitrary as detailed field checking has not been possible. The distribution of the transects used to derive the regions is shown by stars and arrows, and the method of derivation is discussed in Campbell (1984a).

TABLE 3: The major fynbos communities of the mountains of the Fynbos Biome (Campbell 1984a) These major communities are further subdivided into 63 types (see Campbell 1984a for further details).

GROUP			FYNBOS			
SERIES	GRASSY FYNBOS	ASTERACEOUS FYNBOS	RESTIOID FYNBOS (RESTIOVELD)	ERICACEOUS FYNBOS (HEATH)	PROTEOID FYNBOS (PROTEAVELD)	CLOSED-SCRUB FYNBOS
Differentiating characteristics	Grasses; nanophylls; forbs; rosette forbs; rosulate succulents	Low total cover; succulents non-ericaceous evicoids; fleshy leaves; intermediate cover; grass and/or elytropappoid cover; high shrub cover relative to restioids and sedges	High restioid and sedge cover relative to shrubs	Ericaceae; Penaeaceae; Bruniaceae; Grubbiaceae; sedges	>10% cover Proteoids	Microphylls; tall shrubs; orthophylls; plumose restioids
Environmental characterization	Eastern mountains; finer-textured soils; mostly 600 mm rainfall	Most xeric community of fynbos; low altitudes; interior mountains	Shallow, rocky soils, more mesic than Asteraceous fynbos, more xeric than Ericaceous fynbos; often high altitude, north aspects	Deeper, often organic soils; mesic situations often high-altitude, south aspects of coastal mountains	Deeper, finer-textured soils, low altitudes; often mesic, coastal situations	Rivers; streams
SUB-SERIES AND TYPES	DRY GRASSY FYNBOS MESIC GRASSY FYNBOS MESOTROPHIC GRASSY FYNBOS	DRY ASTERACEOUS FYNBOS MESOTROPHIC ASTERACEOUS FYNBOS OLIGOTROPHIC ASTERACEOUS FYNBOS TALUS ASTERACEOUS FYNBOS	DRY RESTIOID FYNBOS MESIC RESTIOID FYNBOS AZONAL RESTIOID FYNBOS	MESIC ERICACEOUS WET ERICACEOUS fynbos	MESOTROPHIC PROTEOID DRY PROTEOID FYNBOS (Pd) MESIC PROTEOID FYNBOS WET PROTEOID FYNBOS	

proteoid, falling in the tall to low height categories. This type probably includes Campbell's (1984a) Mesic Ericaceous Fynbos, Dry Proteoid Fynbos, Mesic Proteoid Fynbos, Mesic and Dry Restioid Fynbos, and Oligotrophic Asteraceous Fynbos.

1.1.3 Dry Mountain Fynbos

These open to sparse (often less than 50% canopy cover) Mountain Fynbos communities are on xeric sites, usually on northern slopes in the south of the fynbos biome, on inland mountains, or located in the northern Cedarberg range. They generally have tall restioids and a predominance of low shrubs; equivalent to Campbell's (1984a) Dry Asteraceous Fynbos, Mesotrophic Asteraceous Fynbos and Dry Restioid Fynbos. There are occasionally non-proteoid mid-high shrubs present, such as Rhus sp., Heeria argentea, Phylica buxifolia and Dodonaea viscosa.

GRASSY FYNBOS

Much of what Acocks (1953) called False Macchia (70), and some of the Mountain Fynbos referred to by Taylor (1978) and Kruger (1979b), we refer to as Grassy Fynbos. Recent workers (Campbell 1984b, Cowling 1983a & Bond 1981) have drawn attention to the increased grassy nature of fynbos at the eastern limits of the biome occuring on sandstones, quartzites and Enon conglomerates.

Biogeographically Grassy Fynbos is characterized by a high proportion of Cape-Afromontane linking species and widely distributed tropical C4 grasses (Themeda, Trachypogon, Heteropogon, Brachiaria, Eragrostis). Cowling (1983a) records good diagnostic species including a number of regional and local character taxa. Structurally, grassy fynbos is similar to the mountain fynbos types described above, except for the prominence of grasses in the understorey at the expense of restioids. Soils are marginally more fertile than those of Mountain Fynbos (Campbell 1984b, Cowling 1983a).

Features that are more characteristic of Grassy Fynbos include non-proteoid nanophylls and forbs (especially rosette forbs and pubescent forbs).

1.1.4 Mesic Grassy Fynbos

These are open to dense (50-90% canopy cover), tall to low grassy communities on seasonally water-logged mesic sites. Mesic Grassy Fynbos includes much of Campbell's (1984a) Mesotrophic Grassy Fynbos and Mesic Grassy Fynbos. However, it also includes what Campbell places in his non-fynbos Grassland and Grassy Shrubland Group (i.e. Suurberg Grassland, Hankey Grassland and Elandsberg Grassy Shrubland).

1.1.5 Dry Grassy Fynbos

These are sparse to open (often 50% canopy cover), low to mid-high communities on xeric sites usually on the northern slopes, or on arid mountain tops. Much of this category would fall into Campbell's (1984a) Dry Grassy Fynbos, but a considerable portion would be regarded as non-fynbos by Campbell and would be placed in Bosrug Grassy Shrubland and Baviaanskloof Grassy Shrubland.

LOWLAND FYNBOS

Previous workers have grouped all Lowland Fynbos types into a heterogeneous entity called Coastal Macchia, Veld Type 47 (Acocks 1953) or Coastal Fynbos (Taylor 1978, Kruger 1979b). Acocks subdivided Coastal Macchia into west and south coast blocks, but acknowledged that further sub-division was necessary. Taylor and Kruger largely adopted Acocks' scheme in their treatment of Coastal Fynbos. However, we recognize four lowland types, distinguished largely on substrate differences.

1.1.6 Sand Fynbos

These are open to closed (25-90% canopy cover), low to mid-high graminoid shrublands. We define Sand Fynbos as vegetation confined to the deep acid sands of the west coast lowlands (cf Milewski & Esterhuizen 1977; Boucher 1982) and also occurring locally on the south coast (eg sandy flats fynbos on reddish sands in the Riversdale district, Muir (1929)). Boucher's (in prep) study of the west coast lowlands should provide a floristic characterization of Sand Fynbos in that region. It should be possible to distinguish between western and southern blocks of Sand Fynbos, but the fragments which occur on the south coast were too small to be mapped from satellite imagery.

1.1.7 Elim Fynbos

These communities are open to closed (35-90%) low shrublands, with very occasional tall shrubs. Acocks (1953) recognized that the dwarf to low fynbos of the Elim flats should be considered a distinct veld type. On the Augulhas Plain there are extremely species-rich fynbos communities on a variety of depositional landscapes with gravelly, lateritic and often seasonally waterlogged soils. This fynbos has numerous local endemics (Cowling unpublished records).

1.1.8 Limestone Fynbos

These communities are open to closed (40-90% mid-high shrublands). The south coast Limestone Fynbos centred between Walker Bay and Vlees Bay is another well circumscribed type (Acocks 1953, Taylor 1978). These communities are restricted to calcareous, neutral to alkaline, shallow sands overlying limestone of the Bredasdorp Formation, and are characterized by a number of endemics (see Taylor (1978) for a list). Van der Merwe (1977) has described communities for the De Hoop Nature Reserve and Muir (1929) gives a general account of limestone fynbos in the Riversdale district. We term this type Limestone Fynbos, which also occurs on scattered small patches of calcrete from Saldanha Bay to the Gouritz River.

2. ELEMENTS OF CAPE AND PALAEOTROPIC FLORAL KINGDOMS

Within the geographic region of the Cape Floral Kingdom are a number of communities that consist of an admixture of Cape and non-Cape elements, and/or non-heathland communities. Two major categories have been recognised and are discussed below.

2.1 Mosaic of Cape Fynbos Shrublands and Subtropical Elements

Only Dune fynbos is recognised, being an admixture of Cape fynbos shrubland and sub-tropical elements.

2.1.1 Dune Fynbos

These are generally mid-dense to closed (50-100%) mid-high shrublands. Communities belonging to this category occur on recent, deepish, calcareous or acid sands from the Cape Flats to Cape Recife, near Port Elizabeth. They are characterized by good diagnostic species (see Cowling 1983a).

2.2 Cape Transitional Shrublands

These consist of a variety of non-succulent, small-leafed and broad-leafed shrublands which, according to the concepts developed above, are distinctly non-fynbos. Although some of these shrublands have been the subject of a recent review (Boucher and Moll 1981) there are few published phytosociological surveys and the formation of syntaxonomic concepts is therefore severely limited.

RENOSTERVELD

Cowling (1983a) characterizes Renosterveld as follows:

(i) Phytochorological spectra are dominated by ecological and chorological transgressor species linking the Cape communities with adjacent phytochoria, particularly the Karoo-Namib Region with some Afromontane elements, and at the eastern limits of the biome, with the Sudano-Zambezian Region. Cape endemics comprise about one third of a given sample flora.

(ii) Regional endemism is lower than for Cape Fynbos Shrublands and not all endemics are species of Cape affinity.

(iii) Structurally the communities are small-leafed shrublands dominated by Asteraceae but lacking most of the "heathland" (sensu Specht 1979) features typical of the Cape Fynbos Shrublands. Restioid and proteoid growth forms may be present but today are not consistently dominant and can be entirely lacking. Deciduous geophytes are prominent, if not in cover, then in richness. A considerable proportion of the small-leafed woody shrubs having fleshy to semi-succulent leaves (Cowling & Campbell 1983), and showing some seasonal leaf dimorphism, may be prominent, particularly in the east. Shrubs with large dorsiventral leaves do occur.

(iv) Ecologically they are restricted to fine grained soils derived from Cretaceous mudstones and conglomerates, Malmesbury and Cango phyllites, Bokkeveld shales, Cape granites, and the tillites and shales of the Karoo Supergroup. The soils are generally more fertile than Cape Fynbos soils, and the communities are found in areas receiving at least thirty percent winter rain where the annual precipitation is from 300 - 600 mm yr^{-1}.

Dominant genera in these small-leaved shrublands are Elytropappus, Eriocephalus, Anthospermum, Passerina, Relhania, Aspalathus, Helichrysum, Pteronia, Selago, Felicia, and Hermannia.

We include the following Acocks' (1953) Veld Types: Coastal Renosterveld (46), Mountain Renosterveld (43) and parts of the Karroid Merxmuellera Mountain Veld (60). The last mentioned has strong links with Afromontane grasslands of the north eastern Cape (Acocks 1953). In general these shrublands have mostly karroid, subtropical or temperate grassland affinities (Cowling 1983a).

Acocks (1953) recognized two coastal renosterveld types: a west coast form and a south coast form. This distinction was also upheld by Taylor (1978) and Boucher and Moll (1981).

We differentiate four Renosterveld types in our scheme. They are all small-leafed shrublands with a prominent cupressoid-leafed element and are: West Coast Renosterveld, found mainly on Malmesbury shales and Cape granite; South Coast Renosterveld, found mainly on Bokkeveld shales; Central Mountain Renosterveld, encountered on Bokkeveld and Witteberg shales; and Eastern Renosterveld, found mainly on Bokkeveld and Cango shales, and Cretaceous conglomerates. Of the four forms of these cummunities distinguished three have essentially Cape/Karoo-Namib/Afromontane affinities, and the other (Eastern Renosterveld) has essentially Cape/Karoo-Namib/Sudano-Zambizian affinities. The major distinction between these two forms is the higher proportion of grasses in the latter.

West Coast Renosterveld differs from South Coast Renosterveld in having a sparser grass cover composed largely of C_3 genera (Ehrharta, Pentaschistis, Merxmuellera, Lasiochloa, Plagiochloa, Cymbopogon, and Eragrostis while today the Mediterranean grasses Avena, Briza and Lolium are wide-spread and common), a higher diversity of deciduous geophytes and annuals, and the presence of Relhania ericoides and Leyserra gnaphaloides as characteristic subdominants with Elytropappus rhinocerotis. Species used to characterize small-leafed shrublands of the west are: E. rhinocerotis, Restio cuspidatus, Mohria caffrorum, Olea europaea, Felicia filifolia and Euclea tomentosa (Boucher in prep).

West Coast communities have a stronger fynbos influence, especially on granitic soils (Cowling 1983a). Boucher (1983) has suggested that West Coast Renosterveld is derived from mountain fynbos and strandveld elements (sensu Acocks 1953).

South Coast Renosterveld ranges from Bot River to Riviersonderend. Typical subdominants and diagnostic shrub species are Relhania genistaefolia, R. cuneata, Helichrysum anomalum, Indigofera denudata and Hermannia flammea.

Our concept of Central Mountain Renosterveld does not correspond exactly to Acocks' Mountain Renosterveld (43), but is similar to it. Central Mountain Renosterveld has a greater proportion of succulents and sometimes dominance by Pteronia incana. Much of Mountain Renosterveld (sensu Acocks 1953) is very similar to our West Coast and South Coast Renosterveld (eg mixtures of Relhania and Elytropappus).

2.2.1 West Coast Renosterveld

This type is comprised of mid-dense to closed (50-90 % canopy cover) cupressoid and small-leafed, mid-high evergreen shrubs, with regular broad-leafed tall shrubs as emergents. The understorey is essentially annual and herbaceous with occasional perennial graminoids.

2.2.2 South Coast Renosterveld

These communities are essentially mid-dense (50 - 75% canopy cover) cupressoid and small-leafed, mid-high evergreen shrubs, with rare broad-leafed tall shrubs as emergents. The understorey is also essentially herbaceous with occasional perennial graminoids.

2.2.3 Central Mountain Renosterveld

This is comprised of open to mid-dense (25-60% canopy cover) cupressoid and small-leafed, low to mid-high shrubs, with Rhus, Acacia karroo, Euclea undulata and Aloe ferox as scattered emergents. The understorey consists of discontinuous herbaceous elements which usually lack the perennial graminoid component through veld deterioration.

2.2.4 Eastern Renosterveld

This is comprised of open to mid-dense (25-60% canopy cover) cupressoid and small-leafed, low to mid-high shrubs with no emergents. The understorey consists of scattered herbaceous elements, and on well-managed sites of perennial grasses.

STRANDVELD

Strandveld communities are mid-dense to closed, broad-leafed shrublands of essentially tropical and sub-tropical affinity which penetrate into the fynbos biome from the east; roughly from the Gouritz River and extending along the west coast into Namaqualand. Physiognomically these shrublands may consist of an impenetrable tangle of shrubs sometimes interwoven by woody climbers, with occasional clumps of low trees. Communities of similar structure and generic composition are found throughout tropical and subtropical Africa (Okali et al 1973; Tinley 1975; White 1982) and are termed thicket. Tinley (in: Heydorn & Tinley 1980) extended the thicket concept to the fynbos biome, but the floristic affinity of some of the shrub species in particular are strongly tropical with few species endemic to the Cape mediterranean-climate region. Cowling (1983a) distinguishes these strandveld communities as sub-tropical transitional thicket. He characterizes the type as follows:

(i) Phytochorological spectra are dominated by ecological and chorological transgressor species essentially of Tongaland-Pondoland origin, with Cape and some Karoo-Namib elements being present.

(ii) Regional endemics are few relative to Cape Fynbos Shrublands, and usually of non-tropical affinity: karroid shrubs, particularly succulents (Euphorbia, Crassula, Delosperma, Aloe) comprise most of the endemics, especially on the west coast.

(iii) Structurally the communities are dominated by broad-leafed evergreen shrubs many of which are semi-spinescent. Succulents are conspicuous in dry areas and vines as scattered throughout.

(iv) Ecologically the communities are restricted to deepish, well-drained soils of moderate fertility status, in areas which receive at least thirty per cent of the rainfall in winter.

These broad-leafed shrublands are more or less equivalent to Acocks' (1953) West Coast Strandveld (34).

The drier form of the broad-leafed shrublands has a number of endemic succulent shrubs of karroid affinity, belonging to the genera Delosperma, Senecio, Euphorbia, Crassula, Zygophyllum and Lampranthus (Cowling 1983a).

Despite Cowling's treatment we have chosen to place the Strandveld Communities in the Mosaic of Cape and Palaeotropic Floral Kingdoms, mainly because Restionaceae are widespread and may be locally dominant. Also some of the genera with sub-tropical affinities are Cape species, thus strengthening ties with the Cape Floral Kingdom.

Patches of emergent tall restioids such as Thamnochortus erectus, T. insignus and T. spicigerus occur scattered through and are often associated with species depauperate strandveld vegetation. These clumps usually have an open canopy. Towards the inner margins of this vegetation type, Willdenowia riata and W. teres (1,00-1,5 m tall) become increasingly prominent to extensively dominant with a closed canopy, particularly in the west. The short restioid, Restio eleocharis becomes increasingly common as an understorey element, from Langebaan southwards and eastwards, particularly in the early successional stages of Strandveld (Boucher in prep).

We recognize two forms of these broad-leafed shrublands: that located on the west coast which tends to have a greater proportion of semi-deciduous to deciduous shrubs, and succulents of Karoo-Namib affinity; and the south coast form which tends to have more evergreen shrubs and generally a higher percentage cover.

2.2.5 West Coast Strandveld

This is comprised of open to closed (40-90% canopy cover), usually high and rarely tall communities, with a mixture of broad-leafed, evergreen, deciduous and succulent elements. The understorey has a perennial graminoid component, as well as a large annual component, consisting of annual herbs, including succulents and geophytes.

2.2.6 South Coast Strandveld

These communities tend to be open to closed (40- 80% canopy cover) mid-high, with a mixture of evergreen and deciduous broad-leafed elements and a less conspicuous succulent element. An understorey of annual herbaceous species is present.

