THE FEASIBILITY OF USING LANDSAT TM IMAGERY FOR LONGTERM VEGETATION MONITORING IN THE FYNBOS BIOME.

By

J.D.F. Kotzé

Thesis project submitted in partial fulfillment of the requirements for the degree of Masters of Science (Nature Conservation) at the University of Stellenbosch.

1 July 1999

Project Supervisor: Dr. N. Fairall

DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis project is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

SUMMARY

Those who would successfully manage the fynbos biome require management oriented information. Managers, strategic planners and researchers often lack information about fynbos areas and changes that occurs in these areas upon which they can, with reasonable confidence, base decisions. Landsat Thematic Mapper (TM) data provides a potentially strong base to work from. The objective of this project was to determine the feasibility of using TM imagery to quantify fynbos communities within a specific area that can be used for the long term vegetation monitoring in the fynbos biome. TM imagery have advantages over other data sources such as aerial photography, for large area land cover classifications, in part because of their frequent repeat cycles, large-area sample, wide spectral range, cost effectiveness and amenability to automated classification. Considering the very detailed scale the study was done at, another objective of the project was to determine the feasibility of using TM imagery to quantify fynbos communities at a far more detailed scale than the recommended operating scale for TM imagery. At this detailed scale fynbos vegetation can be managed effectively in the long term. A small scale vegetation and vegetation community study of the study area was done to obtain a detailed ground map. The vegetation communities as defined by image processing of the TM data was compared with the accurate ground map. By means of this comparison it was shown that TM imagery could be used effectively to obtain a detailed fynbos community description of a fynbos area at the desired scale. Another objective of the study was to determine the feasibility of Principal Component Analysis (PCA) to reduce the amount of natural variation and noise within TM imagery. It has been shown that PCA can be used effectively to achieve the latter and by doing so, baseline imagery can be obtained for a specific area and time period in terms of its vegetation communities, while portraying the maximum environmental variation within the imagery. The final part of the study entailed the determination of the feasibility of using TM imagery to determine vegetation change over time. It has been shown that TM imagery can be used effectively for this purpose. This resulted in some very interesting findings, especially with the recovery of burnt fynbos areas. The objectives of the study have been met and this scale of monitoring holds much promise. Further application is warranted in different areas as well as with additional thematic data.

Opsomming

Diegene wat die fynbos bioom suksesvol sal bestuur vereis bestuursgerigde inligting. Bestuurders, strategiese beplanners en navorsers ondervind gereeld tekorte aan informasie oor spesifieke fynbos gebiede asook veranderinge wat plaasvind in hierdie areas om hulle instaat te stel om grondige besluite te neem. Landsat "Thematic Mapper" (TM) data verskaf 'n baie sterk potensiële basis om vanaf te werk. Die doelwit van hierdie projek is die bepaling van die toepaslikheid van TM data om fynbos gemeenskappe binne 'n spesifieke area te kwantifiseer en dus sodoende hierdie data aan te wend vir langtermyn montering in die fynbos bioom. TM data het voordele bo ander data bronne soos lug fotos, vir die klassifikasie van grondbedekking oor groot areas, a.g.v. die gereelde beskikbaarheid van data, wye spektrale dekking, koste effektiwiteit en die eenvoudige en effektiewe gerekenariseerde verwerkbaarheid van data. Inaggenome die gedetaileerde skaal waarop die studie gedoen is, was 'n ander objektief van die studie die bepaling van die vermoeë van TM data om fynbos gemeenskappe te kwantifiseer op 'n ver meer gedetaileerde skaal as die normaal aanbevole skaal. Op hierdie skaal kan fynbos plantegroei effektief bestuur word oor die langtermyn. 'n Indiepte plantegroei en plantegroeigemeenskap studie van die area is gedoen om 'n baie akkurate plantegroeikaart van die area te verkry. Plantegroeigemeenskappe soos verkry met beeldverwerking is vergelyk met die akkurate plantegroeikaart. D.m.v. hierdie vergelyking is dit bewys dat TM data effektief gebruik kan word om 'n gedetaileerde fynbos gemeenskap beskrywing van 'n area te verkry teen die verlangde skaal. Nog 'n mikpunt van die studie was om die effektiwiteit van Hoofkomponent Analise (PCA) te bepaal om natuurlike variasie en geraas in TM data te verminder. Dit is gewys dat PCA effektief gebruik kan word om laasgenoemde doelwit te beryk en sodoende is basislyn data verkry vir 'n spesifieke area en periode in terme van plantegroeigemeenskappe, terwyl die maksimum omgewings variasie behou word. In die finale gedeelte van die studie is die effektiwiteit van TM data bepaal om plantegroei verandering oor tyd te monitor. Dit is bewys dat TM data effektief aangewend kan word vir laasgenoemde. Dit het gelei tot die verkryging van baie interessante resultate, veral in die geval van die herstel van gebrande fynbos areas. Die mikpunte wat daar gestel is vir die projek is bereik en die skaal van monitering lyk baie belowend. Verdere aanwending van die resultate is geregverdig in ander fynbos areas asook met adisionele satelliet data.

Acknowledgements

No study can be taken in isolation, and I am grateful for the willing assistance that I have received from all quarters.

In particular, my promoter Dr. Neil Fairall, for always providing guidance and his willingness to assist me with the project at any time and place. For supplying advice and information and sharing his passion for nature conservation and incredible knowledge and wealth of experience with me. My only regret being that there wasn't more time to tap into this vast source of information.

The staff at De Hoop Nature Reserve for their support and assistance. In particular, Ben Swanepoel, Roelof and Liz Jalving, Paul Bothma, Rory and Eileen Allardice, Nicky Hess and Mike Dowry. Two very special friends and staff members, namely Werner and Rushenca Fourie, with whom I often had very late nights during which we often solved all nature conservation's problems.

Chris Burgers at Cape Nature Conservation Scientific Services in Jonkershoek for always being willing to help.

Chris Martens and Duncan Heard of Cape Nature Conservation for allowing me to do this project in such an incredible and lovely place as De Hoop.

For my parents a special word of thanks. I don't think they ever understood or will ever understand why I did this project, but they have always supported me in whatever possible ways they could and in more ways that they would ever realize.

A very special person in my life, Inge Mitchell for her love, patience, friendship, support and for always being there. For sharing many adventures with me at De Hoop and exploring and discovering as much as possible of such an incredible place in such little time. But for most of all for understanding and knowing why.

TABLE OF CONTENTS

LIST OF APPENDICES

Appendix 1

The one page summaries of all the quadrat data as they were sampled and described within their various communities within the study area. Also included is the summary of the description of the quadrats within the burnt area that is to the east of the study area.

Appendix 2

The one page data matrix of all the areas sampled and described within the study area, including the burnt area.

Appendix 3

TWINSPAN classification of the 7 different communities as identified during fieldwork and the sampling process within the study area.

Appendix 4

TWINSPAN classification of the Euchaetis, Erica, Thatch, Passerina and Fire community quadrat data, including the Fire community quadrats' soil features.

Appendix 5

TWINSPAN classification of the Euchaetis, Erica, Thatch, Passerina and Fire community quadrat data, excluding the Fire community quadrats' soil features.

Appendix 6

The Principal Component analysis (PCA) results as obtained for the different data sets. Component 1 obtained from each of the PCA's was used to obtain the representative imagery for the various years.

Chapter1

Introduction

Every time that I have gone up in an aeroplane and looking down have realized that I was free of the ground, I have had the consciousness of a great new discovery. "I see," I have thought. "This was the idea. And now I understand everything."

- Isak Dinesen

Land-use planning, management and conservation strategies must be based on sound plant ecological principles (Schulze, Theron and Van Hoven 1994). To facilitate optimal resource utilization in general and to assess the conservation status of the vegetation in particular, a detailed identification, classification and mapping of the vegetation of a region should be undertaken (Fuls, Bredenkamp and Van Rooyen 1992).

The Cape fynbos vegetation found in the south-western, southern and south-eastern Cape, has a rich floral diversity with more than 8 500 plant species, accounting for almost 10% of the plant species of the world. More than 70% of these plant species are endemic, growing nowhere else in the world. With these figures in mind it is clear that the fynbos vegetation is very unique and should be conserved (Bossi 1984, Cowling, Holmes and Rebelo 1992). The need for conservation becomes urgent when it is considered that a large number of these fynbos plant species face possible extinction. The threat to the fynbos vegetation has occurred mainly through clearing of land for agriculture and development, invasion of alien plant species, uncontrolled and unmanaged veld fires and general neglect. For effective conservation planning, management and research to be done to ensure the long term existence of the fynbos biome it is necessary to put in place an effective monitoring system for fynbos.

The objective of any monitoring program is to ensure that management, research and planning decisions are based upon accurate and relevant information within specified financial and time period limitations. Satellite based remote sensing has the technical capability to be used for the spatial assessment of landscape characteristics and thus natural resource monitoring (Williams and Carter 1976, Short 1982, Short and Stuart 1982, Richason 1983, Holz 1985, Lo 1986, Short and Blair 1986). Because of its multispectral capabilities, satellite remote sensing presents a unique perspective for observation and measurement of biophysical characteristics (Colwell 1983). This study will attempt to determine the feasibility of using Landsat Thematic Mapper (TM) imagery as an operational monitoring tool in South Africa by resource managers, researchers and planners with specific reference to the conservation of the fynbos biome.

Satellite image data have advantages over other data sources such as aerial photography, for large area land cover classifications, in part because of their frequent repeat cycles, large-area sample, wide spectral range, cost effectiveness and amenability to automated classification (Lulla and Mausel 1983, Bolstad and Lillesand 1992). Several studies have established the utility of digital image data obtained from the Landsat Thematic Mapper (TM) satellite for automated vegetation classification (Nelson, Latty and Mott 1984, Shen, Badhwar and Carnes 1985, Horler and Ahern 1986, Vogelman and Rock 1986, Hopkins, MaClean and Lillesand 1988, Moore and Bauer 1990, Dymond, Page and Brown 1996, Apan 1997, Langford and Bell 1997).