3. PALAEOTROPIC FLORAL KINGDOM

Within the geographic region of the fynbos biome, outliers of the Palaeotropic Floral Kingdom communities occur. We do not differentiate these communities to any extent.

3.1 SUBTROPICAL TRANSITIONAL THICKET AND FOREST

3.1.1 Kaffrarian Thicket

This is equivalent to Cowling's (1983a) Kaffrarian Thicket, and consists of the non-succulent, subtropical transitional thicket communities, with depauperate outliers extending to the south western Cape. These Thicket communities have strong affinities with the Afromontane forest flora although Tongaland-Pondoland endemics and linking species dominate the phytochorological spectrum. Endemism is low. Structurally the thicket is a closed shrubland to low forest dominated by evergreen, sclerophyllous trees and shrubs with a high cover of stem spines and vines (Cowling 1983a). Included in this type are parts of the thickets in Acocks' (1953) Eastern Province Thornveld (7b), Alexandria Forest (2), False Thornveld of Eastern Cape (21), Coastal Renosterveld (46) and Coastal Macchia (47).

Without additional data, particularly on the floristic relationships of the southern and south western Cape thicket, further sub-division of this type is difficult. Kaffrarian Thicket ranges from Algoa Bay to the Cape Peninsula with possible outliers along the west coast south of Lambert's Bay (Boucher and Jarman 1977). It is characterized by a number of species restricted mainly to deep, calcareous, coastal dune sands but found also in non-dune environments (eg Cassine maritima, Olea exasperata, Euclea racemosa ssp. racemosa, Tarconanthus camphoratus, Rhus crenata, R. schlechteri, Maytenus procumbens, M. lucida). It must be distinguished from the more tropical Mimusops caffra - Brachylaena discolor Dune Thicket of the subtropical east coast (Moll and White 1978).

3.1.2 Valley Bushveld (undifferentiated)

We do not attempt to sub-divide this category. Acocks' (1953) subdivisions suffice for our present purposes.

3.2 AFROMONTANE FOREST

3.2.1 Afromontane forest communities (undifferentiated).

There is little problem with this category and readers are referred to Cowling's (1983a) review and to McKenzie (1978) and White (1978) for a regional perspective.

3.3 KARROID SHRUBLANDS

3.3.1 Karroid shrublands (undifferentiated)

Again, we do not attempt to subdivide this category, and Acocks' (1953) sub-divisions suffice for our present purposes.

4. ECOTONES AND AREAS PARTLY CLEARED OF NATURAL VEGETATION

At the scale at which the map of the fynbos biome was produced, it was impossible to distinguish fairly extensive mixed vegetation types in certain areas. These were mapped as mosaics, and the following were recognized:

4.1 Mosaic of Dry Mountain Fynbos and Karroid Shrublands occurring north of Clanwilliam on the Cedarberg Mountains and in the Vanrhynsdorp area;

4.2 Mosaic of Sand Fynbos and West Coast Strandveld occurring on the west coast lowlands, particularly north of Saldanha Bay to Olifants River;

4.3 Mosaic of Dune Fynbos and Kaffrarian Thicket occurring in the south coast region; and

4.4 Mosaic of Eastern Renosterveld and agriculture inland of Port Elizabeth.

PROBLEMS AND LIMITATIONS OF THE SCHEME

The production of a broad synthesis such as has been attempted here, particularly by a number of individuals, is fraught with difficulties. All the authors have had to make concessions and at times one of us (EJM) has made final decisions when concensus could not be reached. Three major problem areas have imposed limitations to the scheme. These are considered separately.

(i) Method of mapping

It could be questioned whether the best products available for visual interpretation were used in this study. There are systematically enhanced and geometrically corrected photographic images available, but these were not utilized. Budget constraints determined the choice of products (14 Landsat scenes involved), as the emphasis in the study originally was placed on computer digital processing of Landsat CCTS.

The computer generated maps were not as useful as it was originally hoped. This was because the computer generated categories did not always agree with vegetation classes as defined by botanists. The computer produces categories by classifying only the spectral reflectance of the earth's surface, whereas the vegetation categories obtained through manual interpretation are derived from information such as geology, topography and field experience, in addition to the spectral reflectance. Thus the computer generated maps were not used as a replacement for manual interpretation but merely as an aid.

Using the combination of a standard 1:1 000 000 scale false colour transparency and a 1:250 000 black and white photographic print for visual interpretation purposes was successful. Field surveys that were undertaken during and after the photo-interpretation process, and comments from botanists, confirmed that the vegetation boundaries drawn from satellite images were good. However, there was controversy over the naming of these vegetation categories as the mapping project did not include comprehensive vegetation studies to substantiate a new nomenclature.

Difficulties that did arise in categorizing certain parts of the biome, either through lack of available vegetation descriptions or because of the occurrence of ecotones were:-

(a) Cape Fynbos Shrublands

Although Wet Mountain Fynbos was easily distinguished from Mesic Mountain Fynbos, some difficulties were experienced in isolating young plantations and small forest patches from Wet Mountain Fynbos areas.

Mesic Mountain Fynbos was a relatively easy category to map, having distinct boundaries. A note of interest was that Mesic Mountain Fynbos on granite in the south western Cape, for example Paarl, Helderberg and Klein Drakenstein Mountains, was distinguished as a different category in the computer classification (Bossi in prep). However, in the final map this category was mapped as Mesic Mountain Fynbos as the areas involved were too small to be mapped separately.

The Dry Mountain Fynbos occuring in the Clanwilliam and Calvinia areas could not easily be separated from the Karroid Shrublands even at 1:250 000 scale. These areas were therefore, mapped as a mosaic of the two types. One of the present authors (BMC) does not agree with the subdivision of fynbos mapped in the Cedarberg Mountains and in the region north of Clanwilliam to Calvinia. His data suggests that the Mesic Mountain Fynbos of the northwestern region is much more xeric than the Dry Mountain Fynbos of the Southern Mountain region. Taking his point we must state that we could only successfully map Mountain Fynbos into a dry type in the southern region, as the landsat images did not provide good discrimination in the northwest. Extensive field checking may well prove that what we have mapped as Dry Mountain Fynbos - in the north west is in fact more arid (see Taylor 1978 Arid Fynbos discussion), and our Mesic Mountain Fynbos in the Cedarberg is in fact more xeric and thus more similar to our Dry Mountain Fynbos of the southern region.

In the Swartruggens Mountains (area I on Figure 1), Dry Mountain Fynbos and Central Mountain Renosterveld could not be easily distinguished, partly because of the small size of the former and the encroachment into it of the latter. In this area the mixture was mapped as Central Mountain Renosterveld.

Because of the increased grassy nature of Grassy Fynbos in the south eastern Cape some of the land is used for grazing. Thus extensive and heavily grazed areas were indistinguishable from adjacent agricultural areas and were mapped as such, while mosaics of lightly grazed and good condition natural veld was mapped as Mesic Grassy Fynbos or as Dry Grassy Fynbos.

The vegetation on the west coast, north of Saldanha Bay, was mapped as a mosaic of Sand Fynbos and West Coast Strandveld as these two could not be interpreted separately. The vegetation is more sparse because conditions are drier and the area has many old lands, which makes interpretation even more difficult. In addition local edaphic factors are more complex, leading to a greater admix of these types (Boucher in prep).

Along the south coast moving eastwards, Dune Fynbos becomes increasingly interspersed with Kaffrarian Thicket. This was mapped as a mosaic of two types.

The vegetation occuring along the whole coastline, namely Dune Fynbos Lowland Fynbos, West Coast Strandveld and South Coast Strandveld is partially or densely infested by alien vegetation in certain areas. Only the most densely infested areas covering at least 2 km^2 could be seen on the satellite images and these areas were excluded from the natural vegetation categories. Any smaller areas , or areas moderately or lightly infested with aliens, have been included as natural vegetation.

(b) Cape Transitional Shrublands

Eastern Renosterveld, occurring along the south coast, has a large number of Valley Bushveld elements present, especially in the steep valleys, but these were too small to map at 1:250 000 scale and were, therefore considered characteristic of Eastern Renosterveld.

In the southeastern Cape the area mapped as Eastern Renosterveld includes scattered fields; only the larger agricultural areas were excluded from this type in this region.

(c) Subtropical Transitional Thicket and Forest

These pure non-fynbos communities occurring adjacent to the fynbos biome have been identified only as broad categories on the final map, although differentiation of these categories was evident on the satellite images. These types include Kaffrarian Thicket, Valley Bushveld, Afromontane Forest and Karroid Shrublands.

(ii) Hierarchical inconsistencies

Bearing in mind the procedure whereby the major vegetation categories were mapped we acknowledge that there are limitations with respect to more detailed floristic information in the scheme proposed here. It is acknowledged that with more phytosociological data different vegetation types may be placed in hierarchical categories other than those in this scheme. For example Boucher (in prep) recognises at least three different types of West Coast Renosterveld. Also we realize that all the mapped types are not necessarily at the same hierarchical level. For example, Campbell (1984a) has recognised seven regions of Cape mountain vegetation all of which contain our Mesic Mountain Fynbos type. It is clear that on floristic criteria we should have divided this category into at least seven sub-types, however, these were not readily recognisable on the satellite images.

(iii) Divergent interpretations

One of the most contentious concepts where unanimous concensus could not be obtained concerned the interpretation of the term heathland, used in the structural/environmental description to describe the communities of the Cape Floral Kingdom. In the present scheme the term heathland was used to indicate that fynbos is not simply a mediterranean-type shrubland but rather that it's structural and functional characteristics are strongly determined by edaphic conditions (Specht 1979, Specht and Moll 1983). However, Campbell and Cowling (also Bond 1981) do not entirely agree with this usage. They have argued that fynbos is not a heathland and that only limited fynbos types (where Ericaceae are dominant) are true heathlands (see Campbell et al 1981, 1984b and Cowling 1983a for further discussion). The divergence in opinion has provoked Moll and Jarman (1983a) and Campbell & Werger (1984) to attempt a re-evaluation of the term heathland in world context, in which the southern African forms have been specifically highlighted.

Another area of some disagreement concerns the exclusion by Cowling (1983a) of Acocks' Strandveld from the vegetation of the Cape Floristic Kingdom as he (Cowling) considers it to be part of the Tongaland-Pondoland Regional Mosaic, and placed it in the category Kaffrarian Thicket as a component of the Palaeotropic Floral Kingdom. In this scheme we have decided to adopt a more conservative approach and include Strandveld as a component of the Mosaic of Cape and Palaeotropic Floral Kingdoms. This is a compromise between Kruger's (1979b) treatment where Strandveld is considered part of the fynbos biome and by implication part of the Cape Floral Kingdom, and the approach of Cowling (1983a).

RECOMMENDATIONS

This exercise has been limited by the lack of information from certain areas or vegetation types. We suggest the following priorities for phytosociological surveys, in order of importance:

(a) Elim Lowland Fynbos (communities on depositional landscapes) and Limestone Lowland Fynbos on the Agulhas Plain.

(b) Central Mountain Renosterveld

(c) Lowland vegetation formations generally (but especially Eastern Renosterveld and all dune communities between the Gouritz and Groot Brak rivers).

(d) The Dry Mountain Fynbos and Karroid Shrubland mosaic of the north western part of the fynbos biome.

(e) All categories of Mountain Fynbos and Grassy Fynbos throughout the biome. This is a long term project which will ultimately result in the emergence of well-defined syntaxonomic concepts. To date there are published accounts of the vegetation in very few areas (eg Jonkershoek, Cape Peninsula, Jakkalsrivier, Cape Hangklip Outeniqua, Rooiberg, Swartberg, Elandsberg, Suurberg).

It is not necessary for the survey work to be detailed formal phytosociological studies. Workers could use 0,1 ha plots or compile species lists from small areas so as to sample at least once the major community types in a large region. This type of sampling intensity should be sufficient to define concepts at the veld type level of a syntaxonomic hierarchy.

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PART IV. THIRD PAPER. COMPUTER CLASSIFICATION OF LANDSAT II MULTISPECTRAL SCANNER DATA FOR MAPPING FYNBOS BIOME VEGETATION

L. Bossi

ABSTRACT

Landsat II satellite data was used to map the vegetation of the fynbos biome at 1 : 250 000 scale by employing computer-aided analysis of the multispectral scanner (MSS) data. This paper describes the computer processing of each of the fourteen images covering the biome. Supervised training area selection, in combination with unsupervised classification techniques were used to produce computer classified maps. Broad fynbos classes were distinguished and were well delineated where it occurred adjacent to land cleared of natural vegetation, but the boundaries between fynbos and non-fynbos shrublands were not well defined. The distinction between classes appeared to be mainly due to vegetation canopy cover and density. A qualitative assessment of the computer-generated classes is provided.

INTRODUCTION

Landsat II satellite imagery was used to map the vegetation of the fynbos biome. This paper describes the computer-aided analysis of the digital images used in identifying and classifying the major vegetation cover types.

The fynbos biome encompasses a large geographic area (74 500 km^2) with the approximate limits being 31° to 35°S and 18° to 27°E (Day et al 1979). Fynbos is a broad category of heathland vegetation whose communities characteristically include growth forms of restioid, ericoid and proteoid types (Taylor 1978). However the Fynbos Biome Programme includes additional vegetation types in the description of the region (Day et al 1979), namely Acocks' (1953) Strandveld, Coastal Renosterveld and Mountain Renosterveld. Since a Phase I objective of the Fynbos Biome Project is the definition of the geographic distribution and extent of the major vegetation types of the biome (Kruger 1978), an investigation into the usefulness of various remote sensing products for studying and mapping the biome was initiated (Jarman, Bossie and Moll 1981). Analysis of Landsat I and II data at a "reconnaissance" level of operation (1 : 250 000 mapping scale) was selected as being the method best suited to meet the overall mapping objective of the Fynbos Biome Project.

DATA CAPTURE AND ANALYSIS

The multispectral scanner (MSS) located on the Landsat - II satellite records reflectance values in four bands of the electromagnetic spectrum, namely band 4 : 0,5 - 0,6 µm (green); band 5 : 0,6 - 0,7 µm (red); band 6 : 0,7 - 0,8 µm (near IR); band 7 : 0,8 - 1,1 µm (near IR). The effective ground resolution (pixel size) is 79 m x 56 m (0,44 hectare). The reflectance values are stored on computer compatible tapes (CCT's) in digital form allowing flexible manipulation of the data with the aid of computer processing techniques. The principal advantages of these methods are their versatility and repeatability.

Digital image processing is divided into three broad categories: Image restoration, image enhancement and information extraction (Sabins 1978). In this project, processing of the images involved correcting the geometric distortion and the application of multispectral classification techniques to extract information. The classification procedures used compare the spectral values of the pixels to be classified to the spectral characteristics of known classes. The processing steps prior to the classification are directed toward locating and identifying known classes and assuring that these classes, called training classes, are representative and sufficiently different to prevent confusion among them. There are two techniques known for defining the training classes: the supervised approach and the non-supervised approach. In the supervised approach, the analyst selects pure areas of a known cover type and specifies these to the computer as training classes. Each training class contains statistical information for a specific cover type. In the non-supervised approach a clustering algorithm divides a representative sample chosen by the analyst from the image, into a number of spectrally different classes. Neither the location of the pixels relative to one another (spatial information), nor the ground cover type is considered in determining the classes. Rather, it groups those pixels with similar response values in the multiple bands. These natural groupings in the data are called spectral classes. The spectral classes have to be related to cover types (information classes) on the ground by the analyst, using reference data or cover type maps. A hybrid approach involves designating several small training areas to the clustering algorithm, then identifying each spectral class within the small training areas. The statistics for a single spectral class are combined, using data from several of the small training areas.

The hybrid approach was used in this project as this method is particularly useful in a heterogeneous area in which the likelihood of observing a sufficiently large area of the same cover type is low.

PIPS, the computer processing system used to analyse the CCT's, was developed by the University of Natal (Durban), Department of Survey. The version used in this project is the one available on the UNIVAC 1100/18 computer at the University of Cape Town. Details of the system are available in the user manual obtainable from the Institute of Remote Sensing and Photogrammetry, University of Cape Town.

METHODS

The fourteen images required for complete coverage of the fynbos biome are listed in Table 1. Summer images were chosen as these displayed the greatest contrast between fynbos and the surrounding vegetation. All images chosen were recorded during the same season (December 1980 - February 1981).

Table 1. Listing of the 14 Landsat images which cover the fynbos biome

WRS	SCENE - ID	DATE	AREA DESCRIPTION
188-082	22229-07533	81-02-28	Verlorenvlei
188-083	22211-07535	81-02-10	Langebaan
187-082	22228-07474	81-02-27	Calvinia
187-083	22228-07481	81-02-27	Ceres
187-084	22228-07483	81-02-27	Cape Town
186-083	22209-07422	81-02-08	Laingsburg
186-084	22209-07424	81-02-08	Bredasdorp
185-084	22208-07370	81-02-07	Mossel Bay
185-083	22208-07363	81-02-07	Oudtshoorn
184-083	22243-07305	81-03-14	Uniondale
184-084	22243-07312	81-03-14	Plettenberg Bay
183-083	22224-07251	81-02-23	Port Elizabeth
183-084	22224-07254	81-02-23	Humansdorp
182-082	22169-07195	80-12-30	Grahamstown

Before starting the computer processing of the CCT's, visual interpretation of all the photographic images was completed at 1 : 250 000 scale. A detailed account can be found in Moll et al (in prep.). After these visually interpreted vegetation maps had been field checked, they were used as reference data for the classification of the digital images. The computer analysis methods used are similar to the ones described by Fleming and Hoffer (1977), Nelson and Hoffer (1979) and Boyd and Lindenlaub (1979).

Each of the fourteen Landsat images were analysed independently. The sequence for the analysis appears in flowchart form in Figure 1 and is described as follows:

1) Identification and extraction of the study area from a CCT which covers 185 km^2. Although fourteen images were required, it was not necessary to analyse whole images due to side overlap with neighbouring images or areas lying outside the biome limits. All four MSS bands of each image were utilized in the processing procedures.

The MSS data was compressed from approximately 1 : 24 000 scale to 1 : 250 000 scale by using an averaging routine. A geometric correction routine was applied making it compatible with the visually interpreted maps.

2) Training areas were selected from the image by referring to the visually interpreted vegetation maps of the area being classified, histograms of the distribution of spectral reflectance values and the MSS band 6 computer grey-scale of the image being analysed. The MSS band 6 data was "stretched" over the full digital number range (0 to 255) to allow most of the sixteen line printer characters to be utilized, thereby providing a clearer grey scale. The reflectance characteristics of the fynbos vegetation produced distinctive grey levels on the image which made the manual selection of representative training areas easier. To ensure that the best classification accuracy was obtained, a sample of each cover type was included in one or more of the training areas. This provided a reasonably representative data set to the classification algorithm. The number of training areas per image varied according to the complexity of the area. Generally four to six training areas per image were used.

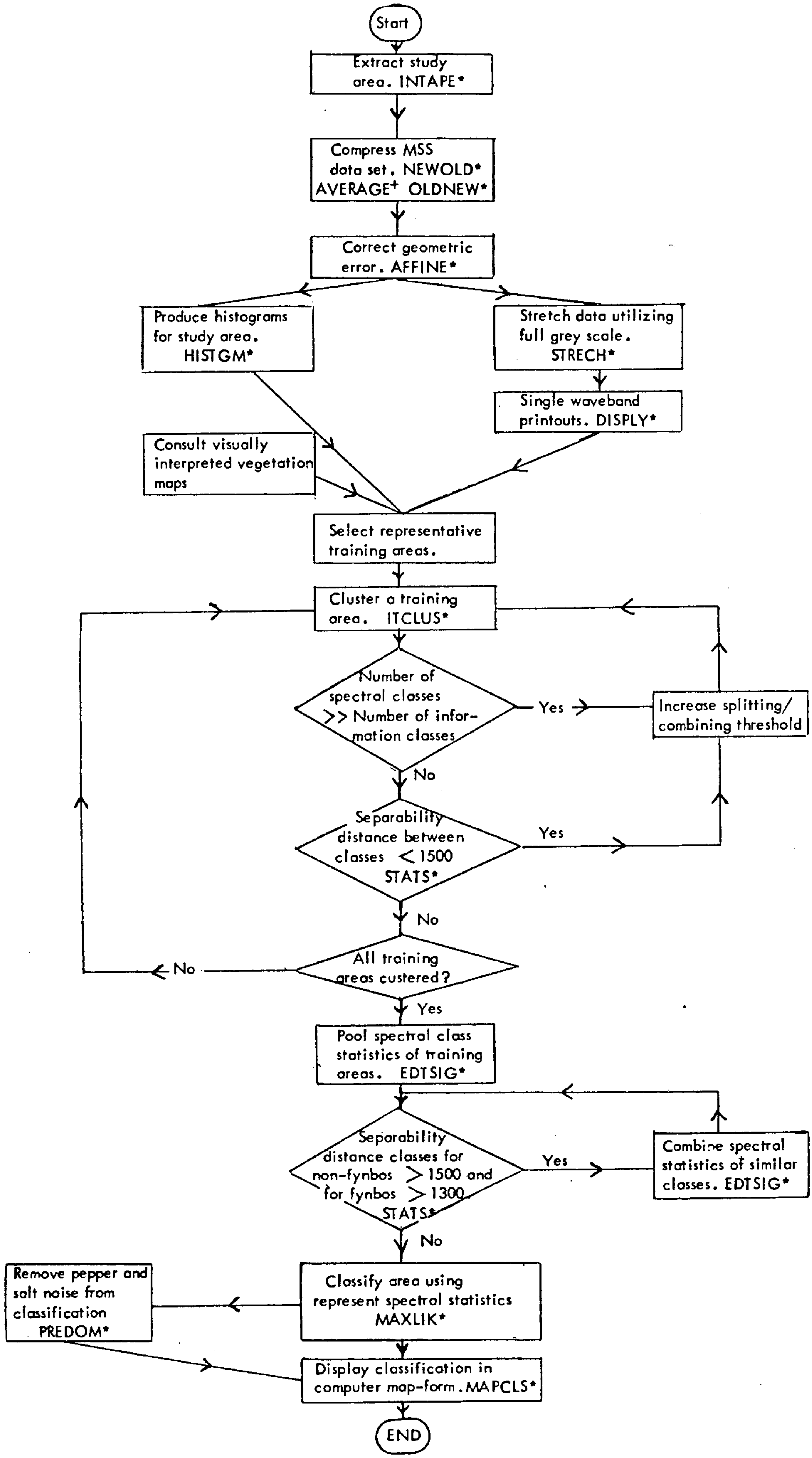

Figure 1. Flowchart for the computer-aided analysis sequence of the Landsat MSS data.

* Routines available in PIPS

\+ Routine available in CATNIPS

The raw data of each training area was clustered independently by employing an iterative clustering algorithm based on the ISODATA technique of Ball and Hall (1965). The clustering algorithm output was in a map-form where every pixel is represented by the class number it belongs to. The number of spectral classes that each area was clustered into depended on the number of cover types and the variability of each cover type. The cluster splitting/combining threshold parameters of the iterative clustering routine were adjusted in order to generate the desired number of classes. Statistics and separability algorithms were used on each training area to determine whether the spectral classes were separable. If the distance between classes was not sufficient then the number of spectral classes for that training area was reduced. The separability algorithm provides a transformed divergence (TD) and a J-M distance number (Swain 1978) which is a measure of the statistical distance between classes in multi-dimensional space. A balance between the level of detail desired and the minimum TD and J-M distance number must be found, one at which acceptable accuracy will be obtained for most of the classes of the desired informational content. Each spectral class was then associated to an actual cover type by referring to the vegetation map and other support data to check whether all cover types were represented in the training areas.

All the spectral classes from every training area were pooled together. The separability algorithm was again used on each pair of spectral classes. This time all pairs of classes having a J-M value less than 1 500 (on a scale 0 to 2 000) were combined. The combined spectral classes were checked against the cover classes of the vegetation map and now called information classes. These were required to run through the separability algorithm again to check whether any further combining was necessary. At this stage if two classes had a J-M distance number less than 1 500, but greater than 1 300 and were of particular interest, they were not combined. The information classes at this point were ready to be used in the classification.

3) Classification. The statistics of the information classes were used to classify the whole image. A Bayesian Maximum Likelihood classification procedure (Schlien and Goodenough 1973) was utilized in this classification. The final classification of the image was presented in a map-form. Statistics and extent of each class were also printed. A printout of the final classification which had been "tidied up" by applying a 3 x 3 mask to remove the pepper and salt noise was also produced.

RESULTS

A classification map at 1 : 250 000 scale was produced for each of the fourteen images covering the fynbos biome. These classification maps are at the same scale as the visually interpreted vegetation maps, allowing a direct comparison.

As adjacent images were not registered to permit the production of a contiguous classification map, each classification map was utilized and assessed individually. The computer classes could be compared by overlaying the transparent visually interpreted maps on each computer classification map. Some conclusions were drawn on the usefulness of the computer maps and where possible the visually interpreted maps were corrected, in sections where there had been doubtful boundaries or the maps were found to be incorrect after field checking.

DISCUSSION

The algorithms used in this project are all available in PIPS except for the averaging routine. This one is only available in CATNIPS, a predecessor of PIPS, developed by the University of Cape Town, Image Processing Unit. No specific methodology nor special software routines were developed for this computer classification operation and only routines already available in the two systems were used.

Previous experience obtained in an investigation into the usefulness of various techniques available in CATNIPS for mapping the fynbos biome was helpful. Perhaps more sophisticated classification algorithms and data preprocessing methods should be researched for mapping natural vegetation such as fynbos vegetation. This could result in a more accurate classification map. Maxwell (1976) stated that several noise sources (causing random fluctuations of radiance values) were identified as significantly degrading the quality of ERTS data. These included source noise, atmospheric propagation changes, radiometric errors, electronic system noise and data analysis errors.

The compression of the MSS data to reduce the scale of operation was administered due to the extent of the fynbos biome region. It was unrealistic to produce computer classifications at a detailed scale (approximately 1 : 24 000 scale) when the objective of the mapping operation was to determine the distribution of the major vegetation types at 1 : 250 000 scale with a final mapping scale at 1 : 1 000 000.

The time and money needed for computer processing and man-hours at 1 : 24 000 scale was not available for this project.

An averaging routine replacing the average of 10 x 10 pixels by one pixel was used for data compression. No resampling was used. The smoothing effect of the averaging routine does not impair the processing analysis, as in vegetation mapping the aim is to simplify the detail into manageable categories (Jarman, Jarman and Edwards 1983). Turner and Thompson (1982) have also stated that if pixel consolidation is required in digital data processing pixel averaging should be used rather than the more expensive cubic convolution interpretation, as nearly identical results were produced. The averaging routine also seems to have minimized the effect of shadow resulting from topographic variation of the land. When operating with the raw digital data at approximately 1 : 24 000 scale of rugged terrain, digital topographic data such as elevation, aspect and slope are required to obtain good classification results (Hoffer et al 1979).

The classification performance depends primarily on the analyst's ability to correctly identify the spectral classes and to properly merge those classes. Therefore once an adequate training set of spectral classes has been defined, it is not difficult to classify a large geographic area using computer analysis techniques. On completing the classification the general view on procedures is that unless one can verify the accuracy of such computer classification results, little has been accomplished by simply classifying the data over various areas of interest. These are the views of authors such as Fitzpatrick-Lins (1981), Hoffer et al (1979), Hord and Brooner (1976) and Van Genderen and Lock (1977). The approach taken in this study was not the procedure usually adopted where the computer classification has been used as a final map. Here the computer classification has been used rather as another source of information in producing the final map. It was therefore not regarded as essential that a detailed accuracy evaluation was provided. A qualitative evaluation was however performed by visually comparing the classification map to the map drawn from visual interpretation of the Landsat photographic images.

In classifying the MSS data, it was attempted to obtain information classes which could be associated with the scheme of major vegetation categories appearing in Table 2. This scheme was developed from a synthesis of descriptive studies which was aimed at mapping, classifying and characterizing the fynbos biome vegetation, and from categories distinguished during a first attempt at visual interpretation of the Landsat photographic images.

The information classes displayed on the classification maps did not always correspond favourably with the vegetation types described in Table 2. This was mainly due to certain vegetation types being structurally similar but floristically dissimilar, yet still being classified into a class of the same spectral reflectance characteristics.

A discussion follows on the defined vegetation types (Table 2) and their representation on the computer classified maps by the information (spectral) classes.

Cape Fynbos Shrublands

Mountain Fynbos: As a broad category, the classification classes corresponded well with the Mountain Fynbos category. Mountain Fynbos is spectrally distinct from its surrounding area and is therefore easily separated (Bossi in prep.). However the different types of Mountain Fynbos, namely Wet Mountain Fynbos, Mesic Mountain Fynbos and Dry Mountain Fynbos, were not consistently distinguished. On one of the images where Wet Mountain Fynbos is extensive (Knysna area), Mesic Mountain Fynbos and Wet Mountain Fynbos were not separated and were classified together with only two Mountain Fynbos classes recognised, i.e. Wet Mountain Fynbos and Mesic Mountain Fynbos, and Dry Mountain Fynbos. In some images Dry Mountain Fynbos did not appear to be a pure class. It was often represented as Karroid Shrubland or Renosterveld, due to the low cover of the Dry Mountain Fynbos.

The computer classifications displayed an interesting distinction between Mountain Fynbos on Table Mountain sandstone and Mountain Fynbos on granite in the southwestern Cape. Mountain Fynbos on granite on the Simonsberg and Helderberg was classified as a mosaic of equal proportions of two Mountain Fynbos classes in sharp contrast to the Mountain Fynbos on Table Mountain sandstone which was classified as purely one or the other class.

Table 2. Major categories recognized in mapping vegetation in and adjacent to the Cape Floral Kingdom (after Moll et al in prep).

MAPPED VEGETATION CATEGORIES	STRUCTURAL ENVIRONMENTAL DESCRIPTIONS	BIOGEOGRAPHIC AFFINITIES	FLORAL KINGDOM DIVISIONS
AREAS OF NATURAL VEGETATION			
CAPE FYNBOS SHRUBLANDS			
Mountain Fynbos		Cape Communities	Cape Floral Kingdom
Wet Mountain Fynbos Mesic Mountain Fynbos Dry Mountain Fynbos	Heathlands on sandstone and quartzite mountains		
Grassy Fynbos			
Mesic Grassy Fynbos Dry Grassy Fynbos	Grassy heathlands on sandstone, quartzites and conglomerates		
Lowland Fynbos			
Sand Fynbos	Heathlands on lowland acid sands		
Elim Fynbos	Heathlands on lowland laterites		
Limestone Fynbos	Heathlands on lowland limestone		
MOSAIC OF CAPE FYNBOS SHRUBLANDS AND SUBTROPICAL ELEMENTS			Elements of Cape and Palaeotropic Floral Kingdoms
Dune Fynbos	Shrublands on coast dunes	Cape/Sudano-Zambezian Communities	
CAPE TRANSITIONAL SHRUBLANDS			
Renosterveld			
West Coast Renosterveld	Small-leafed shrublands mainly on Malmesbury shales and Cape Granite	Cape/Karoo/Namib/Afromontane Communities	
South Coast Renosterveld	Small-leafed shrublands on Bokkeveld shales and Cretaceous conglomerates		
Central Mountain Renosterveld	Small-leafed shrublands mainly on Bokkeveld and Witteberg shales		
Eastern Renosterveld	Small-leafed shrublands mainly on Bokkeveld and Cango shales	Cape/Karoo-Namib/Sudano-Zambezian Communities	
Strandveld			
West Coast Strandveld South Coast Strandveld	Broad-leafed shrublands on coastal, calcareous sands	Sudano-Zambezian/Tongaland-Pondoland/Cape Communities	
SUBTROPICAL TRANSITIONAL THICKET AND FOREST			Palaeotropic Floral Kingdom
Kaffrarian Thicket	Tongaland-Pondoland Regional mosaic communities mainly on coastal sands	Tongaland-Pondoland Communities	
Valley Bushveld (undifferentiated)	Zambezian Domain communities on shales and conglomerates	Sudano-Zambezisan/Tongoland-Pondoland Communities	
AFROMONTANE FOREST			
Afromontane Forest Communities (undifferentiated)		Afromontane Communities	
KARROID SHRUBLANDS			
Karroid Shrublands on shales and mudstones (undifferentiated)		Karoo-Namib Communities	

Ecotones

Mosaic of Dry Mountain Fynbos and Karroid Shrublands
Mosaic of Sand Lowland Fynbos and West Coast Strandveld
Mosaic of Dune Fynbos and Dune Thicket

AREAS PARTIALLY CLEARED OF NATURAL VEGETATION

Mosaic of Eastern Renosterveld and agriculture

AREAS CLEARED OF NATURAL VEGETATION

Cultivated land, plantations, dense alien communities and open sandy areas
Reservoirs, pans and Lakes
Cities and towns

AZONAL COMMUNITIES (not mapped or described in detail)

Riverine Communities
Wetland Communities
Littoral Communities

Grassy Fynbos: Mesic Grassy Fynbos and Dry Grassy Fynbos were never recognised as pure classes but were always represented as mosaics. Mesic Grassy Fynbos appeared as a mosaic of Mountain Fynbos, Renosterveld and sometimes a good cover Karroid Shrubland type. Even the mosaics did not appear to occur in any conclusive ratios and therefore these classes were not interpreted consistently as Grassy Fynbos. Trends however, could be recognised.

Lowland Fynbos: This category was often classified as Mesic Mountain Fynbos. However in certain areas, for example on the west coast, Sand Fynbos was represented as a Strandveld type and near Stilbaai Limestone Fynbos was classified as a Strandveld and Renosterveld mosaic. Lowland Fynbos, except for Limestone Fynbos along the south coast, occurs in small patches. It was therefore difficult to obtain a distinct spectral class for this type in the training areas. Accordingly this type was not distinguished from the vegetation type surrounding it.

<u>Mosaic of Cape Fynbos Shrublands and Subtropical Elements</u>

Dune Fynbos: This vegetation was not classified as a distinct type but was recognised as part of the broad Fynbos class. Because of its location next to the coast it could be interpreted as Dune Fynbos by the analyst.

The occurrence of fire in all fynbos types results in a striking change of spectral reflectance due to the removal of the vegetation and exposure of the soil. All recently burnt areas were misidentified as fallow lands. Burning is an essential part of fynbos veld management and will always be a problem in the analysis of Landsat data in fynbos vegetation.

<u>Cape Transitional Shrublands and Karroid Shrublands</u>

The four different types of Renosterveld were not recognised as separate classes by the classifier. These classes often included types such as Strandveld or good cover Karroid Shrubland. This occurred because spectral reflectance characteristics of the vegetation are affected by canopy cover, density and overall colour appearance, rather than floristically distinct species composition (Bossi in prep.). The type of classes distinguished for Renosterveld, Strandveld and Karroid Shrublands were classes of different ground cover. Three to four of these classes were separated in each image. Mosaics of these classes also occurred.