Landsat TM imagery however has certain limitations. Landsat data capture is weather dependant and therefore the frequency of successful satellite image acquisition during the cloudy Cape winter is low. This limitation could have serious implications, depending on the monitoring objectives, since the active growth period for fynbos is during winter and spring, during and after the winter rain period. Monitoring objectives such as burn mapping activities at the end of the dry summer would not be hampered and the possibility does exist of obtaining cloud free imagery during the winter period. Another limitation is that Landsat imagery cannot equal the fine spatial detail available with large scale aerial photography. Even though these limitations can hamper the effective use of Landsat TM imagery for monitoring purposes, the mentioned advantages far outweigh the disadvantages. With the use of Landsat TM imagery the objectives of the applicable study or project must be considered in relation to the capabilities of Landsat TM imagery and thus the suitability and the feasibility of using TM imagery for the specific project.

The choice of Landsat TM imagery to be used in this study is based solely upon the required mapping scales, repeat cycles, technical capabilities, image coverage and cost limitations. The inherent distortions associated with aerial photography and the time-consuming task of creating orthophoto products are possibly the greatest drawback in the use of such data for routine monitoring purposes. Computer based geographic information systems (GIS) are the ideal tool for managing the spatially related databases associated with resource monitoring. Digital satellite imagery has the distinct advantage in comparison to analogue photographic data, of being immediately compatible with digital GIS databases, allowing direct data integration and analysis.

The area coverage provided by a single Landsat TM image is 185x185 km and thus 34 225 km². In relation to the proposed fynbos monitoring region in the Western Cape, a single TM image provides coverage from approximately Saldanha (NW) to Cape Point (SW) to Touws River (NE) to Gans Bay (SE). The size of the coverage provided by a single TM image is of such a nature that it is possible to cover the total area of the fynbos biome, being approximately 74 500 km², effectively by means of very few Landsat TM images (Bossi 1984).

By definition, a satellite monitoring program will be based upon a series of mapping activities. It is the comparison of these multitemporal mapping activities that provides the monitoring capability. Mapping accuracy is therefore a critical component of monitoring accuracy, and the ability to determine the rate and extent of natural resource change over time (Thompson 1993). Landsat TM imagery can provide very detailed maps, but only at the intended scales of the data. It is therefore very important to define beforehand the mapping accuracies required for a specific survey and thus to determine the capabilities of the data to be used. Mapping accuracy is a factor of both the level of classification and cartographic scale of the survey. Classification levels can vary between broad, generic surveys aimed at mapping, for example, the total extent of fynbos with respect to other land uses on a regional basis (Moll and Bossi

1984, Jarman 1985); or mapping detailed fynbos community structures in a specific location.

The optimal scale of remote sensing will vary with the objectives of the analysis and the inherent characteristics of the landscape in question. Community level information is essential to ecosystem studies, and it is apparent that remote sensing offers a capability for identifying community characteristics (e.g. pattern, extent, vigor, and disturbance) from a synoptic perspective (Turner and Gardner 1991). The objectives of this study were to determine the feasibility of using Landsat TM imagery to identify the various vegetation communities that occur within a fynbos area and thus the long term monitoring of such fynbos areas. The minimum area to be used in this study comprised a selected area of 1 730 ha within which a study area of 900 ha is included. This is a fairly small area to be used for the detection of fynbos communities by means of Landsat TM imagery. The ideal operating range for Landsat TM data is at a scale of 1:50 000 to 1:250 000 (Thompson 1993). Considering that the most detailed scale to be used in this study is 1:25 000, it can be considered that another objective of the study is to determine the feasibility of Landsat TM imagery to quantify fynbos communities at a far more detailed scale than the recommended operating scale for TM imagery.

All satellite data is based on a grid structure, i.e. pixels, it follows that minimum mappable areas and maximum operating scales are directly dependant on the grid size. The structure and function of a landscape can be perceived differently at different scales, and it is important for the observer to decide upon appropriate scales for a study (Allen and Hoekstra 1988, Turner, Dale and Gardner 1989). It is also important to recognize that the concepts of heterogeneity are scale dependent because they describe how individual land cover components or processes are interrelated across a landscape (Meentemeyer and Box 1987, O'Neill, Milne, Turner and Gardner 1988). For efficiency in cost, data processing time, and analysis, it is necessary to choose the broadest scale data available for identifying the landscape characteristics under consideration (Quatitrochi and Pelletier 1991). In remote sensing, spatial resolution, or the ability of a sensing system to resolve objects on the ground is analogous to pixel size. The selection of the spatial resolution of the remotely sensed data to be used is a question of importance concomitant with that of scale. Of concern is the effect of mixed pixels, where the spatial resolving power of the sensor is too coarse to capture the intrinsic spatial heterogeneity of a landscape. If the spatial resolution of a sensor is too coarse, that is too big a pixel size, it will combine signatures from independent objects on the ground into an aggregated spectral response for a particular pixel. Thus a heterogeneous landscape can become more homogeneous by virtue of a sensor's pixel ground resolution. More spatial resolution, that is a smaller pixel size, however, is not necessarily better. If spatial resolution is too fine, objects may appear more heterogeneous than they really are; this misinterpretation masks their inherent homogeneity.

In an area of heterogeneous land covers, spectral responses for different objects within the given 30 m pixel of Landsat TM imagery will be averaged or aggregated into a composit spectral response for any particular pixel that falls over a specific area on the ground (Quatitrochi and Pelletier 1991). Assuming that the smallest identifiable feature is equivalent to the individual pixel size, and that its ground location could overlap four adjacent pixels; the minimum mappable unit for TM imagery is 0.5 ha. These are however theoretical levels, and in practice it is likely to be between 2-5 ha for Landsat TM imagery depending on landscape structure (Thompson 1993). In this study it was assumed that if it proves feasible to use Landsat TM imagery to quantify fynbos vegetation communities it will be possible to obtain the theoretical minimum level of identification, namely 0.5 ha and therefore it would be possible to quantify very small vegetation communities. This specific minimum identifiable area of 0.5 ha has been considered as being the ideal size for vegetation community identification in the study. This decision is based upon obtaining results at a realistic scale that is user friendly and interpretable by managers and other possible users and thus would result in the effective and long term use of the data.

One of the most important attributes of remote sensing, is the ability to detect and observe temporal changes in habitat conditions (Quatitrochi and Pelletier 1991). To adequately address temporal dynamics would involve the acquisition of remotely sensed data over time as a means for detecting and measuring change. The frequency of each mapping activity making up the monitoring program is important, defining the temporal accuracy of the survey and the ability to monitor weekly, seasonal, annual or greater time period changes in resource status. The frequency of the survey must be linked to the information requirements. For example, whereas two to three year intervals may suffice to monitor the overall loss of fynbos due to agriculture or other human activities, an annual assessment is necessary if accurate data is to be derived on burn severity and frequency. The sixteen-day acquisition period of Landsat data are often sufficient for relatively infrequent analysis (seasonal or longer) or for baseline ecological characterization. Because satellite systems can typically acquire great amounts of data that can be spatially rectified and processed, characterizing the temporal dynamics of large areas may be easier with remote sensing than through traditional field approaches. Thus, most types of remotely sensed data lend themselves to broad-scale analysis on temporal frequencies not feasible in the past.

The mapping of invasive species encroachment is extremely important for the successful management and conservation of the fynbos, and as such receives a high priority. The maximum operating scale of both photographs and satellite imagery will obviously limit the minimum area of infestation that is identifiable. This is important since the smaller more isolated patches of alien species are also key seed dispersal points, and the success of their identification could determine the success of conservation management. The objectives of this study is to determine the feasibility of Landsat TM imagery to quantify fynbos communities within an area to enable the monitoring of such an area in terms of vegetation change over time. The identification of alien species communities is thus not a direct priority in the study, but the results obtained will determine the feasibility to use Landsat TM imagery to identify such alien vegetation communities at a fairly detailed scale and thus to effectively monitor and manage them.

Fire is the principal driving force in fynbos dynamics for both sustaining indigenous flora and controlling invasive species (Van Wilgen, Everson and Trollope 1990). To a very large extent, resilience at the level of species, communities and ecosystems is determined by the fire regime (Richardson and Van Wilgen 1992). In most areas, managing fynbos therefore equates to managing fire (Forsyth and Van Wilgen 1993). Management options include varying the season, frequency, intensity and size of fires and deciding on how best to reconcile ecological and practical requirements. Fire management in fynbos areas is further complicated by invasive alien tree and shrub species. Effective incorporation of alien species control measures into fire management plans is probably the greatest challenge facing managers (Forsyth and Van Wilgen 1993). Satellite remote sensing can provide accurate delineations of fire scar boundaries (Morin, Derenyi, Wein and Yazdani 1988). Satellite derived fire scar maps also offer the capability to improve existing management plans and reports. Wildfire mapping using both Landsat TM and Multi Spectral Scanner data has illustrated significant differences between generalized management field reports and actual fire scar boundaries (Thompson 1993). The objectives of this study is to determine the feasibility to use Landsat TM imagery to quantify fynbos communities within an area and thus the long term monitoring of such an area. The objective is not to do fire scar mapping of an area, but with fire being such an integral part of fynbos, it forms an essential part in the long term monitoring of a fynbos area. If it proves feasible to use TM imagery to map fynbos communities, fire scar mapping can be included within this monitoring process for effective future management and planning and the effective recovery monitoring of fynbos communities after a fire over the long term.

In summary, the objective of the study has been made clear, namely to determine the feasibility of using Landsat TM imagery to quantify fynbos communities within a specific area and thus the long term monitoring of fynbos areas. The spatial and temporal scale for the planned study has been made clear. Some of the most important potential benefits for the use of Landsat TM imagery, if it proves feasible to monitor fynbos areas, have been highlighted, namely alien vegetation and fire scar identification and the effective management of these features. The great paradox of the present environmental crisis is the large gap between the increased accumulation of knowledge on the environment, on the one side, and the lack of applicability of research results (or unwillingness to apply them) on the other side (Di Castri and Hansen 1992). At this level vegetation can be understood by researchers, planners and managers and thus used effectively in the long term management of the fynbos biome.

Chapter 2

Study Site

Wilderness is not dependent upon a vast, unsettled tract
of land. Rather, it is a quality of awareness, an openness
to the light, to the seasons, and to nature's perpetual renewal.

- John Elder

2.1 Introduction

The area used in the study is situated in the De Hoop Nature Reserve. De Hoop was proclaimed in 1957 after the farms De Hoop and Windhoek were obtained by Cape Nature Conservation. Several further extensions have been made to De Hoop by the purchasing of farms and the inclusion of the Eastern Section of the Overberg Test Range (OTR, DENEL) (Hey 1995). De Hoop also comprises a marine component and the De Hoop Marine Reserve was proclaimed in October 1990. De Hoop presently consists of a total terrestrial area of approximately 38 000 ha and a marine reserve of approximately 25 300 ha. The reserve is managed by Cape Nature Conservation.

De Hoop is one of the most important protected areas in the Western Cape. On a biome level the reserve is particularly important in protecting a large representative and viable area of Limestone Fynbos and Dune Fynbos, many threatened and locally endemic plant species, the De Hoop Vlei and a large section of coast in the marine reserve. The Mountain Fynbos on the Potberg is also of special significance with at least fourteen locally endemic plant taxa (Hardcastle 1996).

2.2 Reserve location and description

The De Hoop Nature Reserve and Marine Reserve are situated in the Overberg region about 50 km east of Bredasdorp and 50 km south of Swellendam in the Western Cape Province of South Africa (Figure 2.1). The co-ordinates of the reserve effectively lie between latitudes 34°21'40" S and 34°30'12" S, longitudes 20°18'54" E and 20°52'20" E.

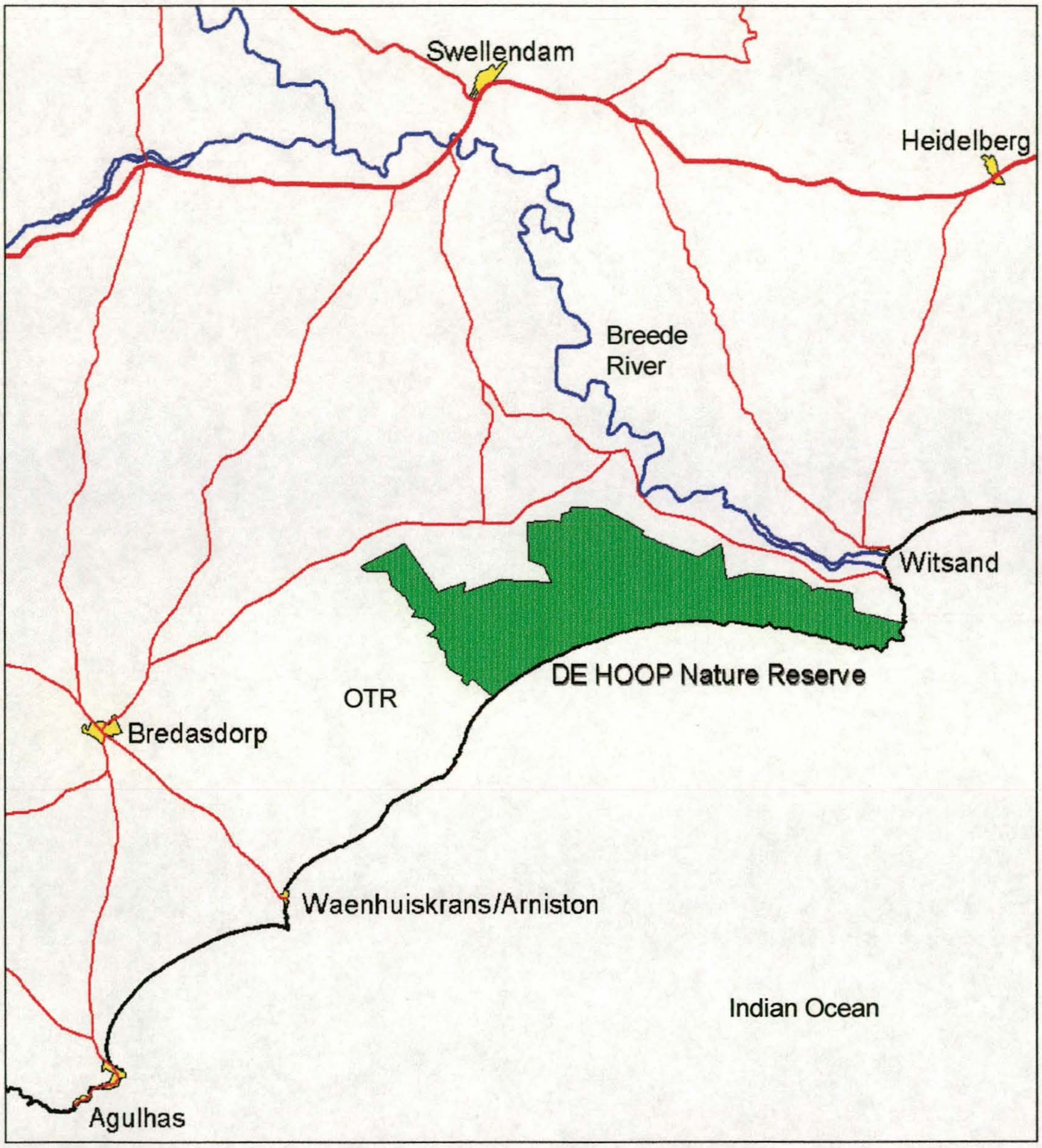

Figure 2.1 Location of the De Hoop Nature Reserve in the Western Cape.

The reserve is bordered by farms to the north, a private nature reserve and the Breede River to the east, the Indian Ocean to the south and the Overberg Test Range (OTR) to the west. Figure 2.2 is a composite (bands 3,5 and 4) Landsat satellite image of the De Hoop area taken in 1997. Clearly visible in Figure 2.2 is the Breede River to the east of the reserve, the Indian Ocean to the south and the De Hoop Vlei to the west.

The northern boundary of the reserve is characterized by the high-lying terrain of the Potberg range and the "Harde Duine" (limestone hills) with a maximum height of 611 m and 224 m above sea level respectively. The land surface drops to the southwest in a series of four distinct terraces. These terraces, at elevation of 90-100 m, 60 m, 30-40 m and 15-20 m, are the result of marine transgressions. A narrow valley separates the Potberg from the "Harde Duine". The Sout River enters the reserve in the north-west and has cut a deep gorge through the "Harde Duine" to discharge into the De Hoop Vlei (coastal lake), which is separated from the sea by the Witsand dunefield (Figure 2.2).

2.3 Geology, geomorphology and soils

The basement geology of the area comprises sedimentary rocks of the Table Mountain Group (quartzites), Bokkeveld Group (shales and mudstones) and Uitenhage Group (mainly shale conglomerates) (Theron 1983). The resistant quartzite of the Table Mountain Group from the Potberg range remained, while the softer shales and conglomerates have been planed by marine transgressions into a gently southward sloping series of terraces.

The greater part of the reserve is underlain by Tertiary limestone of the Bredasdorp Formation. These limestones cover most of the Bokkeveld and Uitenhage basement rocks within the reserve. Only very small exposures of the Uitenhage Formation and Bokkeveld shales occur. The Bredasdorp limestones were deposited as shallow marine environments and as coastal dunes. The oldest deposits form the higher lying "Harde Duine", into which the coastal plain had been eroded during subsequent marine transgressions. Subsequent new dune systems were formed on the coastal plain. The most recent member

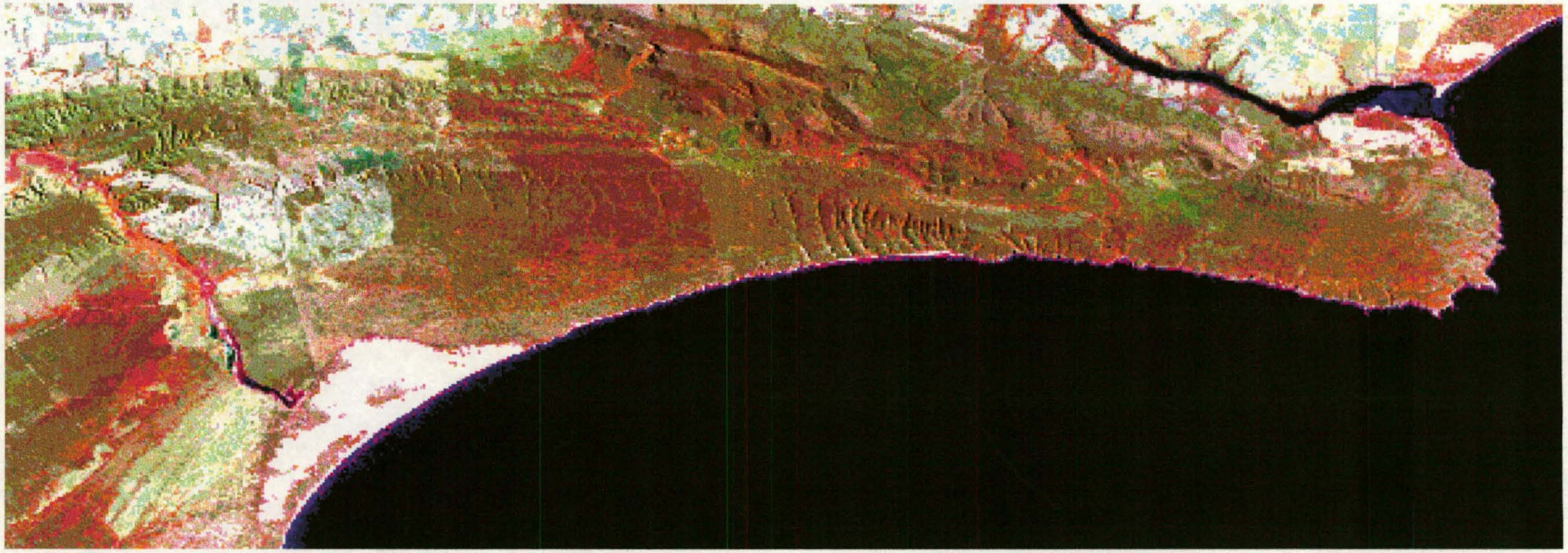

Figure 2.2 Landsat false colour composite image of De Hoop Nature Reserve. Visible on the image is the Breede River to the east and the De Hoop Vlei to the west.

of the Bredasdorp group was deposited within the last 10 000 years as a strip of unconsolidated dunes along the coast (Hendey 1983).