Subtropical Transitional Thicket and Forest

Kaffrarian Thicket and Valley Bushveld were classes that were not distinguished from each other but were classified as different to the shrubland categories. Where Kaffrarian Thicket and Valley Bushveld occurred in small patches on hill or mountain sides of the south and southeastern Cape, they were not separated from the surrounding vegetation.

Afromontane Forest

Afromontane Forests were well separated into a distinct class. The vegetation cover, density and colour was very different, allowing this class to be clearly defined. Only in a few places in the Knysna area where Wet Mountain Fynbos is very dense and tall was Mountain Fynbos classified as Afromontane Forest.

Some areas of natural vegetation, especially on coastal regions, have been infested by alien vegetation. These alien communities have not been distinguished as their spectral reflectance was not that dissimilar from their surroundings and their infestations were not extensive enough to be detected at 1 : 250 000 scale.

Areas cleared or partially cleared of natural vegetation

Mosaics of Renosterveld and agriculture occurring in the southeastern Cape were classified as such. Elsewhere there were a few pure agricultural classes whose spectral reflectance did not differ significantly from certain natural vegetation types, such as Karroid Shrublands and a low cover Renosterveld. These were fallow wheatlands, ploughed lands and heavily grazed areas which were included as natural categories. Cultivated land, green crops, vineyards and orchards were classified as one class. Plantations were not represented as an individual class but were included into either a fynbos class, a forest class, or an agricultural class. Their classification depended on the growth state of the vegetation and consequently the spectral reflectance.

Water bodies such as large reservoirs, pans, lakes and the sea as well as open sandy areas produced good classes. The high contrast between these categories and the surrounding area also produced good boundary lines.

High density urban areas were included in the same class as bare agricultural lands, whereas the low density urban areas were classed as cultivated land.

No particular mapping interest was placed on the non-natural vegetation classes so that if their J-M distance was not greater than 1 750, the classes were combined. This resulted in classes which covered a larger range of spectral reflectances than would have been desired for the natural vegetation types and in particular the fynbos types.

The number of spectral classes resulting from the classification for the sparser natural vegetation areas was greater than the number of cover types present. This occurred with the Karroid Shrubland classes and to a lesser extent with the Renosterveld classes. It was therefore evident that this increased spectral variation was caused by different soil background characteristics and many of these spectral classes could not be related to vegetation types. Trying to reduce the number of spectral classes caused an increase in spectral variance for the combined classes. Conversely the spectral classes corresponding to the fynbos vegetation types were fewer than was desired, illustrating the relatively good canopy cover of the fynbos types and that the variability of these cover types was insufficient to be recognised at a 1 : 250 000 scale. This was confirmed by the lower spectral variance obtained for the fynbos spectral classes.

CONCLUSIONS

The methodology used to classify the Landsat II MSS data covering the fynbos biome has been described here. The procedure used was based on a hybrid approach developed from supervised and unsupervised classifications. As it was not intended to use only the classification maps as a final map, intensive research was not channelled into the computer-aided analysis procedures and its results.

The procedures used were based on generally accepted classification methods for vegetation mapping. Although these methods rely primarily on an automatic, computer-aided analysis, the classification performance is dependent on the analyst's ability to correctly identify the spectral classes and to properly merge those classes. The classes resulting from the computer classification distinguished broad fynbos categories consistently from areas cleared of natural vegetation but was less consistent where adjacent areas consisted of non-fynbos shrublands. This was because the categories expected in the results relied on a strong relationship between the floristic/ structural fynbos types and their spectral response, which probably does not exist.

The spectral classes at 1 : 250 000 scale appear to be mainly dependent on the vegetation canopy cover and density. The structural characteristics of the vegetation should have a more marked influence when operating at smaller scales. In previous work completed at 1 : 50 000 scale on classifying fynbos vegetation, it was found that height of dominant strata and canopy cover was an important factor in areas of greater than 50 per cent ground cover, whereas in lower cover areas, the canopy cover was the single most important factor (Jarman 1981; Lane 1980).

The precise location of boundaries between mapping units is always uncertain because the boundaries between vegetation types may or may not exist on the ground. The classification map of the Landsat MSS data and the visually interpreted map drawn from the Landsat photographic prints were two different interpretations used in drawing up the final vegetation map. There was no other "perfect" representation of vegetation distribution with which to compare the classification map in order to determine the quantitative estimates of accuracy. However a qualitative accuracy interpretation has been presented allowing the reader to conclude his own quantitative estimates.

(Note: The classification map will be published in the Symposium Proceedings of Earth Data Information Systems 1983 in "The role of digital data processing in mapping major vegetation units in the fynbos biome" by M L Jarman, L Bossi and E J Moll.)

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PART V. FOURTH PAPER. SPECTRAL REFLECTANCE CHARACTERISTICS OF THE FYNBOS BIOME VEGETATION FROM LANDSAT II DIGITAL CLASSIFICATIONS

L. Bossi

ABSTRACT

Computer classification techniques were used to analyse the Landsat II digital data for the fynbos biome. The spectral reflectance values resulting from computer classified classes are presented as spectral curves. These spectral curves are examined and characteristics for the fynbos and adjacent vegetation are described. The spectral reflectance characteristics of the fynbos vegetation show that there is a variation within the fynbos classes from different geographical and environmental areas. The fynbos reflectance curves are seen to be very different from adjacent vegetation types such as forests, karroid shrublands and bare sandy areas.

INTRODUCTION

Landsat II satellite images were used to map the vegetation of the fynbos biome at 1 : 250 000 scale. Visual interpretation was applied to the photographic images and the digital Multispectral Scanner (MSS) data was analysed with the aid of computer-aided techniques. The results from these two mapping procedures were combined and after field-checking the final map was produced. The methods are described in detail in Moll et al (in prep) and Bossi (in prep).

Because of the extent of the biome, fourteen Landsat images were required for complete coverage of the area. The initial procedure of the computer-aided analysis was to reduce each image from its original scale of approximately 1 : 24 000 to 1 : 250 000 scale by using an averaging routine. Operating at this large scale, the computer classification procedures used on the MSS data produced broad vegetation categories. These categories were in fact spectral classes which were identified by the analyst as a vegetation type. In this article, the characteristics of the spectral classes occurring in the fynbos biome will be discussed. This preliminary examination of the spectral classes gives some indication of the spectral behaviour of the vegetation of the fynbos biome and may be useful in further applications of the Landsat data in the biome.

METHODS

Computer classification of each image was completed using a guided unsupervised approach. The method involved selecting training areas from the image in which all vegetation cover types were represented. An iterative clustering algorithm (Ball and Hall 1965) was applied to each training area, creating classes of spectrally similar characteristics. These classes were all pooled together and a separability algorithm was applied to the group. All classes were compared to one another and ones which were similar were combined. The transformed divergence and J-M distance numbers were used to determine the spectral separability (Swain and Davis 1978). A final group of spectral classes was chosen to represent information classes (cover types) and used in the classification of the whole image. This classification was based on a Bayesian Maximum Likelihood procedure (Schlien and Goodenough 1973).

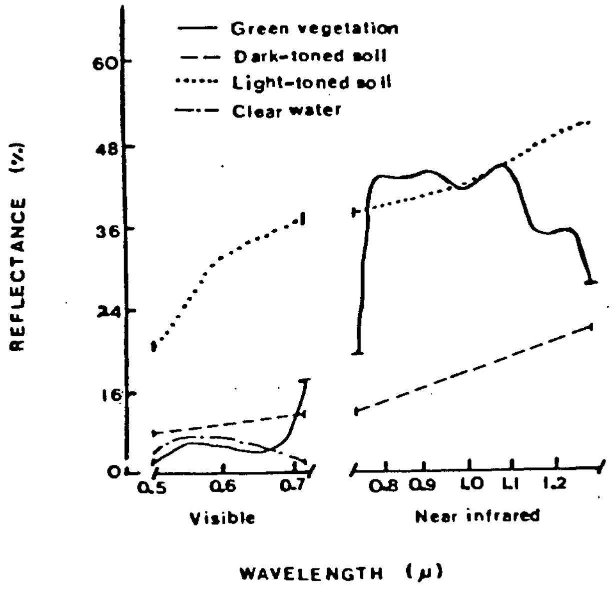
After this computer classification procedure had been applied to all the images, the spectral values of the information classes were examined. Two sets of curves of selected information classes were constructed. One set represented spectral curves for fynbos classes throughout the biome. The other set illustrated examples of spectral curves for various vegetation types occurring in the fynbos biome.

All spectral curves for each class were constructed from the mean digital values in each of the four Landsat spectral bands; band 4, 0,5 to 0,6 μm (green); band 5, 0,6 to 0,7 μm (red); band 6, 0,7 to 0,8 μm (near IR); and band 7, 0,8 to 1,1 μm (near IR). Although there are 128 spectral levels on the computer-compatible tapes (CCT's) for bands 4, 5 and 6 and 64 spectral levels for band 7, these were all stretched to 256 (using constant multipliers of 2, 2, 2 and 4 respectively) for all bands before processing. The spectral values are not given in conventional physical units, but are represented by digital numbers with zero being the darkest and 256 being the lightest.

RESULTS AND DISCUSSION

Mean reflectance values of the fynbos classes obtained from each image, as well as examples of the reflectance values of adjacent vegetation types, are shown in Table 1. The computer classifications of each image recognised only one or at most two fynbos classes. A map displaying the geographical location of each fynbos class presented in Table 1, is shown in Figure 1. On investigating the mean spectral reflectance values of the fynbos classes, a variation from one area to another was found. This variation is best seen when the spectral reflectance values are represented as spectral curves. For the sake of clarity only five fynbos classes are represented as spectral curves in Figure 2.

A noticeable tendency of these spectral curves is the decrease in spectral reflectance for bands 4 and 5 as one moves from west to east in the fynbos biome. There is also a decrease in the steepness of the slope between bands 4 and 5 for the classes in the eastern portion of the biome. This is attributed to the increase in canopy cover of the fynbos vegetation towards the east. From Figure 3 it can be seen that soil has high reflectance values in bands 4 and 5, relative to vegetation, which has low values because much of the incident energy from the visible part of the spectrum is absorbed. The fynbos types with a sparser canopy cover along the west coast have higher reflectance values caused by a larger percentage of exposed soil.



Landsat MSS Bands

Band 4 0,5 - 0,6 μm (green)
Band 5 0,6 - 0,7 μm (red)
Band 6 0,7 - 0,8 μm (near IR)
Band 7 0,8 - 1,1 μm (near IR)

Figure 3. Spectral reflectance of basic cover types (after Hoffer 1978).

Table 1. Mean reflectance values in the Landsat bands for fynbos and adjacent vegetation classes in the fynbos biome.

CLASS NO.	VEGETATION CLASS DESCRIPTION	LANDSAT MSS WAVEBANDS			
		4	5	6	7
1	Fynbos (188 - 082 Verlorenvlei) *	34	46	47	40
2	Fynbos (188 - 083 Langebaan) *	30	34	45	43
3	Fynbos (187 - 083 Ceres) *	31	37	45	41
4	Fynbos (187 - 084 Cape Town) *	31	36	54	51
5	Fynbos (187 - 084 Cape Town) *	27	28	40	39
6	Fynbos (186 - 084 Bredasdorp) *	32	37	51	48
7	Fynbos (186 - 083 Laingsburg) *	28	30	41	37
8	Fynbos (185 - 083 Oudtshoorn) *	29	32	47	46
9	Fynbos (185 - 084 Mossel Bay) *	34	41	63	60
10	Fynbos (185 - 084 Mossel Bay) *	27	27	50	52
11	Fynbos (184 - 083 Uniondale) *	30	39	46	41
12	Fynbos (184 - 083 Uniondale) *	24	25	37	35
13	Fynbos (183 - 084 Humansdorp) *	30	33	52	50
14	Fynbos (183 - 083 Port Elizabeth) *	28	30	52	50
15	Renosterveld/Strandveld/good cover Karroid Shrubland	38	52	62	53
16	Good cover Karroid Shrubland/Strandveld/agriculture	44	68	80	67
17	Low cover Karroid Shrubland/fallow land	54	90	95	78
18	Very sparse Karroid Shrubland/fallow land	63	114	115	89
19	Slightly vegetated sandy soil	80	134	135	106
20	Sand	117	208	199	144
21	Knysna Forest	26	24	68	74
22	Alexandria Forest	35	37	87	88
23	Valley Bushveld	32	35	71	70
24	Irrigated agriculture	44	61	91	88
25	Vines/green wheatlands	39	52	71	65
26	Water	23	14	7	4

* World Reference System number and area description of the image.

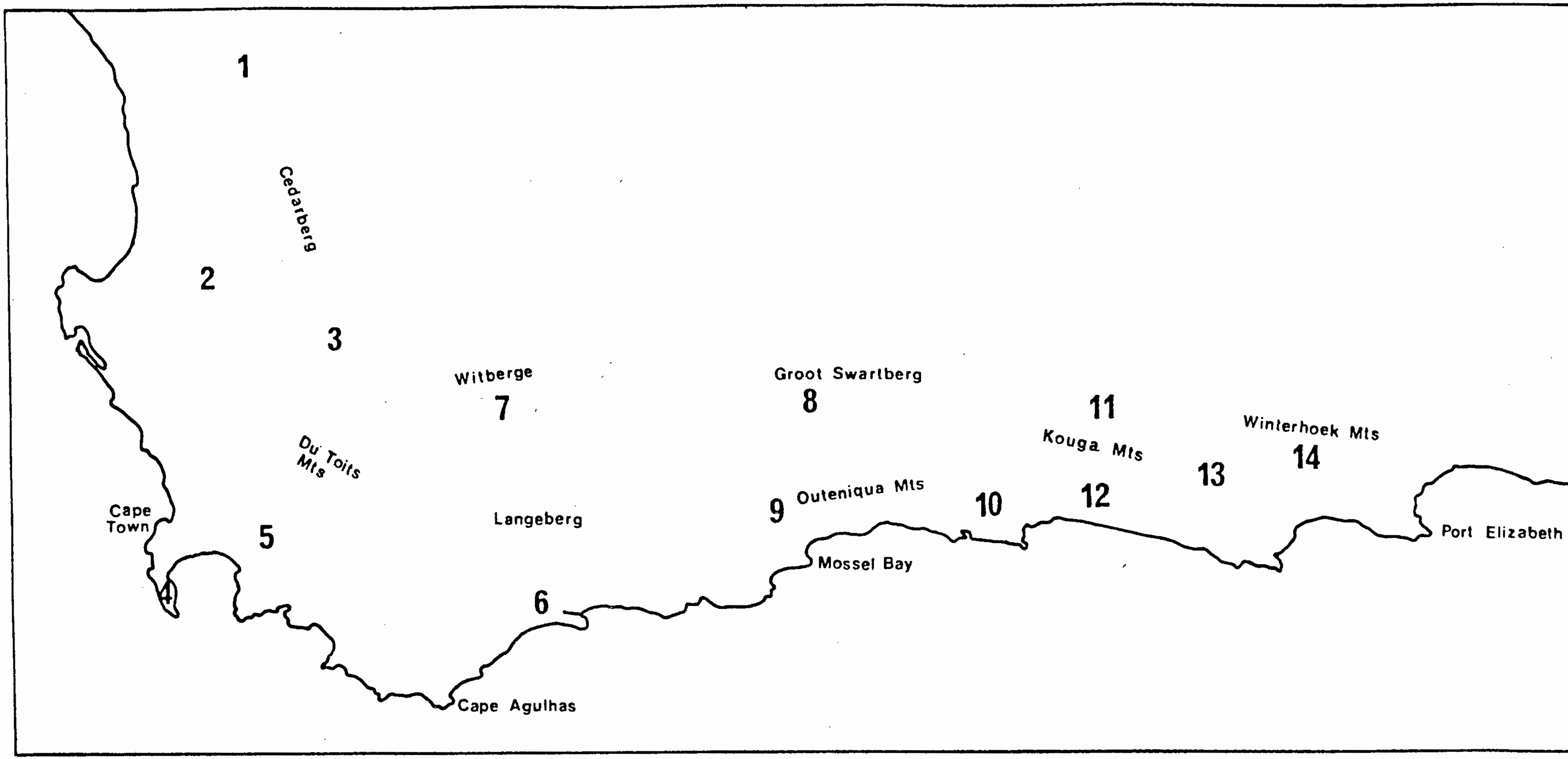


Figure 1. Map showing the geographical location of the fynbos classes presented in Table 1