Dominant land type units are classed as rock areas with miscellaneous shallow soils. The substrate is either calcrete or quartzitic sandstone with a shallow sandy A-horizon (Lambrechts 1979, Schloms, Ellis and Lambrechts 1983). More limited areas of deep regic sands and other soils occur in the valley between Potberg and the limestone hills ("Harde Duine") and unconsolidated calcareous dunes along the coast. Very limited areas of eutrophic red plinthic soils are also present.

2.4 Vegetation

De Hoop falls within the Fynbos Biome. Acocks Veld Types Coastal Macchia (no. 47) and Macchia (no. 69) are the predominant veld types on the reserve with very small areas of Coastal Renosterveld (no. 46) and Knysna Forest (no. 4) (Acocks 1988).

According to the new vegetation classification for South Africa (Low and Rebelo 1996), three major vegetation types are recognized in the reserve, namely Limestone Fynbos (no. 67), Mountain Fynbos (no. 64), and Dune Fynbos and Dune Thicket (no. 4). Only very small areas of Laterite Fynbos (no. 66), South and South-west Coast Renosterveld (no. 63) and Afromontane (Knysna) Forest (no. 2) occur. The Milkwood thickets that occur on the reserve can be regarded as a form of Dune Thicket.

The reserve includes a very good representative range of the habitat variation within the Limestone Fynbos. This diversity is enhanced by the presence of a range of sandy forms of Limestone Fynbos from calcareous to neutral and acid sands overlying the limestone bedrock. A representative area of the mesic Mountain Fynbos is included in the reserve on the southern slopes of the Potberg and the highest peaks of the mountain. A good representative sample of Dune Fynbos occurs in the reserve along the coast on the system of recent dunes. Dune Thicket is present as interspersed patches in the Dune Fynbos as well as in coastal kloofs and below limestone cliffs. Milkwood thicket, which can be regarded as a form of Dune Thicket, is best developed along the De Hoop Vlei. Only very small remnants of South and South-west Coast Renosterveld and Laterite Fynbos are protected in the reserve. Only a very small patch of Afromontane Forest occurs in a kloof in the Potberg (Van der Merwe 1977, Kruger 1979).

2.5 Climate

The reserve is situated in the eastern part of the temperate winter rainfall region that has a Mediterranean climate (Fuggle and Ashton 1979). A climograph was compiled by using rainfall figures and temperature readings obtained at the De Hoop homestead (Figure 2.3). From Figure 2.3 it can be seen that the rainfall is fairly evenly distributed over the year with the mean annual rainfall being approximately 420 mm. Rainfall can however vary by 15-17% from one year to the next. Summer rain commonly occurs as cloud bursts, but rainfall is predominantly cyclonic, associated with eastward movement of low pressure cells crossing the South-western and Southern Cape. Orographic rainfall may account for large differences in rainfall between the lowlands and the high-lying ground such as the limestone hills ("Harde Duine") and the Potberg, particularly towards the eastern extremity of the Potberg. Rainfall on the "Harde Duine" may exceed 450 mm and that on the Potberg may exceed 700 mm per year. Precipitation in the form of mist occurs in autumn and winter.

The warm Agulhas current results in temperate winters and warm summers. Temperature averages 16.8 °C per annum with an average summer maximum of 20.5 °C and average winter minimum of 13.2 °C. The warmest month is January with a mean air temperature of 22 °C. The coldest month is July with a mean air temperature of 11 °C.

Windy conditions are common, particular in summer when the prevailing wind direction is south-easterly with an average velocity of 35 km/h. Wind speeds may reach 60 km/h or more at times.

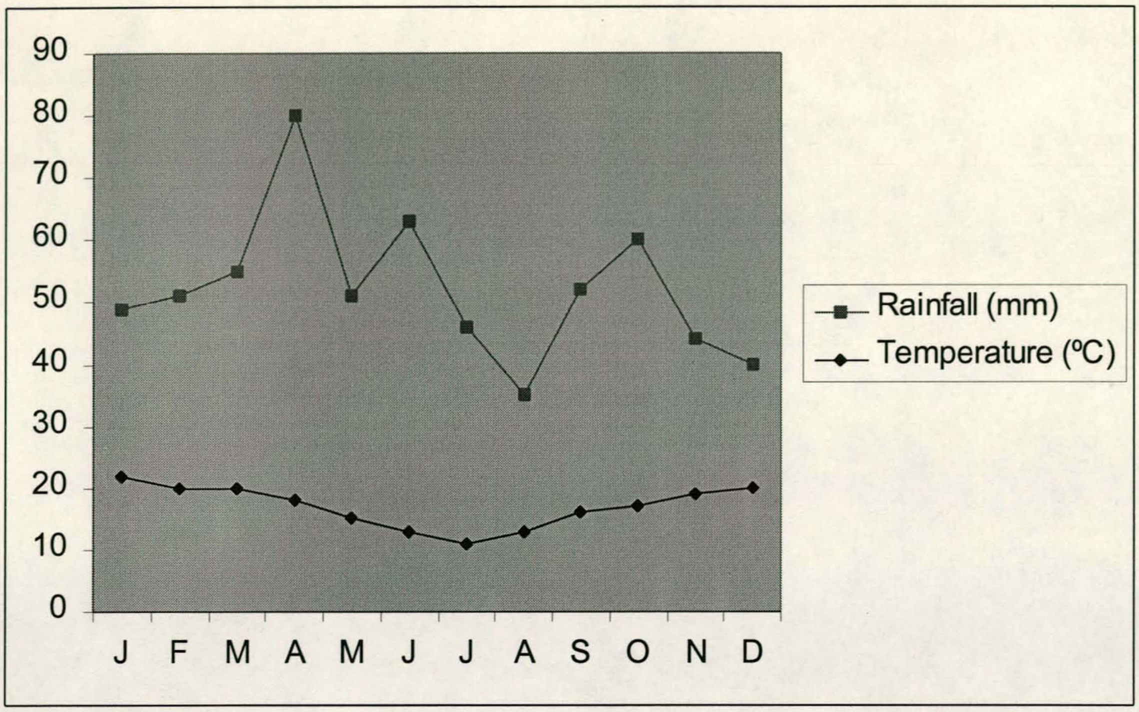

Figure 2.3. Climograph indicating the monthly average rainfall in millimetres and monthly temperature in degrees Celsius for De Hoop.

2.6 Study area

The area selected within De Hoop Nature Reserve to be used as the study area covers approximately 900 ha and is indicated in Figure 2.4. The study area borders the De Hoop Vlei in the west and the white sand dunes to the south. The northern border is represented by old farmlands. The eastern border is a road running from north to south that separates the study area from an area that burnt in 1991. This burnt area is also used in the study and is indicated in Figure 2.4.

The study area consists of fynbos with an age of between fifteen to twenty years and represents vegetation communities that have reached maturity and has stabilized in terms of community development. This allows for the effective monitoring of the study area by means of Landsat satellite images without the effect of temporal variation within the various communities and the inclusion of as much environmental variation as possible.