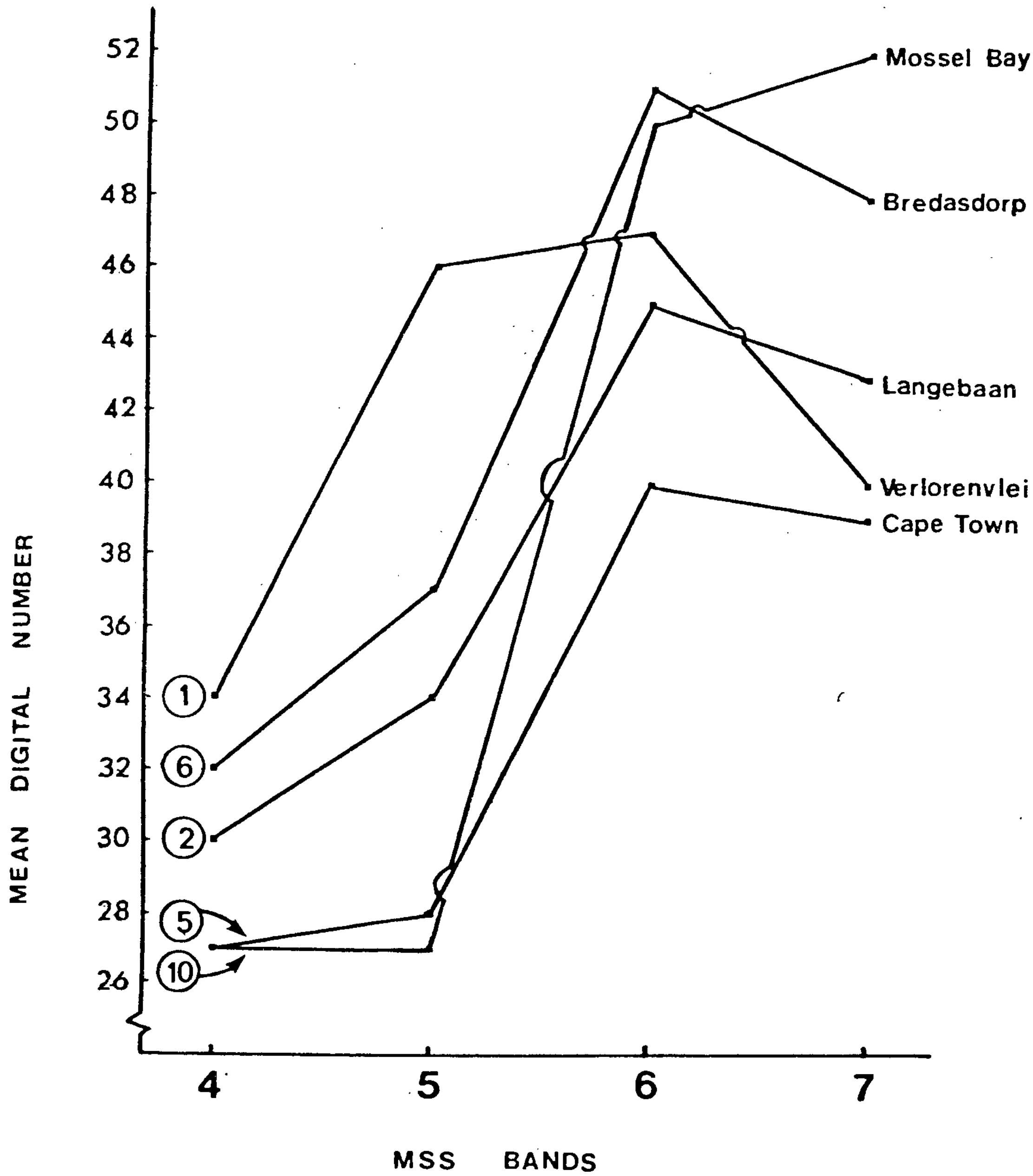


Figure 2. Spectral reflectance values in four Landsat bands for fynbos vegetation classes in the fynbos biome. The circled numbers refer to the class numbers from Table 1.

The increase in spectral reflectance, particularly where band 4 is lower than band 5, as occurs with the fynbos spectral curves, has been described by Mayer and Fox (1981). These authors state that in their study area this was due to the soil type (white pumice soil), the wide node/internode relationship of fir trees and the minimum amount of needle surface area exposed. This is converse to the many studies that have shown that band 5 is traditionally lower than band 4 when examining vegetation (Kalensky and Wilson 1975). Welch et al (1979) suggest that a large positive difference for band 5 minus band 4 may be considered an index of bare soil or dead vegetation cover in an area, whereas a negative difference is associated with live vegetation or water.

Fynbos class 6 which occurs along the south coast (east of Agulhas) has high reflectance values although occurring further east. This occurrence is probably due to the Limestone Fynbos which is burnt frequently, exposing the white calcrete soil. Therefore soil reflectance characteristics, here and in other areas where the soil is exposed, plays an important role (Wiegand et al 1974). Hoffer (1978) mentions that an increase in soil reflectance values is caused by an increase in soil brightness, a decrease in soil particle size, a decrease in surface roughness and a decrease in soil moisture. However he does mention that these factors are very closely interrelated and that these guidelines for interpreting soil spectra will often hold true only for certain ranges of conditions. Consequently, the increased reflectance of the fynbos in the west is probably only due to an increase of exposed drier soil and is not related to soil type as all fynbos classes occur on similar soil types.

A peculiar factor which may be lowering the spectral reflectance of the fynbos on mountain tops in the southwestern Cape, is the lichen-encrusted Table Mountain sandstone rock. Although there is much exposed rock in these rugged mountains, its relatively low reflectance values may be due to the dark colour of the lichen.

The upward slope of the spectral curve between bands 5 and 6 is related to vegetation density and activity. Fynbos type 10 (Knysna area) is a good example of very dense, active vegetation having a steep slope between bands 5 and 6, while fynbos type 1 (Verlorenvlei) demonstrates its sparse, relatively inactive vegetation by having a slope that levels off. The difference in vegetation activity between the winter-rainfall areas and all-year rainfall areas is noted. The Landsat images were recorded in summer, a period of inactivity for the fynbos classes of the western and southwestern Cape. This is represented by the lack of steepness in the slope between bands 5 and 6 for these areas.

The spectral values of bands 6 and 7 are referred to as indicators of vegetation density with the denser vegetation having a higher reflectance (Hoffer 1978). However in the fynbos application, the high reflectance values of bands 6 and 7 also represent sparser vegetation classes, for example types 6 (Bredasdorp) and 8 (Oudtshoorn). These high values arise from reflectance due to soil background and not the vegetation density. Therefore by referring only to bands 6 and 7, one cannot attribute the spectral reflectance either to vegetation or to soil without referring to band 5 as well. To clarify this condition vegetation indices, such as the ratio of band 5 to band 7, or band 7 minus band 5 (in other words the slope between band 5 and 7), are used as practical indicators of vegetation density and cover (Forster 1980; Kauth and Thomas 1976; Wiegand et al 1974). Furthermore, some indication of the degree of vegetation density and activity may be resolved by looking at the slope of the curve between bands 6 and 7. The fynbos classes in Figure 2 demonstrate these theories well. Once again fynbos class 10 is seen as a dense, active vegetation type, while class 1 is seen as sparse, dry and inactive. Band 7 minus band 5 for fynbos class 6 (south coast) shows that although this class has high values for bands 4 and 5, it has a reasonable vegetation density and activity. It can be concluded that, although each part of the spectral curve indicates some characteristic of the fynbos class, one must refer to the curve as a whole in order to decide its type.

Figure 4 displays spectral curves for three fynbos classes and examples of vegetation classes adjacent to the fynbos. This graph shows the reflectance values and distinctive curves that fynbos classes have when compared to the other vegetation types. The non-fynbos vegetation types have high band 4 values, much higher band 5 and 6 values and low band 7 values. The steepness of the slope between bands 4 and 5 indicates the low canopy cover; the levelled off curve between bands 5 and 6 indicates very little vegetation activity. This is emphasised by the negative (downward) slope of bare sandy areas (class 20). The slope between band 6 and 7 suggests there is very little vegetation density. These curves seem to acquire the shape of an inverted U, with the arms of the U drawing closer and the position of the inverted U appearing

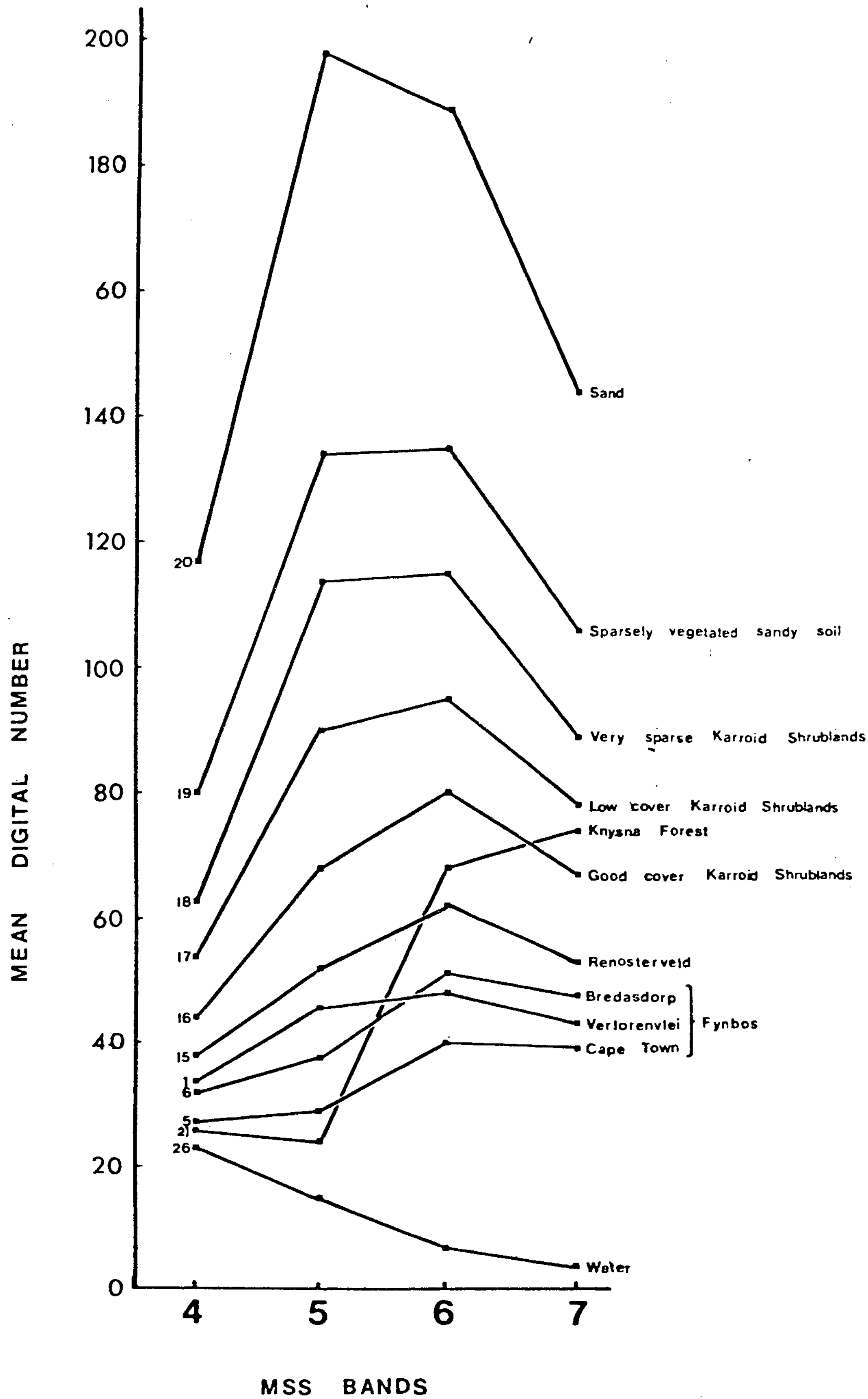


Figure 4. Spectral reflectance values in four Landsat bands for fynbos and adjacent vegetation classes in the fynbos biome. Class numbers correspond to those described in Table 1.

higher up the scale of the graph as the vegetation becomes sparser and less active. Class 15 (renosterveld) still has relatively low reflectance values not unlike fynbos class 1, which is starting to acquire the inverted U shape. When calculating the vegetation index (band 7 minus band 5), it is noted that only the fynbos classes, the renosterveld/strandveld/good cover karroid shrubland class, and the forest class have positive values. The remaining vegetation all has a negative value, becoming more negative as the cover and density decrease.

Some of the increase in spectral reflectance of the barer karroid shrublands and sandy areas may be attributed to the soil characteristics. As stated earlier, a decrease in soil particle size resulting in a smoother soil surface, as well as a decrease in soil moisture caused an increase of the spectral reflectance (Hoffer 1978). Karroid shrublands have smoother soil surfaces and occur in drier environments. Gebermann and Neher (1979) have shown that the addition of sand to soil increased the value factor in the soil colour designation and this increased the percent soil reflectance. Bare sandy areas have no vegetation to obscure this highly reflective soil.

The very dense canopy cover and active vegetation of class 21 (Knysna Forest) may be deduced from its spectral curve. The low values and downward slope between bands 4 and 5; the very steep slope between bands 6 and 7; the high values and unique upward slope between bands 6 and 7; and the high value for the vegetation index (band 7 minus band 5), all portray characteristics that are very different from the various classes of vegetation in fynbos biome.

Class 22 (Alexandria Forest, not shown in Figure 3) appears to have a very high vegetation index representing a very active vegetation but with perhaps not as good cover as the Knysna Forest due to slightly higher bands 4 and 5 values.
The spectral reflectance values for class 23 (valley bushveld) show that this class does not have a vegetation cover, density and activity that is as high as the Knysna Forest class. The spectral values for two pure agricultural classes show a relatively good vegetation density activity although not a very high canopy cover.

The Landsat inter-band correlation has been reported many times. The greatest correlation occurs between the two visible bands 4 and 5 and between the two infrared bands 6 and 7, whereas the lowest correlation occurs between bands 5 and 7. The reflectance data of the vegetation classes from Table 1 have therefore been plotted for bands 5 and 7 in Figure 6. A parallel is drawn between Figure 5 and Figure 6.

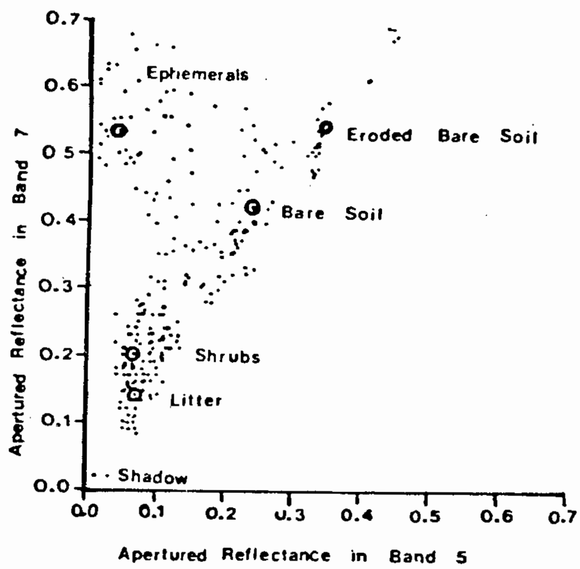


Figure 5. Measurements of reflectance characteristics in the Landsat bands 5 and 7 of the vegetation and soils from a semi-arid shrub rangeland (after Graetz and Gentle 1982)

Figure 5 has been produced from measurements of reflectance characteristics in the Landsat wavebands of the vegetation and soils from a semi-arid shrub rangeland in Australia by Graetz and Gentle (1982). The authors explain that eroded bare soil, "green" ephemerals and shrubs define the vertices of a triangle, with the eroded bare soil component determining the size of the triangle. A vegetation "cover line" rather than just a "soil line" of Kauth and Thomas (1976) can be defined, which passes through the point of shadow, litter and all of the soil points. A similar line may be defined on Figure 6, stretching from the fynbos classes through the karroid shrubland classes to the bare sand class. Graetz and Gentle (1982) also clarify that their shrubs

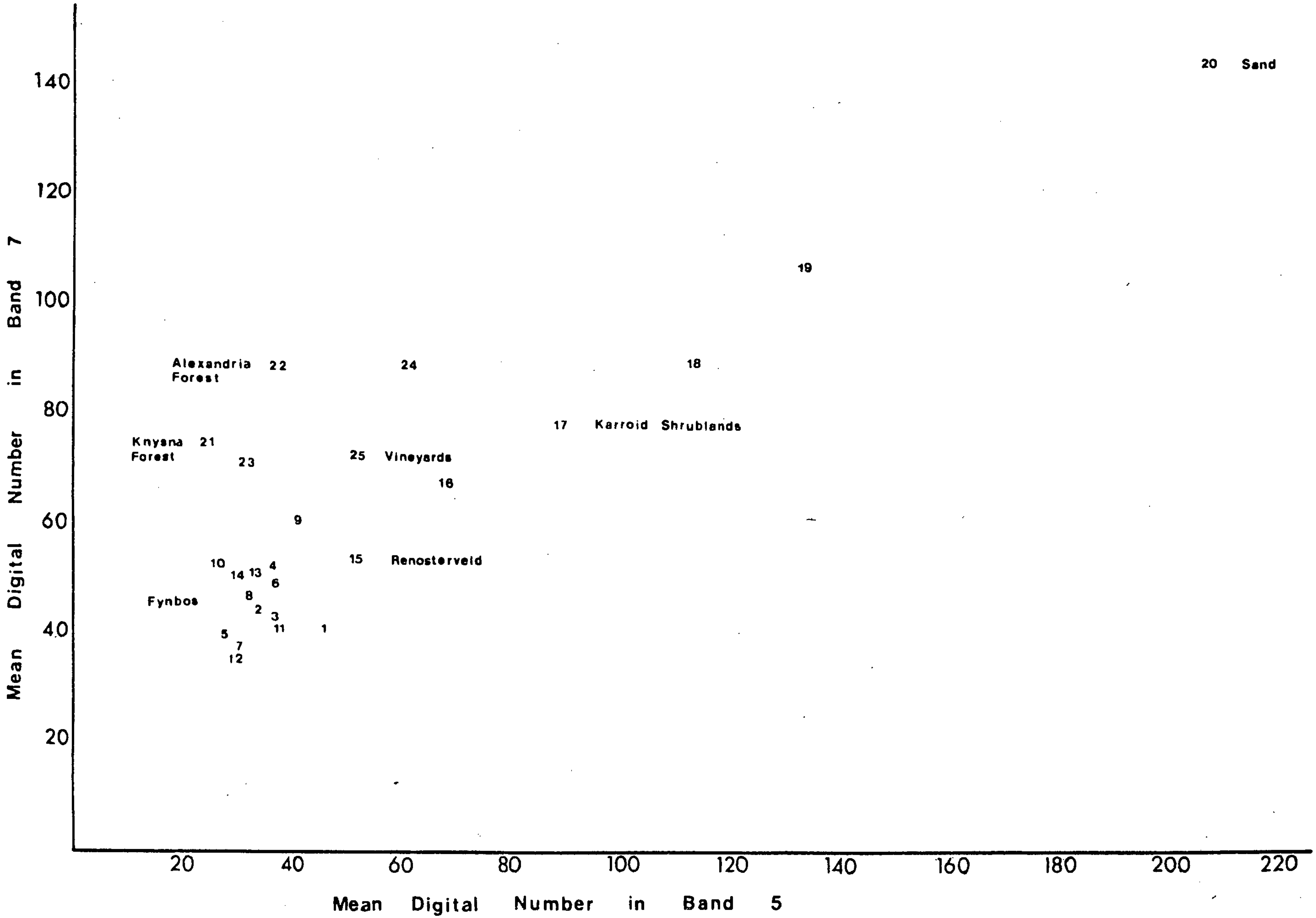


Figure 6. Spectral reflectance values for bands 5 and 7 of fynbos and adjacent vegetation classes in the fynbos biome. The numbers in the graph refer to the class numbers from Table 1.

were not vigorous and actively growing but were only just "greener" than litter. This agrees with the inactive state of the fynbos in the winter-rainfall area during the summer months. The position of the forest classes corresponds to the ephemerals or "green area" which are described by the authors as being very variable. They conclude that the combination of bands 5 and 7 separate out "cover" from "green".