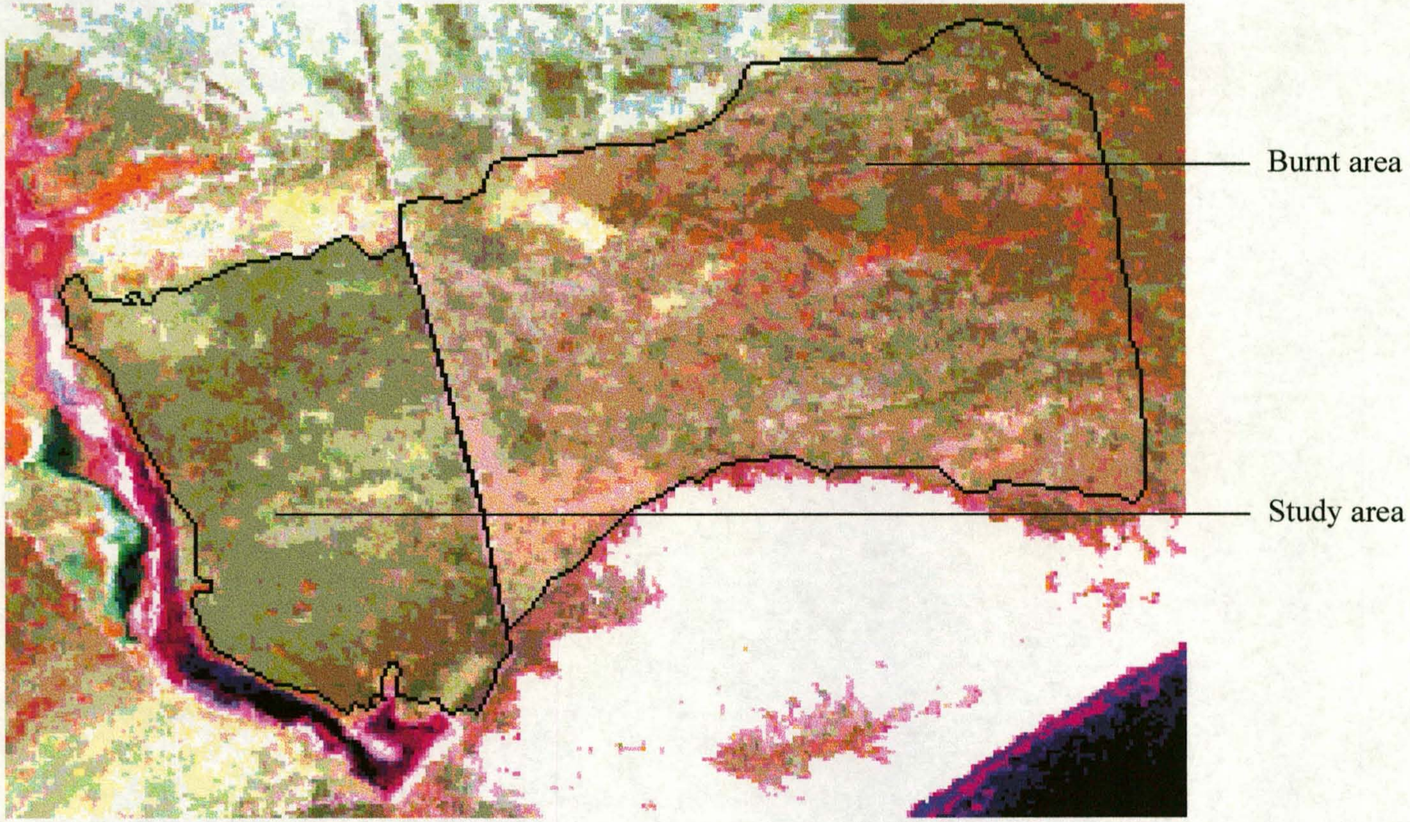

Figure 2.4 False colour composite Landsat image, indicating the study area as well as the burnt area to the east of the study area.

As already mentioned, the study area is bordered by an area that burnt in 1991 and it would be interesting to compare the recovery of vegetation communities within the burnt area with the neighboring communities within the study area.

With the vegetation in the study area being very mature and old, this area is to be burnt within the next two years according to the De Hoop Nature Reserve management plan. This will allow for the ideal opportunity to monitor the recovery of the communities within the study area in future studies by means of remote sensing. Some of the communities within the study area were changed or manipulated by man in previous years by means of agriculture (Van der Merwe 1977). The burning of the study area will also create the future opportunity to see if these areas that have been affected by man will possibly recover to a more natural state after the fire.

It can therefore be seen that there are several reasons for selecting this specific area, as a study area within De Hoop for this project and that it will also create opportunities for future follow up studies.

Chapter3

Vegetation Sampling and Description

Except by the measure of wildness we shall never really know the nature of a place.

- Paul Gruchow

3.1 Introduction

At the start of the project the assumption was made that the patterns that can be seen on Landsat images represent clearly definable fynbos communities in the field. The first aim of the project was thus to determine what vegetation communities actually occur within the study area. These communities, if any, must then be sampled properly. The sampled data can then be grouped by means of classification and ordination into clearly definable and interpretable groups that represent communities as they occur on the ground. The results obtained, together with ground truthing, would be used to determine and draw the community boundaries as they occur within the study area. The community boundary map or ground map will be the norm against which the patterns that occur on the Landsat images will be measured to determine if they actually indicate the various fynbos communities as they occur within the field and if they do, how accurately they indicate these communities. It can therefore be seen that the ground map will serve as the most important tool in the study and will be a measuring tool against which everything else in the study will be measured.

Next to the study area is an area that burnt in 1991. Based on the above assumption that pattern defines communities it would be possible to determine by means of image processing if the communities within the burnt area that borders the study area were part of the study area communities before the fire. If these burnt area communities were part of the neighboring study area communities before the fire, the assumption is made that these communities would recover to their prefire state with time. This assumption would be investigated after it was determined that there are communities within the study area.

3.2 Methods

3.2.1 False colour composite Landsat satellite image

A single false colour composite Landsat satellite image was used throughout this chapter for referencing purposes, orienting purposes and fieldwork. The imagery used for this false colour composite image was obtained in February 1997.

Vegetation is best portrayed by TM bands 2,3,4 and 5 (Woolley 1971, Tucker and Maxwell 1976, Tucker 1978). From the available imagery, bands 3,5 and 4 were selected subjectively and also in this order. The reason for the subjective selection of these bands and in this specific order being that they give the best possible false colour composite image in terms of portraying as much visual vegetation information as possible. Previous work has also conclusively demonstrated that this combination captures nearly all the visual vegetation information in Landsat satellite imagery for vegetation groups other than fynbos (Nelson, Latty and Mott 1984, Horler and Ahern 1986, Peterson, Westman, Stephenson, Ambrosia, Brass and Spanner 1986, Moore and Bauer 1990, Roy, Ranganath, Diwakar, Vohra, Bhan, Singh and Pandian 1991). This composite image is georeferenced and could therefore be used effectively in conjunction with the global positioning system (GPS) that was used for fieldwork.

This false colour composite image is only for viewing and referencing purposes and cannot be used for interpretation purposes, although it was assumed that the visible patterns correspond to vegetation communities.

3.2.2 Sample unit type and size

The sample unit used in the study was the quadrat, for the reason that it is the usual means of sampling vegetation for floristic description and analysis (Kent and Coker 1992). The concept of minimal area and species-area curve was used to determine quadrat size (Cain 1938, Daubenmire 1968, Shimwell 1971). A typical homogeneous limestone fynbos community consisting of species such as *Protea obtusifolia, Leucadendron meridianum, Leucadendron muirii* and *Euchaetis meridionalis* was selected within the study area to be sampled to determine the optimum quadrat size to be used in the study. The community was structurally characterized by vegetation of an average height of between 1-1.5 m and a percentage cover greater than 95%. The selection of this particular area to be used to determine the quadrat size for the study is based on the information obtained from the initial familiarization and reconnaissance of the study area. This particular area had the densest vegetation and largest species variety of the different communities within the study area and would therefore allow for a quadrat size to be obtained that is representative of all the different communities that occurs within the study area.

The initial area was 5x5 m and species within this area were recorded on a qualitative basis. Only species with a percentage cover of 1% and more within the plot were recorded. It was decided subjectively that 1% would be used as the cut off limit for species having an influence on the Landsat images. Both sides of the plot were increased by 5 m at a time and the recording process was repeated with every plot. The maximum plot size used was 30x30 m for the reason that no more new species were recorded. It was also decided not to increase the plot size more for the potential danger existed of sacrificing homogeneity by moving into a neighboring community with an increase in quadrat size (Curtis 1959, Dahl 1960). The results are presented in Table 3.1.

The optimum quadrat size to be used in this study was derived from the species-area curve (Figure 3.1). Although the graph already started to level off at the 10x10 m mark, the optimum quadrat size derived for the study was 15x15 m, a quadrat size slightly larger than the minimal area (Poore 1955, Kenkel and Podani 1991).

Table 3.1 Recording of species on a qualitative basis in the different sized quadrats. This information was used to determine the optimum quadrat size for the study by means of a species-area curve.

	Quadrat size (metres)					
Species	5x5	10x10	15x15	20x20	25x25	30x30
Thamnochortus fraternus	x	x	x	x	x	x
Rhus glauca	x	x	x	x	x	x
Erica spectabilis	x	x	x	x	x	x
Euchaetis meridionalis	x	x	x	x	x	x
Leucadendron muirii	x	x	x	x	x	x
Leucadendron meridianum	x	x	x	x	x	x
Erica bruniifolia	x	x	x	x	x	x
Merxmuellera cincta	x	x	x	x	x	x
Phylica axillaris	x	x	x	x	x	x
Relhania uniflora	x	x	x	x	x	x
Elytropappus rhinocerotis	x	x	x	x	x	x
Aspalathus calcarea	x	x	x	x	x	x
Chondropetalum microcarpum		x	x	x	x	x
Passerina galpinii		x	x	x	x	x
Tarchonanthus camphoratus		x	x	x	x	x
Pterocelastrus tricuspidatus		x	x	x	x	x
Otholobium fruticans		x	x	x	x	x
Chrysanthemoides monilifera		x	x	x	x	x
Nylandtia spinosa		x	x	x	x	x
Protea obtusifolia			x	x	x	x
Erica scytophylla			x	x	x	x
Euryops linearis				x	x	x
Anthospernum spathulatum					x	x
Myrica quercifolia					x	x
Sideroxylon inerme						x

3.2.3 Sampling design and quadrat location

The choice of sampling design was based on the assumption that the different vegetation communities in the field are represented by different colour patterns on the Landsat composite images. The primary sampling objective was to sample each possible community over the whole study area and to include all possible variations within the separate communities. In order to achieve this, each community was treated as an entity and sampled independently from its neighboring communities.