CONCLUSIONS

The spectral reflectance characteristics of fynbos vegetation have shown that there is a variation within the classes from different geographical and environmental areas. The fynbos reflectance curves have been seen to be very different from those of adjacent vegetation types such as forests, karroid shrublands and bare sandy areas. By plotting the spectral reflectances of bands 5 and 7 of all the vegetation types, fynbos may be seen in relation to the "cover line" and the "green area".

Although the spectral reflectance characteristics have been developed from computer classifications at a large scale (1 : 250 000 scale), they still serve the purpose of providing some indication of the variation amongst fynbos classes and their relationship to adjacent vegetation type.

ACKNOWLEDGEMENT

Financial support from the C S I R National Programme for Remote Sensing is acknowledged and appreciated.

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GENERAL CONCLUSIONS

This project was concerned with the mapping of the fynbos biome vegetation with the aid of Landsat images. Vegetation categories based on a scheme by Moll et al (in prep.) were delineated at a 1 : 250 000 scale. Although Landsat images were the main remote sensing products used, other sources of information, such as the Geological Survey maps, Acocks' Veld Type maps and personal field experience were indispensable. Comments from botanists working in the fynbos biome were also most useful for the production of the final map. I have attempted to consolidate all information at hand to producethis fynbos biome vegetation map. However, the precise location of boundaries between mapping units is always uncertain but they are the most accurate yet available at 1 : 250 000 and 1 : 1 000 000 scale. The true value of the final vegetation maps can only be assessed by the users.

The Landsat images were most useful as remote sensing products in this project. They were selected mainly for the following reasons:

1) Direct reception of the images at the Satellite Tracking Station, Hartebeeshoek provided quicker access to new imagery of very good quality.

2) Because of the extent of the fynbos biome, other remote sensing products would have been too expensive.

3) Landsat imagery was well suited to the 1 : 250 000 mapping scale selected for mapping the fynbos vegetation.

4) Previous experience had been gained on an image processing system for the analysis of digital data, which was in operation on the computer at the university.

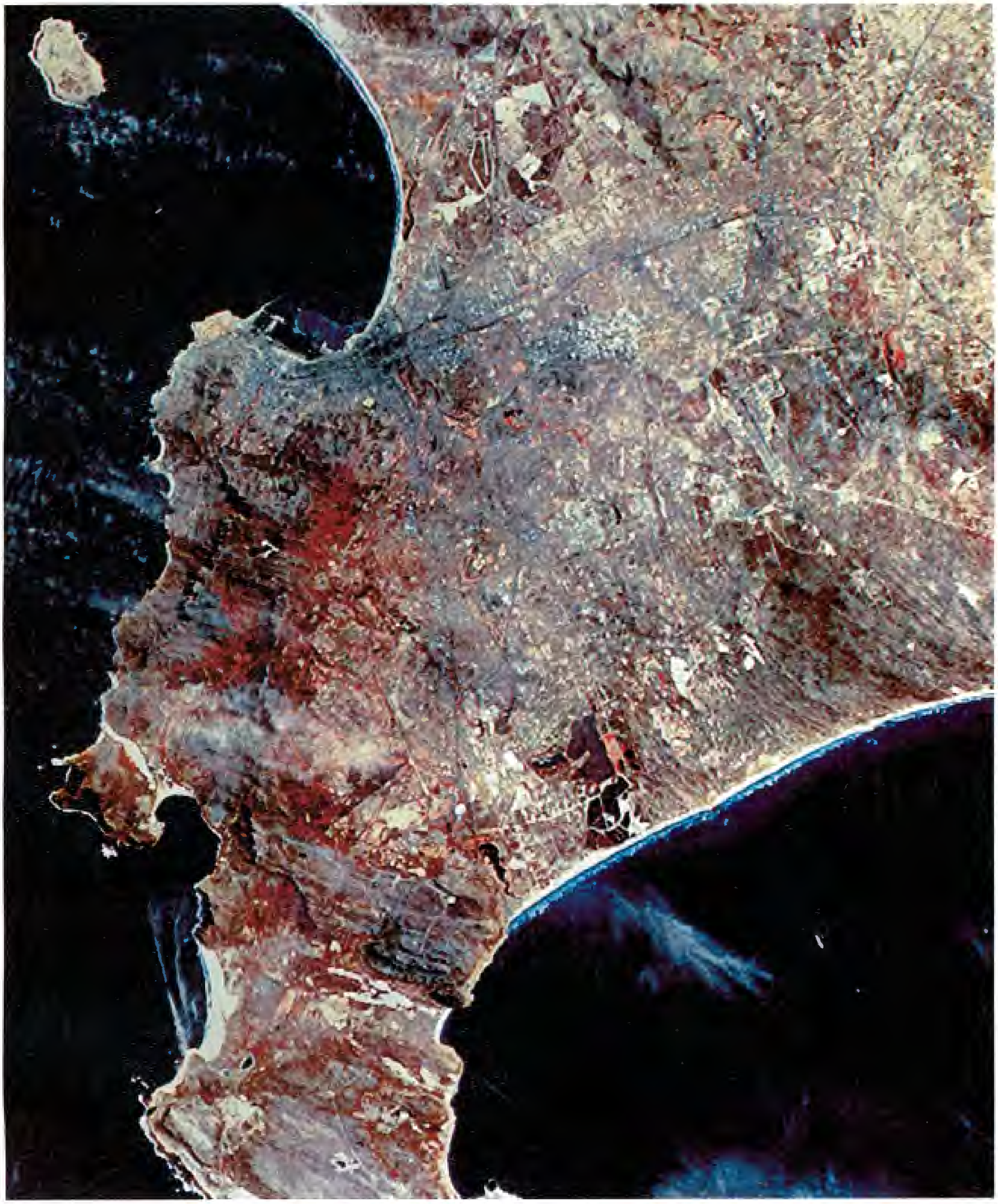
A detailed discussion and conclusions describing the methods used in this mapping operation are provided in the respective papers but the principal concluding comments are repeated here.

The use of visual interpretation techniques on the Landsat photographic images proved to be most successful. Mapping at 1 : 250 000 scales was well suited to the false colour composites and black and white enlarged prints. The fynbos vegetation was clearly distinguished from the surrounding cover types and most fynbos categories could be identified.

The computer-aided analysis of the digital images provided disappointing results. Computer classifications at 1 : 250 000 scale of the digital data produced categories which were too broad for the objectives of the mapping project. Possibly operating at 1 : 100 000 scale for the production of the computer classifications would have produced more useful results. Routines used in the computer-aided analysis were ones which were available on the image processing system and which are generally accepted as the most useful by researchers in the remote sensing field. Further research on algorithms for processing Landsat digital data of natural vegetation, and in particular fynbos vegetation, is needed.

Without the use of Landsat imagery, the mapping of the fynbos biome would have taken a longer time to complete. The costs would have been much higher due to the collection of data, acquisition of other remote sensing products and an increase in man-hours for processing the data. A combination of visual interpretation of Landsat photographic images at 1 : 250 000 scale and the use of computer-aided analysis of Landsat digital data at a larger scale for problem areas is recommended for mapping large geographic areas such as the fynbos biome.

REMOTE SENSING PRODUCTS FOR STUDYING AND MAPPING THE FYNBOS BIOME



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REMOTE SENSING PRODUCTS FOR STUDYING AND MAPPING THE FYNBOS BIOME

ERRATA

Page 1. 1.1.1 Line 3 1976 should read 1978

Page 7. Fig 1.1 wavelength ( ) should read wavelength (μ)

Page 29. 4.1.1 Fig 3.1 should read Fig 3.11

Page 49. Following references must be added:

TAYLOR H C 1969. A vegetation survey of the Cape of Good Hope Nature Reserve. MSc thesis, Department of Botany, University of Cape Town (unpublished).

TAYLOR H C 1978. Phytogeography and ecology of Capensis. In: The biogeography and ecology of Southern Africa. M J A Werger (ed). Junk, The Hague. pp 171 - 230.

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TUPPER G J 1980. Remote sensing and rangelands. Technical Memorandum 80/3. October 1980. CSIRO Division of Land Resources Management.

Throughout report for MAKLIK read MAXLIK.

Cover: Three band colour composite of portion of CCT 10180 - 08015 of 19 January 1973 of the Table Mountain and Cape Flats areas, south west Cape Province. This illustration was produced by the Satellite Remote Sensing Centre, Hartebeeshoek, and is repeated on page 31.

REMOTE SENSING PRODUCTS FOR STUDYING AND MAPPING THE FYNBOS BIOME

- an investigation into the usefulness of various techniques

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TABLE OF CONTENTS

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.

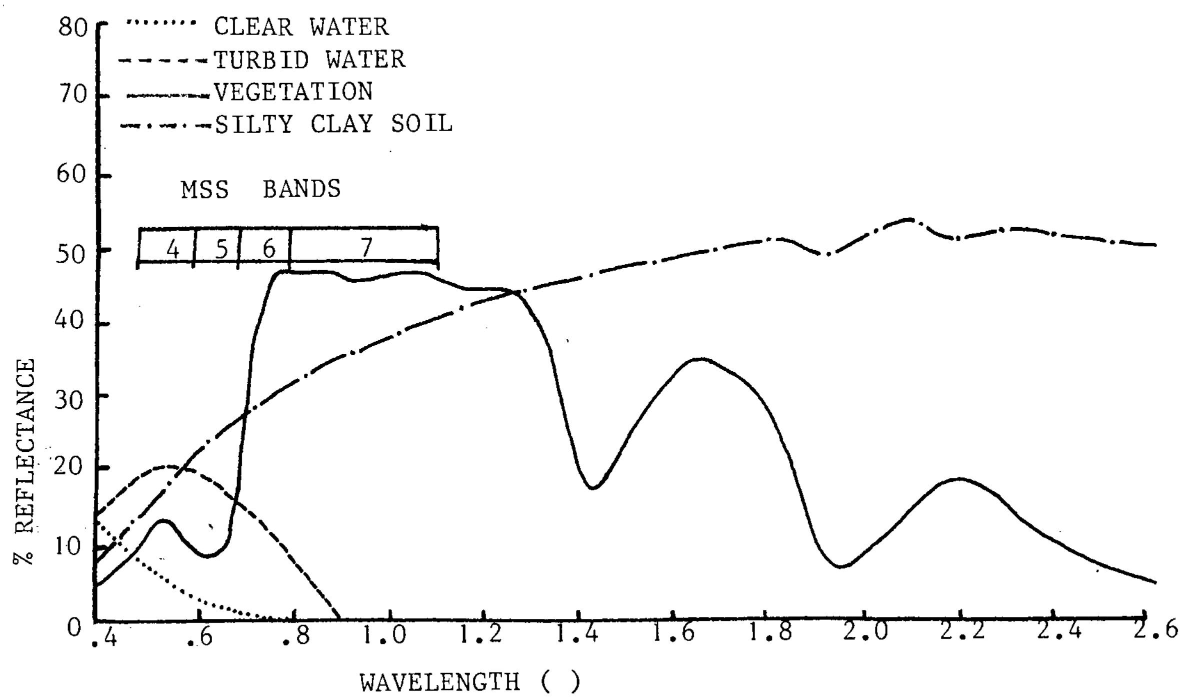

Figure 1.1 Spectral reflectance of basic cover types (After Lane 1980)

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.

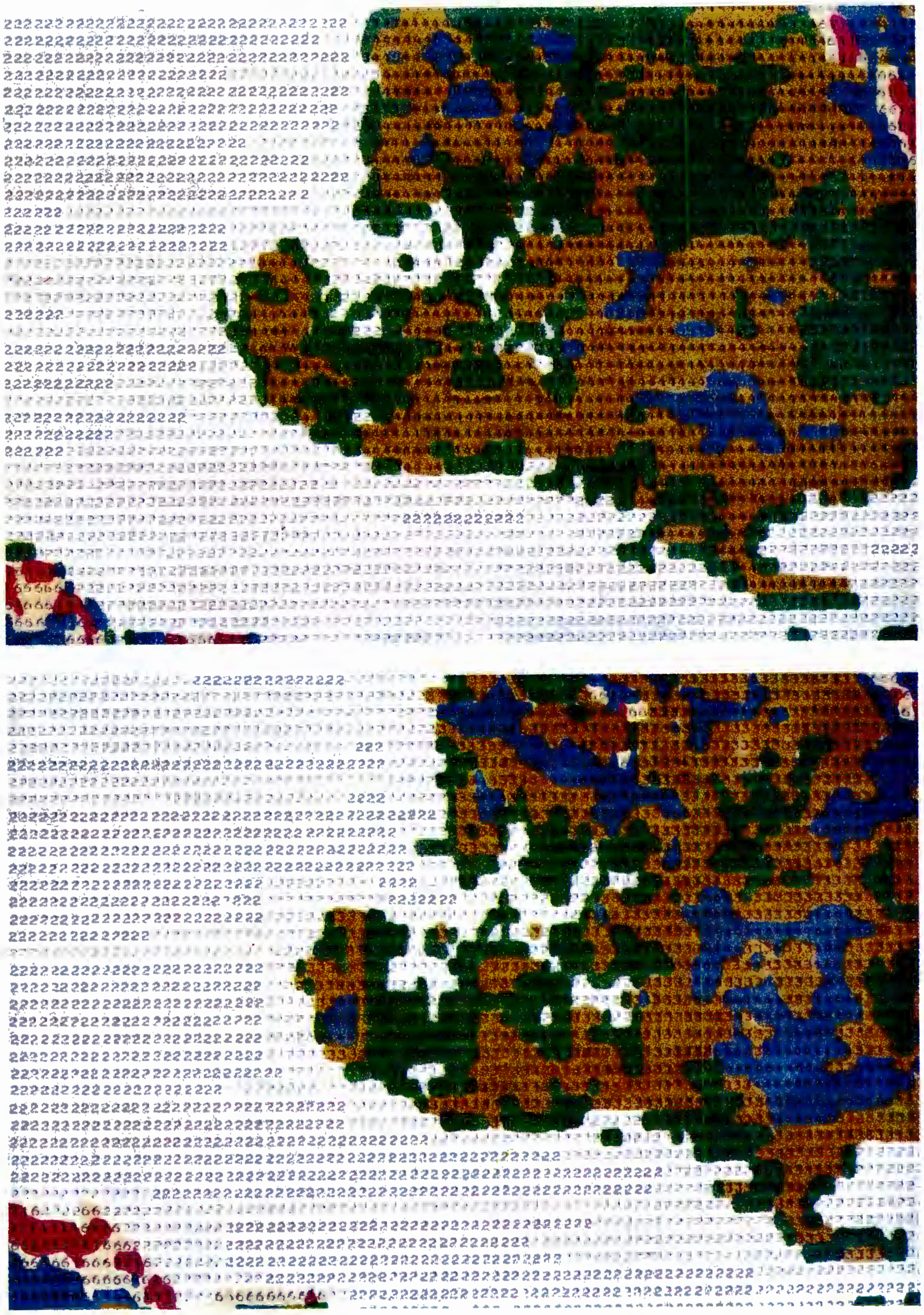

Figure 3.1 Classification of the Langebaan lagoon marsh areas carried out at 1:10 000 scale from CCT 10055 - 08064 16 September 1972 and CCT 10145 - 08073 15 December 1972.

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 step-wise summary of the procedure follows:

(a) <u>Identify and extract area for study</u> (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) <u>Frequency counts</u> (LIST) <u>and Stretch routines</u> (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) <u>Display routines</u> (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			

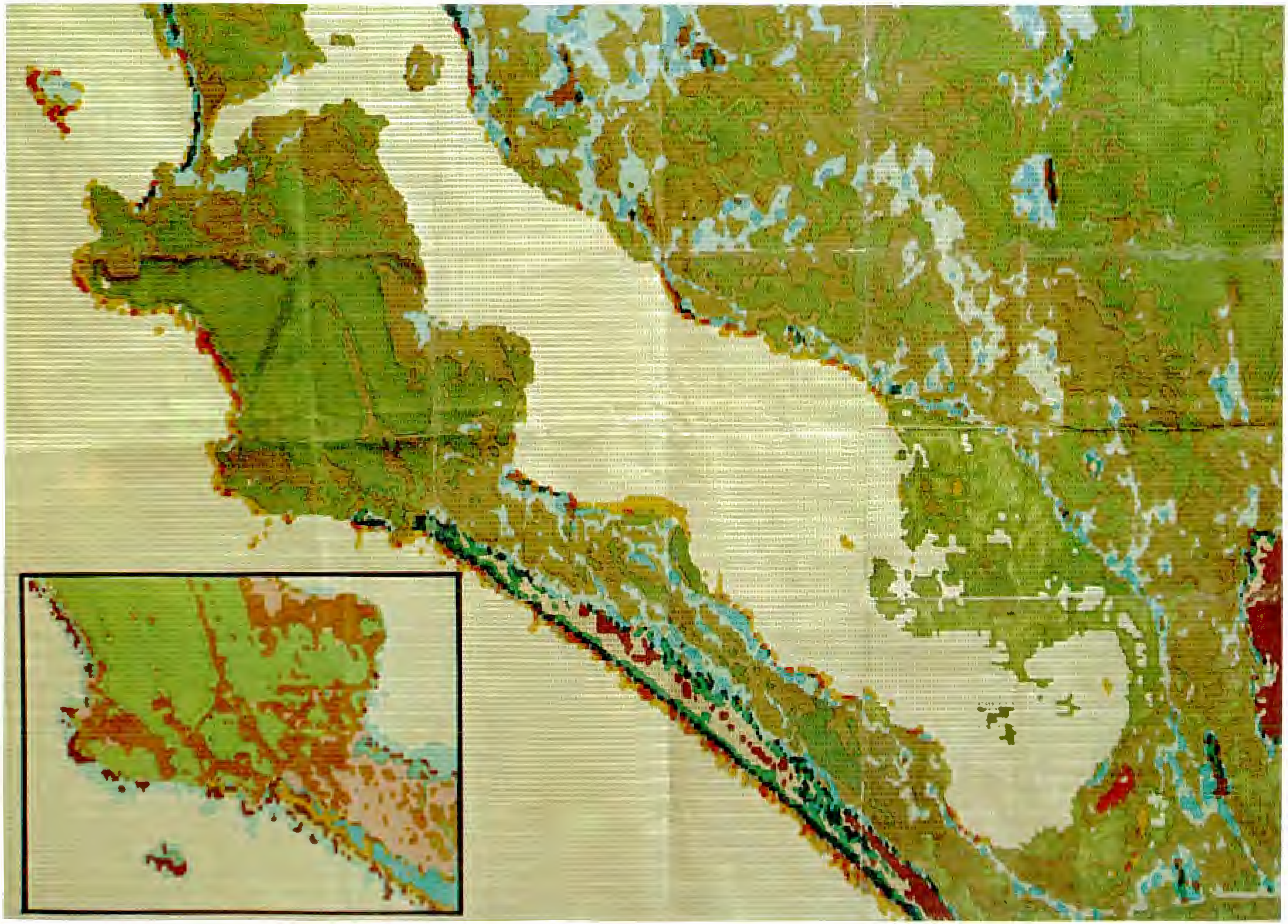

Figure 3.2 Classification of the Langebaan-Saldanha area carried out at 1:20 000 scale using statistics generated from one "representative test area" from CCT 10055 - 08064, 16 September 1972.

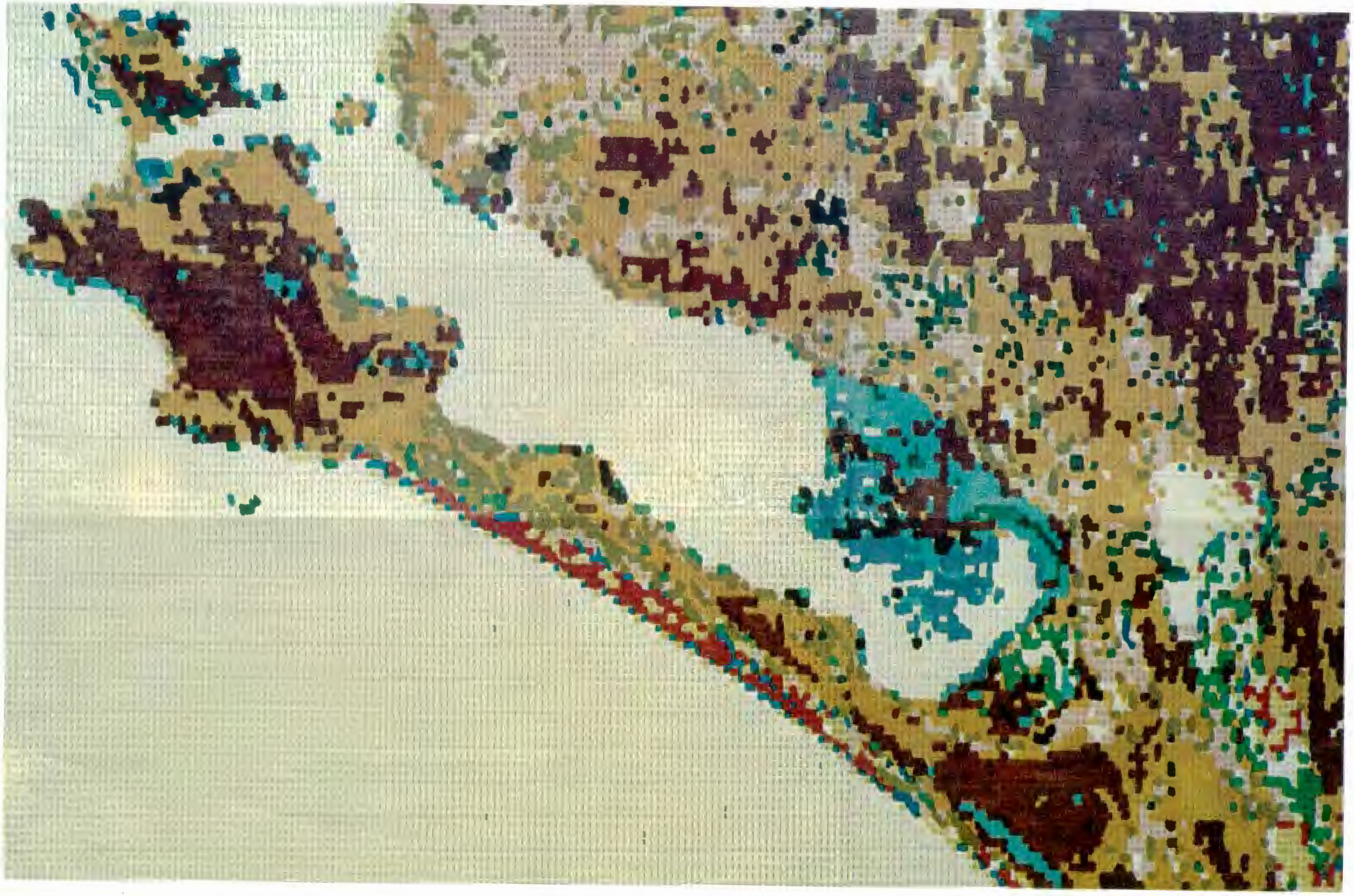

Figure 3.3 Classification of the Langebaan-Saldanha area carried out at 1:50 000 scale from CCT 10055 - 08064, 16 September 1972, using statistics generated from a number of test areas.

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)

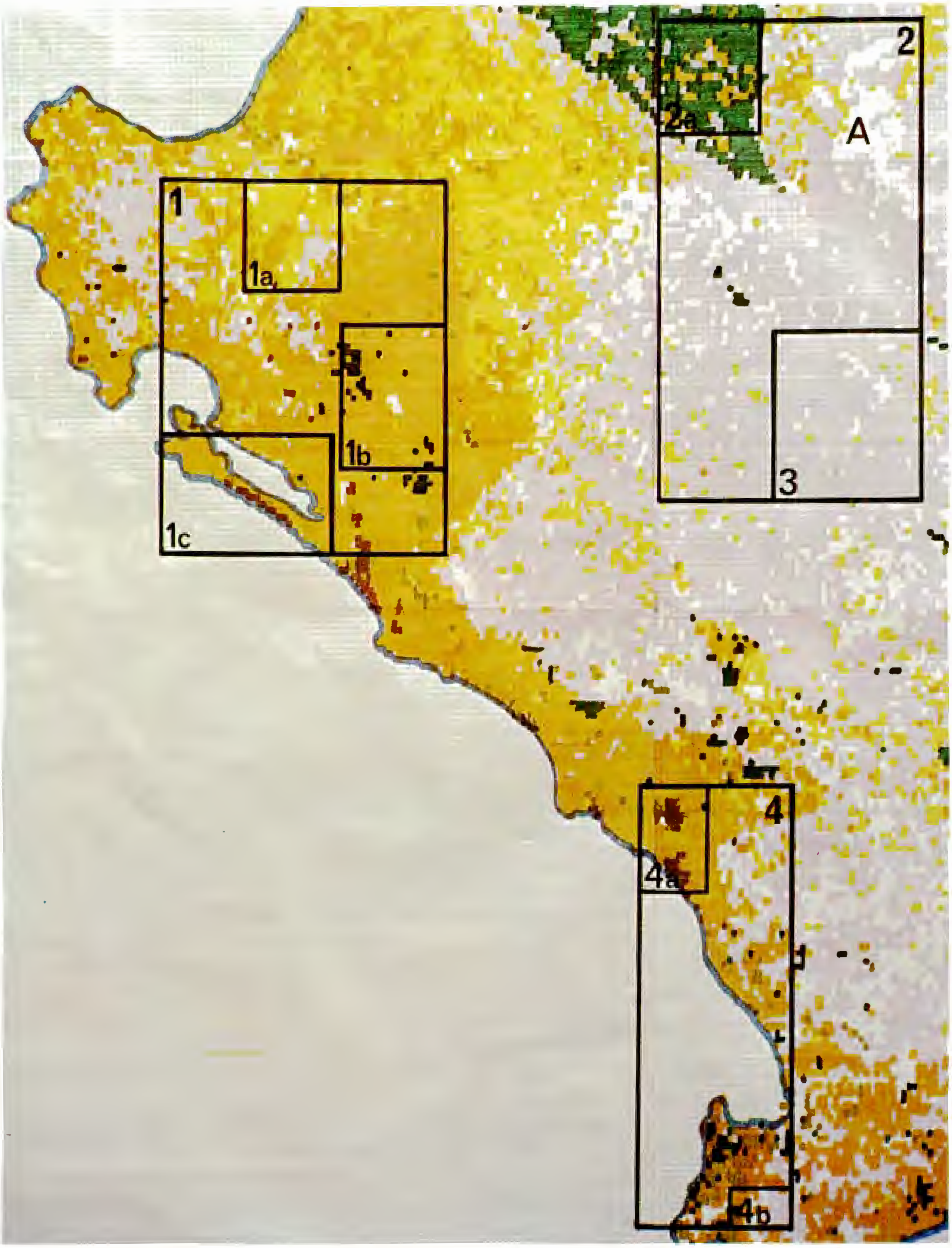

Figure 3.4 Classification of CCT 10055-08064 16 September 1972 carried out at 1:250 000 scale, showing test areas used in classification (7 map classes).

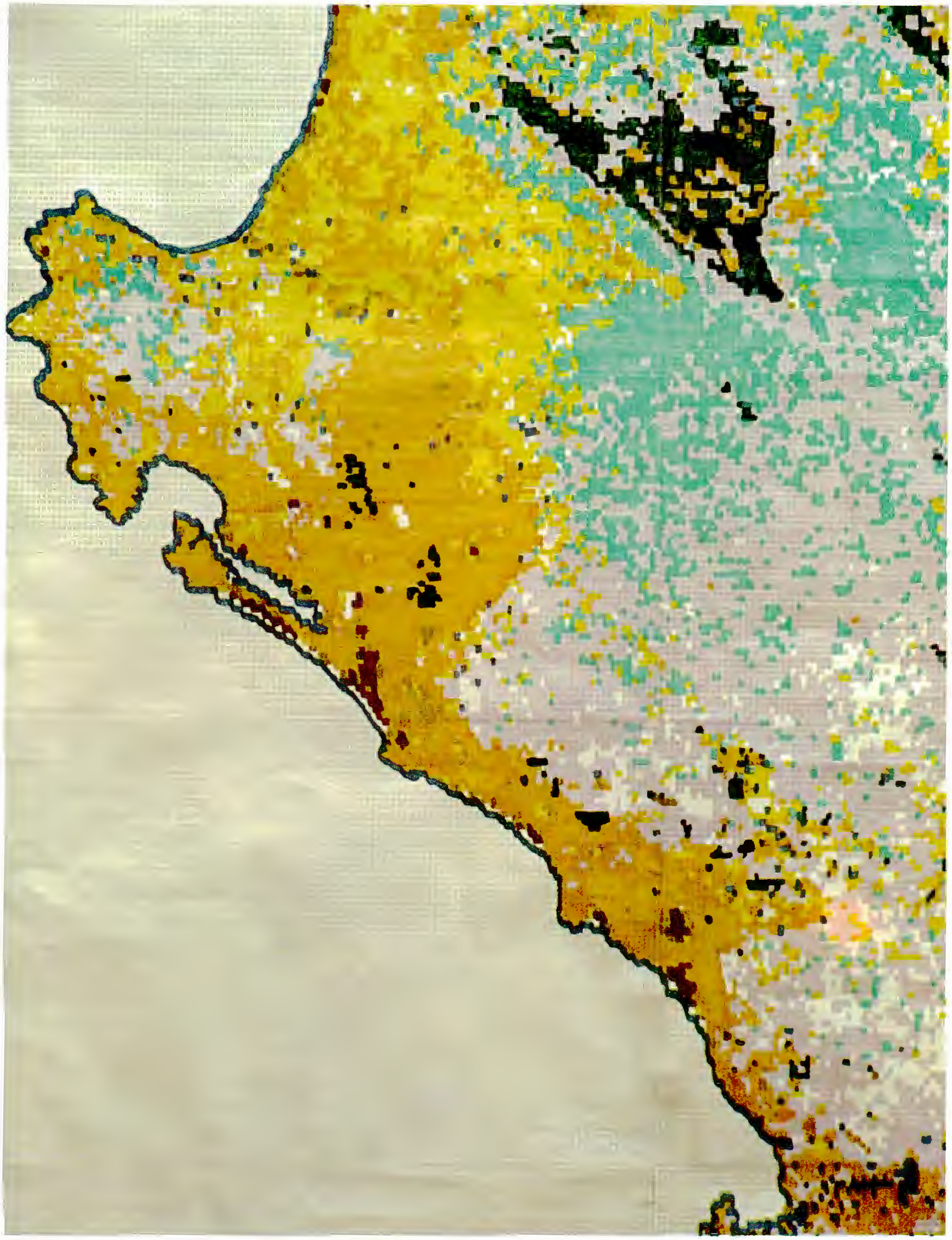

Figure 3.5 Classification of CCT 10055 - 08064 16 September 1972 carried out at 1:250 000 scale. This is an eight class classification.

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.

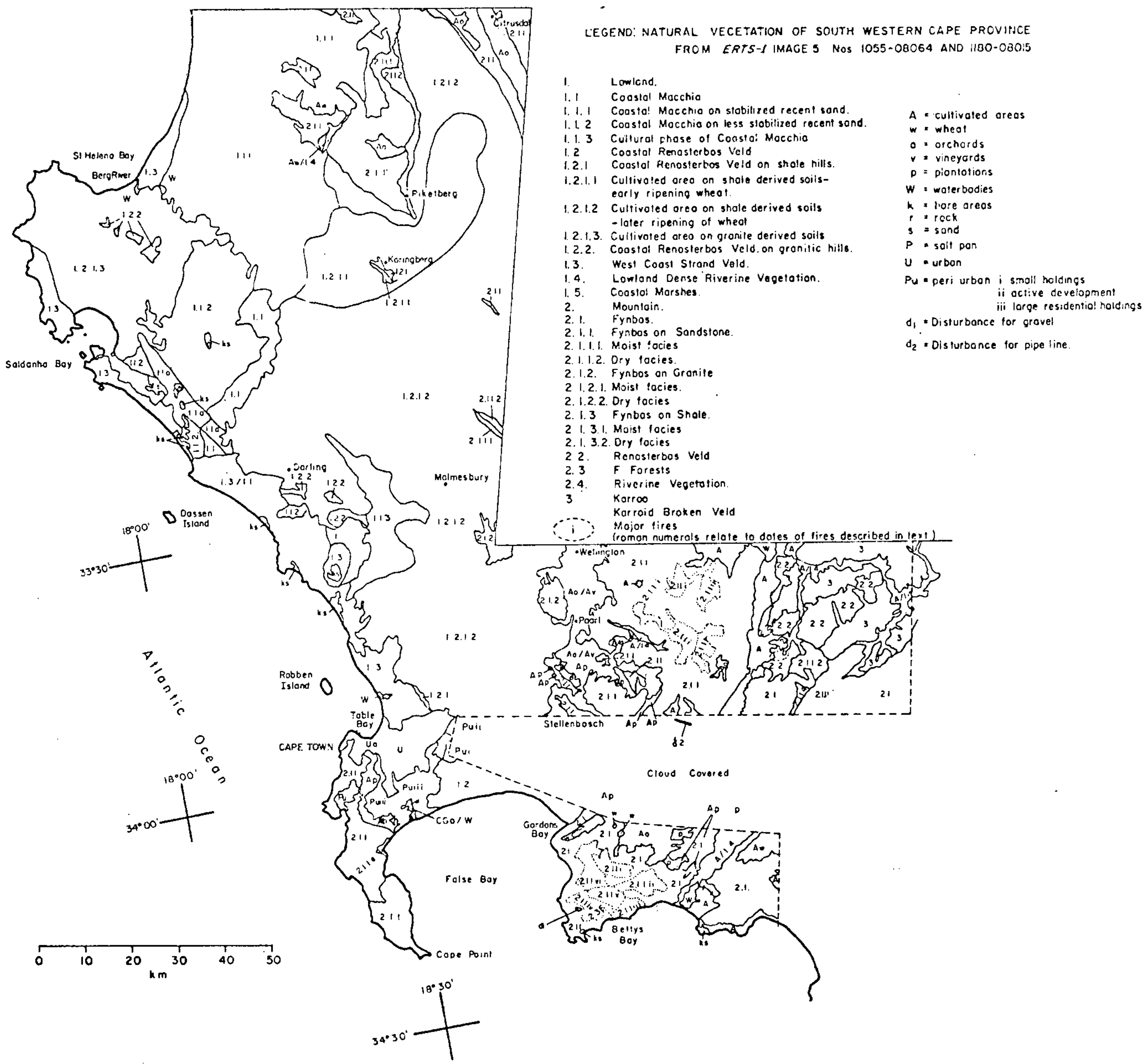

Figure 3.7 Natural vegetation of south western Cape Province from LANDSAT No's 10055 - 08064 and 10180 - 08015 (Taylor and Boucher 1973).