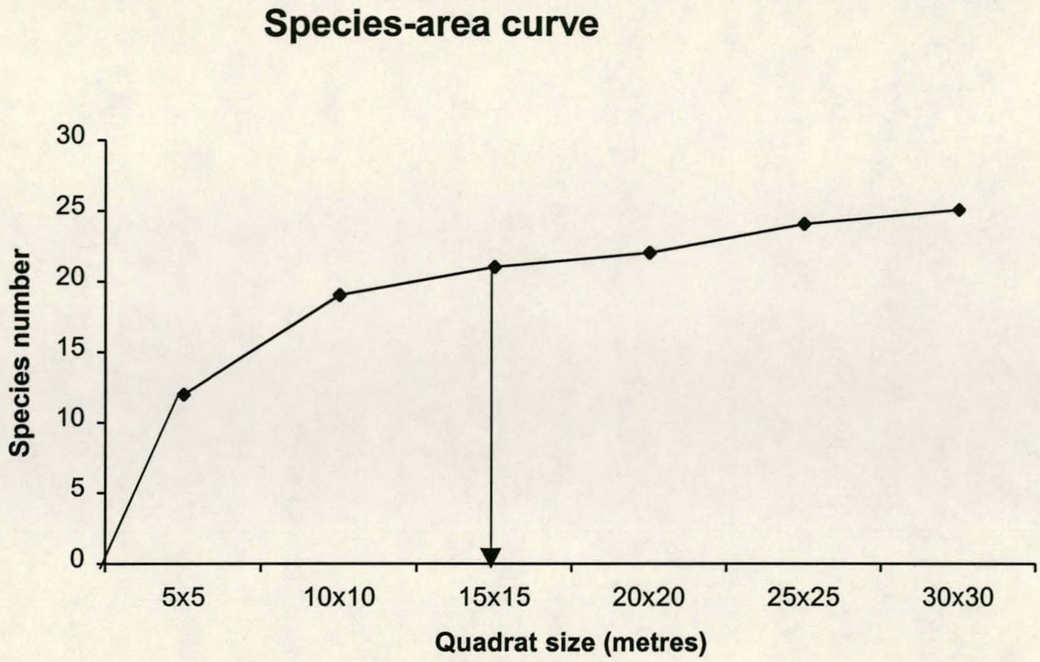

Figure 3.1 The species-area curve was drawn by using the data in Table 3.1. The optimum quadrat size for vegetation sampling and description derived from the graph is 15x15 m, as indicated on the graph.

The principle of stratified sampling (Berry and Marble 1968, Haining 1990, Cressie 1993) was thus applied and the study area was subdivided into different homogeneous communities. The division was done after the initial reconnaissance of the study area and examination of the Landsat composite images. This division is based on the colour patterns in the composite images and the species and structural differences within the vegetation (Westfall and Malan 1986). By dividing the study area into different homogeneous communities, before sampling actually starts, the major sources of variation in the vegetation were recognized and could be sampled (Smartt 1978). Seven different communities were initially identified within the study area. Each of these communities were named according to a distinguishable vegetation type or feature which allowed for easy use in fieldwork, descriptions, summaries, classification and ordination. The seven communities were named as follows: Renoster, Thatch, Passerina, Euchaetis, Erica, Old Lands and Vlei.

The position of individual quadrats were determined before sampling commenced. This was done by using the georeferenced Landsat images and by positioning the quadrats subjectively in the applicable vegetation community (colour pattern) to include representative areas of the perceived community.

The co-ordinates of the predetermined locations of the quadrats were then entered into a global positioning system (GPS) and in this manner the position of the quadrats were determined in the field.

Part of the GPS design entails the degradation of the satellite signals by the United States Air Force for security reasons – known as selective availability (Georgiadou and Doucet 1990). This means a decrease in accuracy of up to 100 m (August 1993). Thus with the locating of quadrats in the field, the possibility always existed of being out by up to a 100 m. This problem could not be overcome, but a more accurate position of the actual quadrat could be obtained by taking four GPS readings over the period of approximately a hour spent in the quadrat while recording quadrat information (Deckert and Bolstad 1994). These four GPS readings were recorded on the quadrat data sheet and later used to determine an average co-ordinate for the actual position of the quadrat that was accurate to within 30 m. This degree of accuracy of the actual field position of the quadrat was accurate enough for the study, due to the fact that the pixel size of Landsat images used was 30x30 m (Szekielda 1988).

3.2.4 Quadrat description

Quadrats were described in three different ways, namely a structural description of the vegetation, physical features of the soil and a botanical description of the quadrat vegetation.

For the structural description of the vegetation a system developed for fynbos by Campbell, Cowling, Bond and Kruger (1981) was used. The system provides standardized structural terms for describing vegetation stands or units irrespective of the manner in which the units were initially delineated and disregarding successional considerations. The system is essentially that of Specht (1979) which was originally devised for Australian heathlands and in the case of forest and woodlands the system is based on Edwards' (1983) system. Two structural features of the vegetation are described, namely height and percentage cover, it is therefore primarily for descriptive purposes and not to name the vegetation units.

The soil in the quadrats was described in terms of its physical attributes as can be seen in Table 3.2. The following factors were included in the description, namely soil colour, soil depth, amount of surface limestone rock, banks and pebble cover, and slope of the area. Either a light leached colour or a brown fertile colour dominated the soil colour of the study area and quadrats were therefore described in terms of these soil colour features. The study area is a fairly flat area and the only dominant slope feature that is a characteristic of the study area is the occurrence of low lying deep basins. Quadrats were therefore described in terms of their slope features as either occurring on fairly level areas or in these typical deep lying basins. The area is predominantly a limestone area and on the initial field visits it was found that most of the area is dominated by limestone rock and other limestone features such as limestone banks. Based on this, the term limestone was used in the relevant soil descriptions. Features such as the amount of surface limestone rock cover in the quadrat were described in terms of three percentage classes, namely: no limestone rocks, being less than 1%, few limestone rocks being between 1 and 10% and large amounts of limestone rocks being more than 11%. The amount of limestone banks and pebbles were described in a similar manner as the amount of surface limestone rocks (Table 3.2). Soil depth was divided into three groups, namely: shallow being between 0-15 cm, medium depth being between 15-30 cm and deep soils being 30 cm and more. Each of these described soil attributes would be represented by a given percentage, as indicated in Table 3.2, in the statistical analysis process. This will enable the effective inclusion of soil as well as floristic features of the different quadrats in the same input data sets to allow for clear, understandable, interpretable and comparable statistical results to be obtained.

Table 3.2 The various physical attributes used for the soil description in each quadrat. Indicated are the different descriptive classes for each soil feature as well as the percentage that would represent these different classes in the statistical analysis process of the quadrat data.

Surface limestone features described in terms of percentage cover.

	Rocks	Pebbles	Banks	Analysis %
None	<1%	<1%	<1%	0%
Few	1-10%	1-10%	1-10%	5%
Plenty	>11%	>11%	>11%	15%

Slope features.

Slope	Analysis %
Flat area	15%
Basin	15%

Soil depth classes in centimetres.

	Depth	Analysis %
Shallow	0-15 cm	15%
Meduim	15-30 cm	15%
Deep	>30 cm	15%

Soil colour features.

Colour	Analysis %
Light leached colour	15%
Brown fertile colour	15%

A subjective botanical description based on the species composition and percentage cover of the permanently recognizable species within quadrats was also done (Coates Palgrave 1991, Cowling and Richardson 1995, Mustart, Cowling and Albertyn 1997, Burgers pers. comm.). Species recorded were divided into two groups. The first one being species with a percentage cover of 1% and more in the quadrat and surrounding area were recorded as having a definite effect on the Landsat images. The second group was species with a percentage cover of less than 1% or that occurred only in very small and localized areas within the community. These species were taken as not having an effect on the Landsat images, but were still recorded for possible future use in the statistical analysis of data and as an indicator of the spread of these species in the different communities. Species that were outside the quadrat perimeter and that were typical of the area surrounding the quadrat were also described by indicating them as being present in the area.

3.2.5 Data recording

Each quadrats' data was recorded on a separate data sheet and included the following: structural description of vegetation, physical soil features, botanical description and four GPS readings taken within the quadrat over time. Information about the typical vegetation surrounding the quadrat and unique visible features within the area were also recorded. A small map was drawn on the data sheet to show the extent of the vegetation within the quadrat beyond its borders and any possible community changes. After completing the sampling process in a community, the borders of a community were walked and GPS readings were taken along the line where there was a clear and noticeable change in vegetation. In this manner a database consisting of quadrat data sheets were obtained for each community in the study area.

The data sheets representing one community were then summarized in a one page spreadsheet (Appendix 1). All the community spreadsheets were then used to summarize the floristic and soil data into a one page data matrix (Appendix 2) (Ludwig and Reynolds 1988). Quadrats laid out in the different communities are indicated in Appendix 1 and 2 by means of a 2 letter symbol. The first letter represents the community the quadrat occurs in and the second letter represents the particular quadrat. For example 5 quadrats were laid out in the Vlei community, namely Va, Vb, Vc, Vd and Ve. The "V" in Va represents the Vlei community and the "a" represents the first quadrat laid out in the Vlei community, namely Va. Quadrats laid out in other communities were indicated in the same manner, except for a difference in the first letter that is representing the applicable community. These 2 letter symbolic representations of the quadrats in the different communities will represent the different quadrats in all future descriptive and analysis processes to be used in the study and where quadrats are involved. The data matrix is colour coded to allow for the easy viewing of quadrats sampled within communities and to compare the different communities (Appendix 2). This also allowed for the easy transfer of data into classification and ordination programs.

3.2.6 Preliminary ground map

Quadrat data obtained from the data sheets in the form of quadrat co-ordinates as well as the GPS readings indicating the change in vegetation between communities and the map describing the area surrounding each quadrat were used to draw a preliminary ground map. This ground map represented the community boundaries within the study area as they were sampled in the field.

The community boundaries obtained from the ground map were then overlaid onto the composite (bands 3,5 and 4) georeferenced Landsat image of the study area that was taken during February 1997 (Figure 3.2). Also overlaid onto the mentioned image are the different quadrat symbols and their positions to indicate the spread of quadrats within the various communities and the study area as a whole. Each of the communities represented in the ground map also represents an area that was treated as an entity or community during the sampling process and sampled independently from its neighboring communities. Only after classification and ordination of the sampled data had been completed would it be possible to obtain an accurate final ground map of the study area, representing the true community boundaries.