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

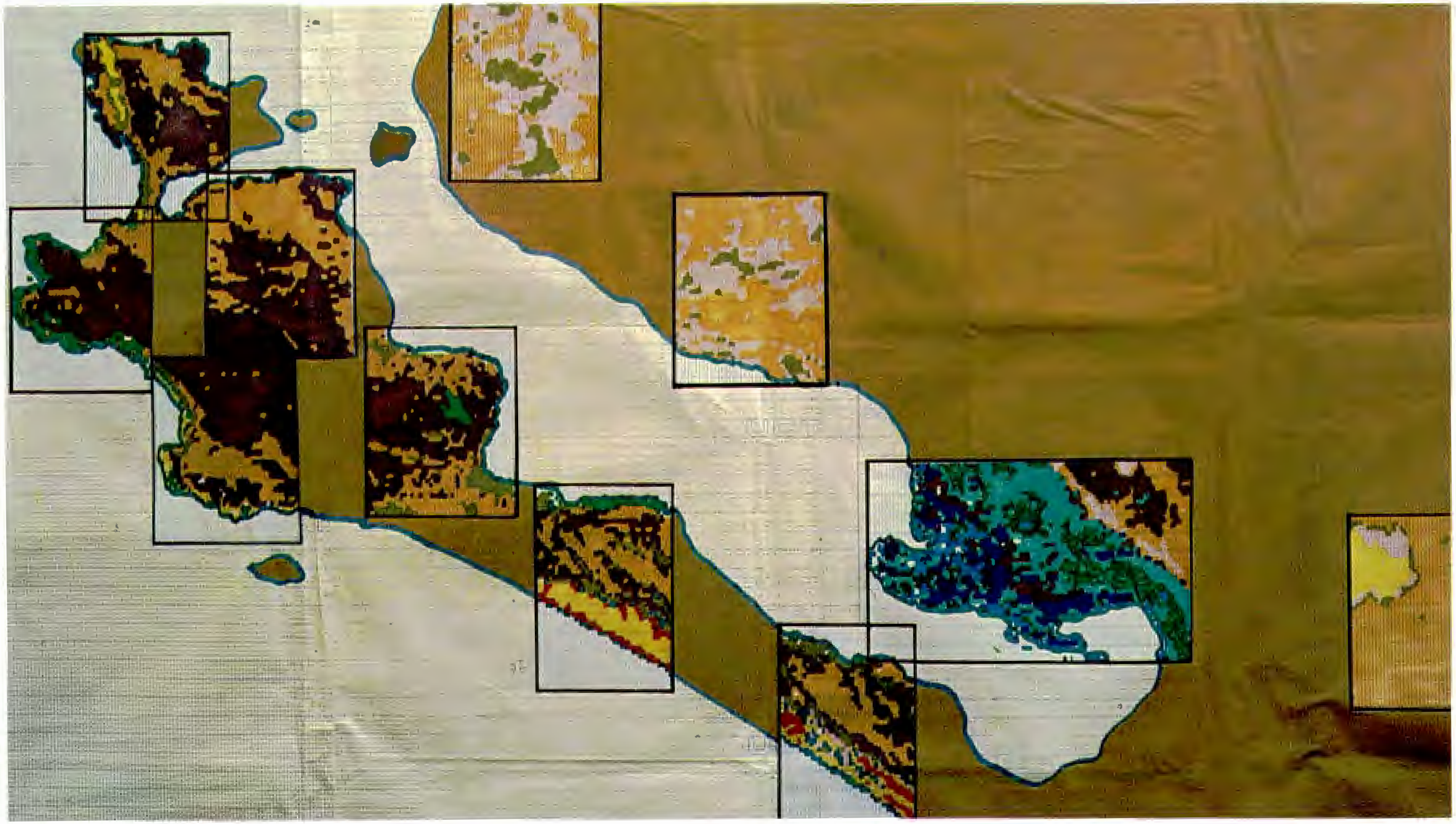

Figure 3.8 Single wave band printout at 1:20 000 scale showing test areas used in classification of Langebaan-Saldanha area of CCT 10055-08064, 16 September 1972.

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

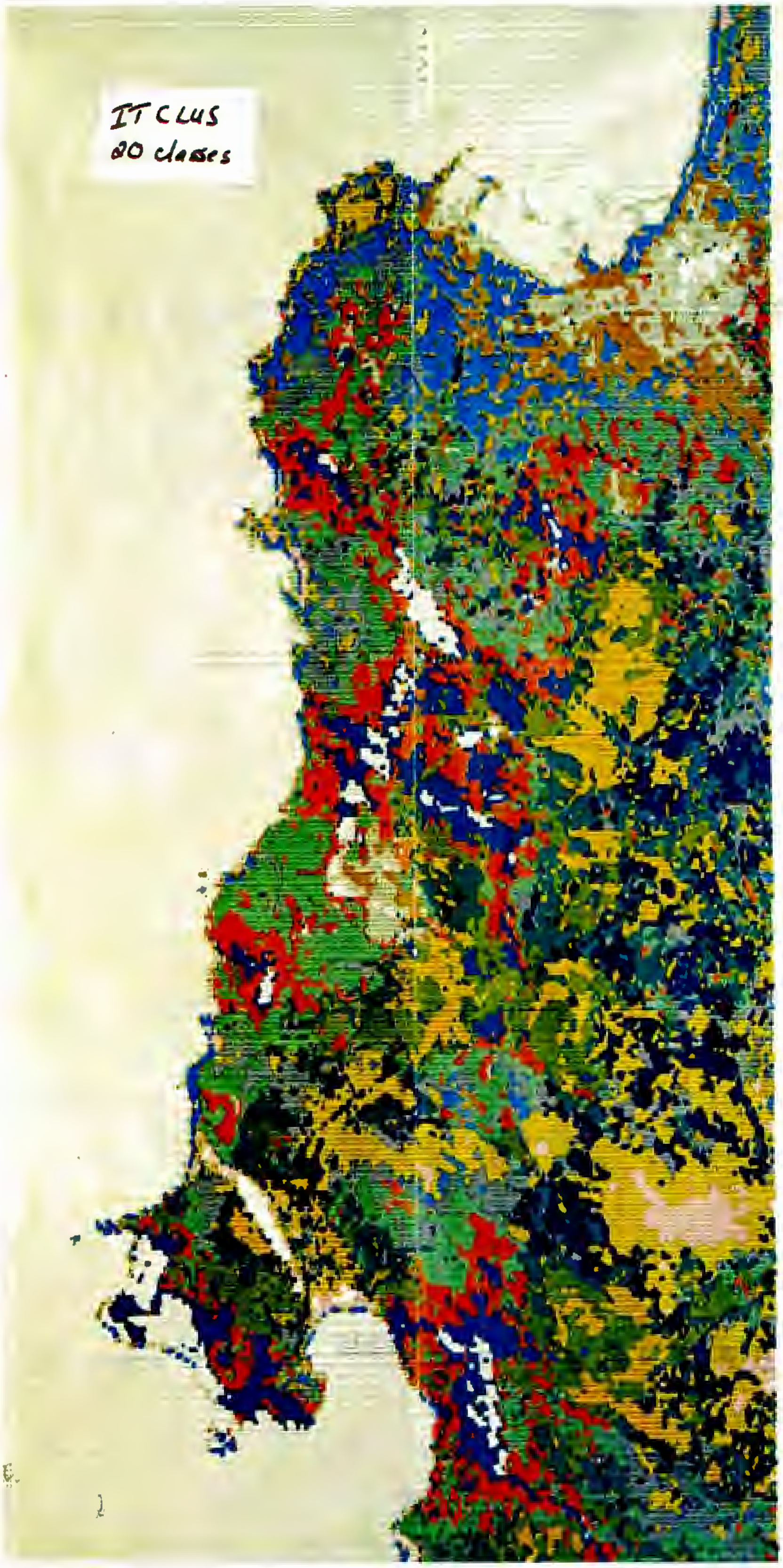

Figure 3.10 Classification of the Table Mountain area carried out at 1:20 000 scale from CCT 10180 - 08015 of 19 January 1973.

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

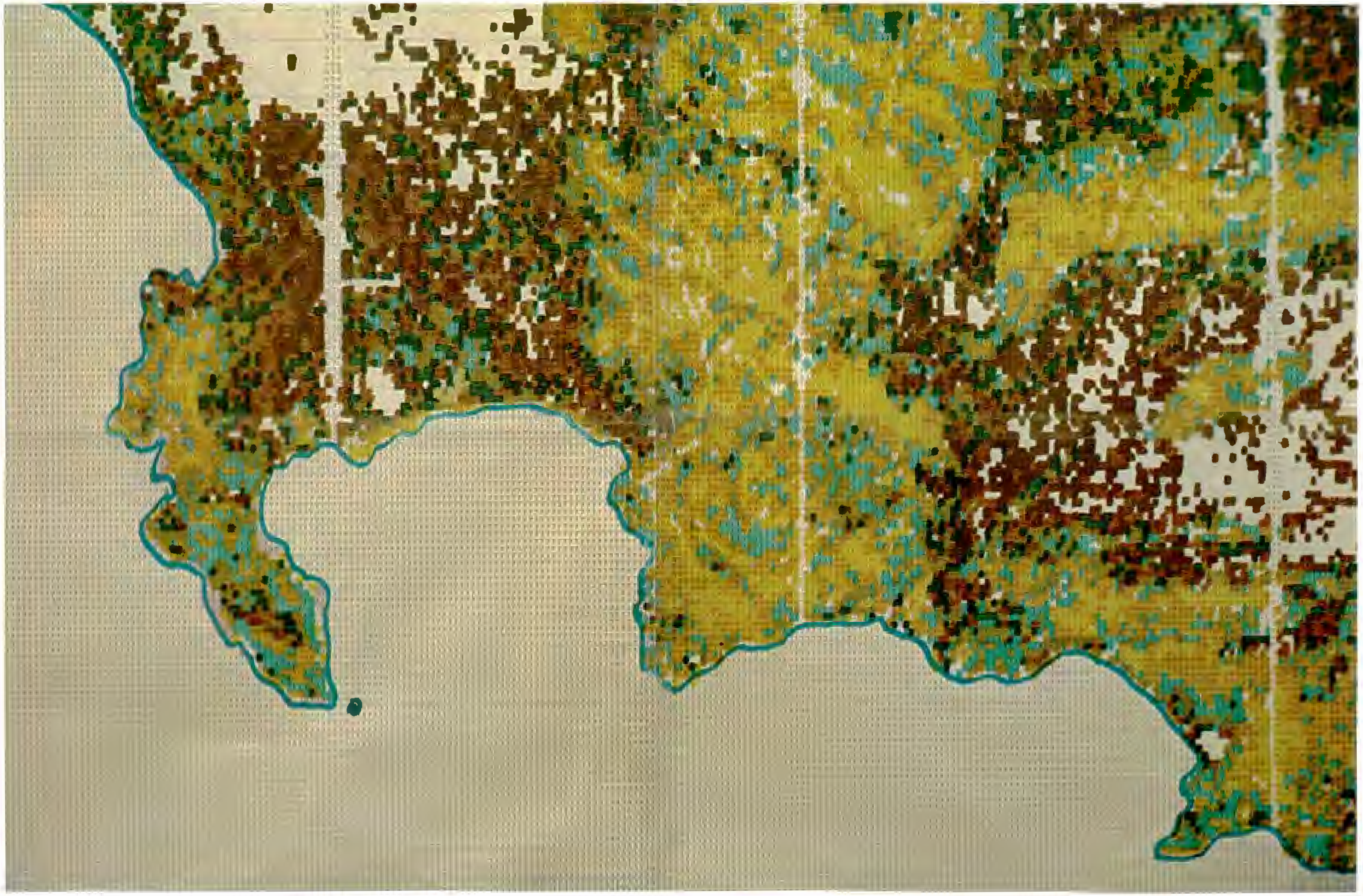

Figure 4.1 Classification of CCT 30271 - 07511 of 1 December 1978 carried out at 1:250 000 scale. Band 5 on this CCT was recorded in high gain mode. This is a ten class classification.

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

(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)

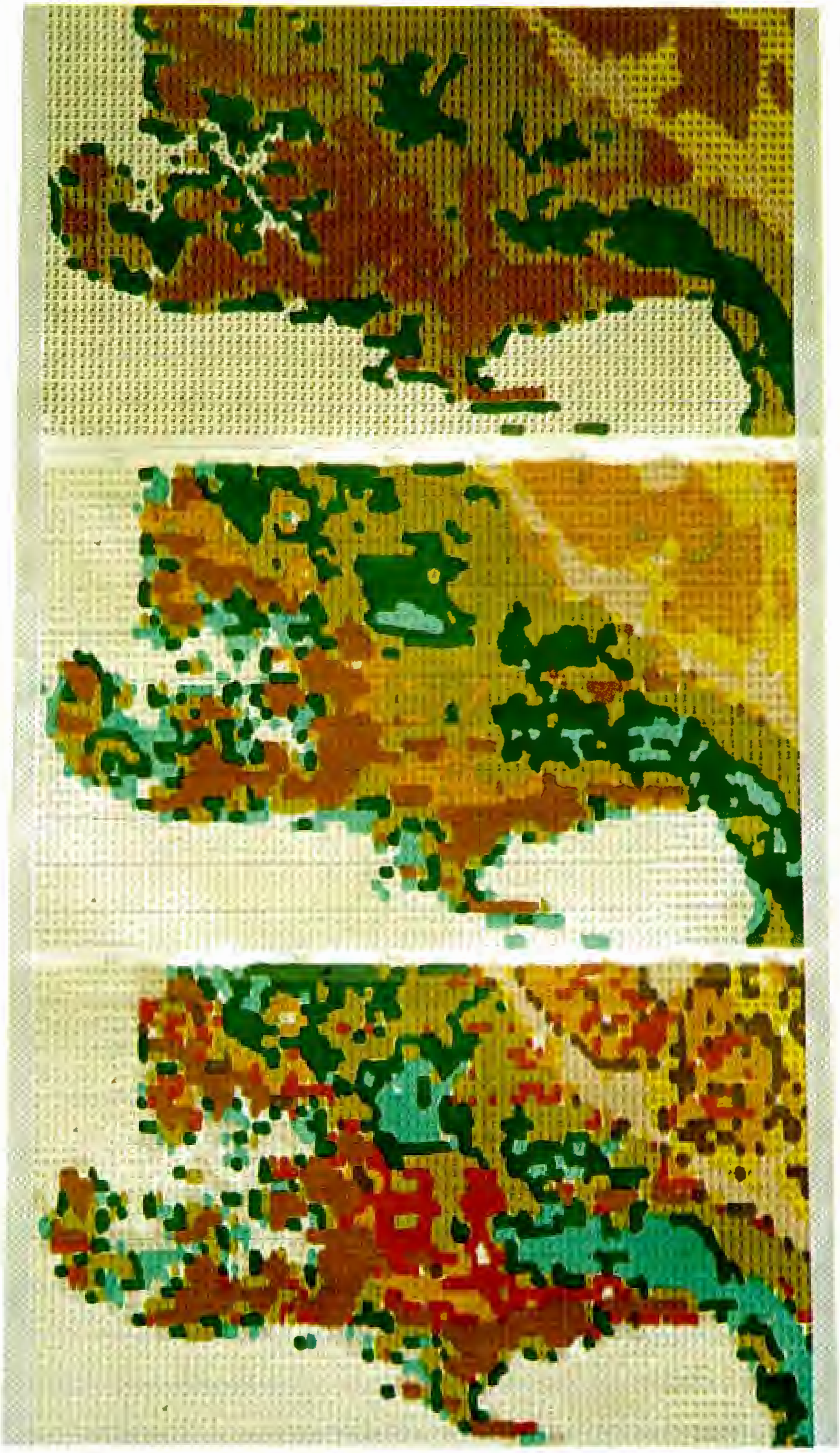

Figure 3.11 6, 10 and 15 class classifications of the marsh area, Langebaan Lagoon from CCT 10055 - 08064 16 September 1972, carried out at 1:10 000 scale.

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 von 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.

6. REFERENCES

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7. APPENDIX : EXPANDED CONTENTS PAGES

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8. ACKNOWLEDGEMENTS

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