From Figure 3.2 it can be seen that there are spaces between communities in certain areas. These spaces could not be put into a definite vegetation community and the possibility existed of them being transitional or ecotone areas between neighboring communities (Holland 1988, Van der Maarel 1990). Quadrats were laid out in exactly the same manner as for the other communities in these possible ecotone areas and the results are summarized in Appendix 1 and 2 and the quadrat positions are indicated in Figure 3.2.

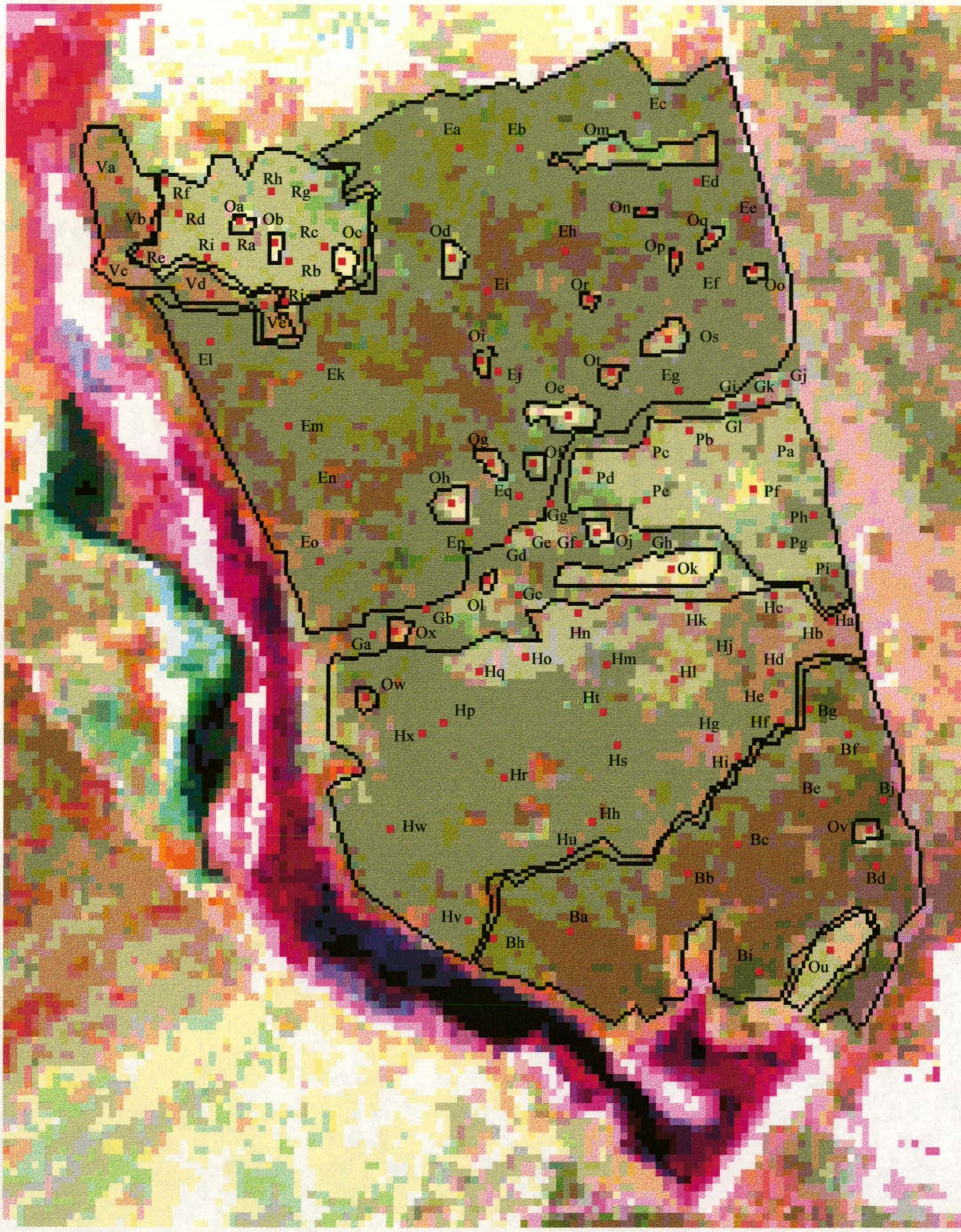

Figure 3.2 Preliminary ground map indicating the different quadrat positions (red squares) as well as the preliminary community boundaries.

3.2.7 Burnt area

Based on the assumption that the different communities in the field are represented by different colour patterns on the Landsat images it would be possible to determine by means of image processing if the communities within the burnt area bordering the study area were part of the study area communities before the fire. If these burnt area communities were part of the neighboring study area communities before the fire, the assumption is made that with time, these communities would revert to their original state.

To investigate this assumption, two quadrats were laid out in the burnt area alongside each community within the study area bordering the burnt area. The sampling process was done in exactly the same manner as for the study area and data obtained was also summarized in Appendix 1 and included in the data matrix (Appendix 2).

3.2.8 Classification and ordination

The floristic and soil data obtained from the data matrix (Appendix 2) was classified by using Two-way Indicator Species Analysis (TWINSPAN) (Hill 1979). Very rare species were omitted to reduce noise (Russell-Smith 1991). TWINSPAN was selected to derive the primary community classification, given its theoretical advantages (Gauch and Whittaker 1981, Gauch 1982), wide usage and general acceptance in phytosociology (Mucina and Van der Maarel 1989). The TWINSPAN default settings were used for the classification process.

All final TWINSPAN dichotomies were explored by means of ordination (Goodall 1954, Austin 1985) by means of correspondence analysis (Hill 1973, Hill 1974, Greenacre 1984) in two dimensions to determine the extent to which dichotomies reflected discontinuity in the site's floristic and soil data. Classification and ordination were thus used to complement each other to find, examine and verify possible vegetation patterns and community structures within the study area (Kent and Ballard 1988). Simple

Correspondence Analysis (SIMCA), a correspondence analysis program, was used for this purpose (Greenacre 1986).

Quadrat data obtained from the data matrix (Appendix2) of the seven communities initially identified within the study area and represented by community boundaries as indicated in the preliminary ground map (Figure 3.2) were used as an input data set for a TWINSPAN classification. The same input data set was initially used for SIMCA as well. Given the size of the data set and the capabilities of SIMCA, it was impossible to derive clear, understandable and interpretable ordination results. Input data was thus divided into groups to overcome this problem. The input groups obtained from the data matrix were created by grouping together plant communities that had similar vegetation and soil features or that were adjacent to each other and where the possibility existed that these different communities might be proven through ordination to actually be the same community. This resulted in the Vlei, Renoster, Thatch and Old Land communities to be used as an input data set. The Passerina, Erica and Euchaetis communities were used as the other input data set for SIMCA and a quadrat, namely Bh of the Thatch community, was also included in the latter due to the fact that it possibly did not belong to the Thatch community, but rather to one of the other communities.

Quadrats that were laid out in the possible ecotone areas between communities, as determined from the preliminary ground map, were not included in the classification of the quadrat data of the seven communities initially identified within the study area. The reason for this being that the possible ecotone areas form a continuum between the bordering communities and it is therefore unlikely that any meaningful groupings will be found through the process of classification. If the possible ecotone area data were to be included into the classification process, it would lead to the ecotone quadrats to be forced into groups and quite arbitrary boundaries would be derived from the process. Classification is a more effective tool in searching for patterns when data show major discontinuities (Mucina 1997), while ordination is more effective when the continuous character is strongly developed (Van der Maarel 1975). The possible ecotone areas was thus included only in the ordination process and by means of the graphical results obtained it should then be possible to make a conclusion to whether these areas are actually ecotone areas, or a completely different community or if they belong to one of the neighboring communities. From Figure 3.2 the decision was made to include the quadrats of the possible ecotone areas with the Passerina, Euchaetis and Erica community quadrats in an input data set to be used for ordination purposes.

The burnt area data was included in an input group that contained the communities of the study area that it was assumed to be part of before the fire, namely the Passerina, Erica, Euchaetis and Thatch communities. This was done for the classification as well as ordination of the quadrat data. Due to the size of the input data set, clear and interpretable results could not be obtained from the SIMCA ordination and therefore the number of quadrats representing each of the communities neighboring the burnt area was reduced to allow for a smaller, but still representative input data set for the ordination process.

3.3 Results

3.3.1 Classification and ordination of quadrat data within the study area

Results obtained from the TWINSPAN classification (Appendix 3) of the seven communities initially identified within the study area are summarized in Table 3.3. The ordination results of the two input data sets for the same seven communities can be seen in Figure 3.3 and 3.4. From Table 3.3 it can be seen that quadrats belonging to the Renoster, Euchaetis, Old Land and Vlei communities were divided into these various communities by TWINSPAN and that no quadrats from other communities were included in them. These results were verified by the ordination results (Figures 3.3 and 3.4).

From the classification results it can be seen that quadrat Bh of the Thatch community was allocated to the Erica community and this was verified by the ordination results. From the initial ground map (Figure 3.2) it can be seen that quadrat Bh lies on the boundary of the Thatch and Erica community. The boundary between the two communities was walked again on three different occasions and GPS readings were taken

Table 3.3 Summary of TWINSPAN results containing the seven different communities identified during fieldwork and the sampling process in the study area. Quadrats laid out in the Renoster community is indicated by "Ra" to "Rj", Thatch community by "Ba" to "Bj", Passerina community by "Pa" to "Pi", Euchaetis community by "Ea" to "Eq", Erica community by "Ha" to "Hx", Old Lands community by "Oa" to "Ox", and the Vlei community by "Va" to "Ve".

Division of quadrats according to the TWINSPAN division as obtained from Appendix 3.

Division level 1	EEEEEEEEEEEEEEEEEHHHHHHHHHHHBHHHHHHHHHHHHHPPPPPPPPPRRRRRRRRRRVVVVVBBBBBBBBBOOOOOOOOOOOOOOOOOOOOOOOO a b c l p d e f g i j k m n o q h w n o p q x k s v m r h a b c d e f g h i j l t u h i c a b d e f g a b c d e f h i g j b a c d e a c b g i j d e f m n o q t p r s g u v w x l d e j f h i k a b c
Division level 2	EEEEEEEEEEEEEEEEEHHHHHHHHHHHBHHHHHHHHHHHHHPPPPPPPPPRRRRRRRRRRVVVVVBBBBBBBBBOOOOOOOOOOOOOOOOOOOOOOOO a b c l p d e f g i j k m n o q h w n o p q x k s v m r h a b c d e f g h i j l t u h i c a b d e f g a b c d e f h i g j b a c d e a c b g i j d e f m n o q t p r s g u v w x l d e j f h i k a b c
Division level 3	EEEEEEEEEEEEEEEEEHHHHHHHHHHHBHHHHHHHHHHHHHPPPPPPPPPRRRRRRRRRRVVVVVBBBBBBBBBOOOOOOOOOOOOOOOOOOOOOOOO a b c l p d e f g i j k m n o q h w n o p q x k s v m r h a b c d e f g h i j l t u h i c a b d e f g a b c d e f h i g j b a c d e a c b g i j d e f m n o q t p r s g u v w x l d e j f h i k a b c
Division level 4	EEEEEEEEEEEEEEEEEHHHHHHHHHHHBHHHHHHHHHHHHHPPPPPPPPPRRRRRRRRRRVVVVVBBBBBBBBBOOOOOOOOOOOOOO OOOOOO a b c l p d e f g i j k m n o q h w n o p q x k s v m r h a b c d e f g h i j l t u h i c a b d e f g a b c d e f h i g j b a c d e a c b g i j d e f m n o q t p r s g u v w x l e j f h i k
Division level 5	EEEEEEEEEEEEEEHHHHHHHHHHHBHHHHHHHHHHHHHPPPPPPPPPRRRRRRRRRRVVVVVBBBBBB OOOOOOOOOOOOOO l p d e f g i j k m n o q h w n o p q x k s v m r h a b c d e f g h i j l t u h i c a b d e f g a b c d e f h i g j b a c d e a c b g i j m n o q t p r s g u v w x l
Division level 6	EEEEEEEEEEEE HHHHHHHHHHBHHHHHHHHHHHHH PPPPPPPRRRRRRRRRR OOOOOO d e f g i j k m n o q h n o p q x k s v m r h a b c d e f g h i j l t u c a b d e f g a b c d e f h i g j g u v w x l

Community summary of the above data.

Community	Quadrat groupings	Quadrats not included in community	Quadrats included from other communities	Division level
Renoster	RRRRRRRRRR a b c d e f g h i j	None	None	5
Thatch	BBBBBBBBB a b c d e f g i j	Bh	None	3
Passerina	PPPPPPP a b c d e f g	Ph Pi	None	5
Euchaetis	EEEEEEEEEEEEEEEEE a b c d e f g h i j k l m n o p q	None	None	3
Erica	HHHHHHHHHHHHHHHHHHHHHHHHBPP a b c d e f g h i j k l m n o p q r s t u v w x h h i	None	Bh Ph Pi	3
Old lands	OOOOOOOOOOOOOOOOOOOOOOOO a b c d e f g h i j k l m n o p q r s t u v w x	None	None	1
Vlei	VVVVV a b c d e	None	None	4

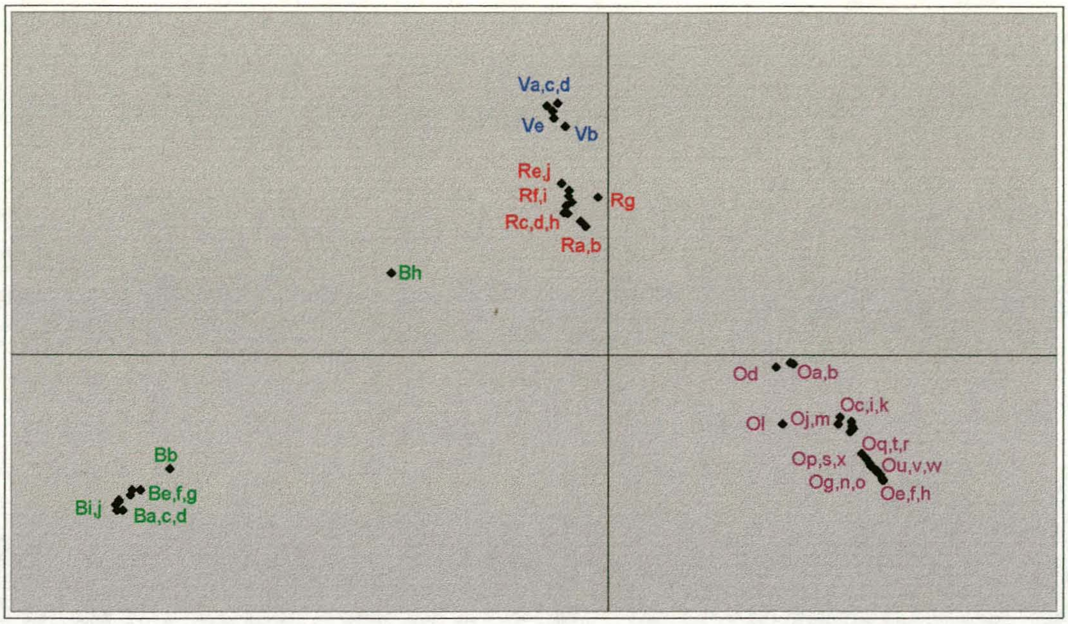

Figure 3.3 SIMCA ordination of quadrats of the Thatch community (indicated by "B"), Vlei community (indicated by "V"),Renoster community (indicated by "R") and Old Land community (indicated by "O").

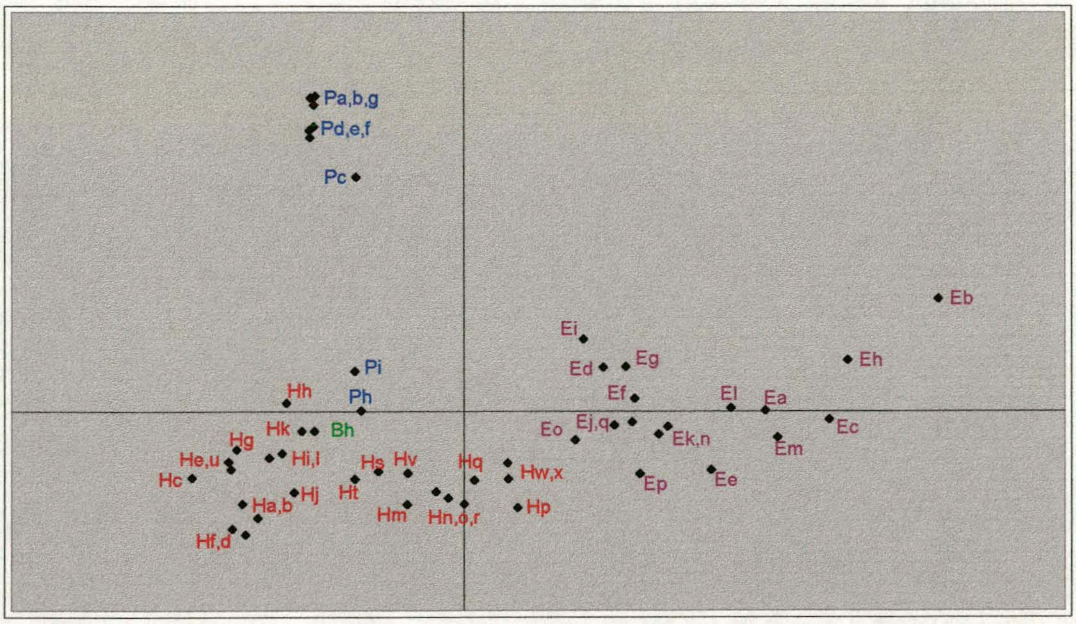

Figure 3.4 Simca ordination of the quadrats of the Passerina community (indicated by "P"), Euchaetis community(indicated by "E"), Erica community (indicated by "H") and quadrat Bh of the Thatch community.

along this boundary. Thus with the help of these GPS reading a more accurate boundary was drawn where the Erica and Thatch communities met and with this new boundary it could be seen that quadrat Bh falls into the Erica community. Thus with the help of classification, ordination and the redrawn boundary between the two communities it was decided to include quadrat Bh in the Erica community.

From the classification results (Table 3.3) it can be seen that quadrats Ph and Pi were not divided into the Passerina community, but the Erica community. This was verified by means of ordination (Figure 3.4). These two areas were revisited and due to similar physical features in terms of plant species and soil features between the two areas and the Erica community and the classification and ordination results, it was decided to include these two areas in the Erica community.

The quadrats within the Erica community were separated into a group by TWINSPAN and included within this group are quadrats Bh, Ph and Pi. These results were verified by ordination (Figure 3.4) and as already mentioned in the previous two paragraphs, it was decided to keep this grouping. From these results it was decided to keep the seven initially identified communities with their quadrats as summarized in Table 3.3, with only slight community boundary changes.

The possible ecotone area that occurs in the study area is depicted in Figure 3.5. The Simca ordination of the ecotone area quadrats and its surrounding neighboring communities' quadrats (Figure 3.6) shows quadrats Ge, Gi and Gj to be grouped strongly with the Passerina community's quadrats and therefore these quadrats most probably do not represent an ecotone area. Quadrats Ga,Gb,Gc,Gd,Gf,Gg,Gh,Gk, and Gl are spread between the Erica, Passerina and Euchaetis communities according to the ordination results and can therefore probably indicate an ecotone area.

Quadrats Gi, Gj, Gk and Gl lie between the Euchaetis and Passerina communities to the east of the study area (Figure 3.5). With further fieldwork and visits it was found that this area is not an ecotone area as such, containing components of both the neighboring

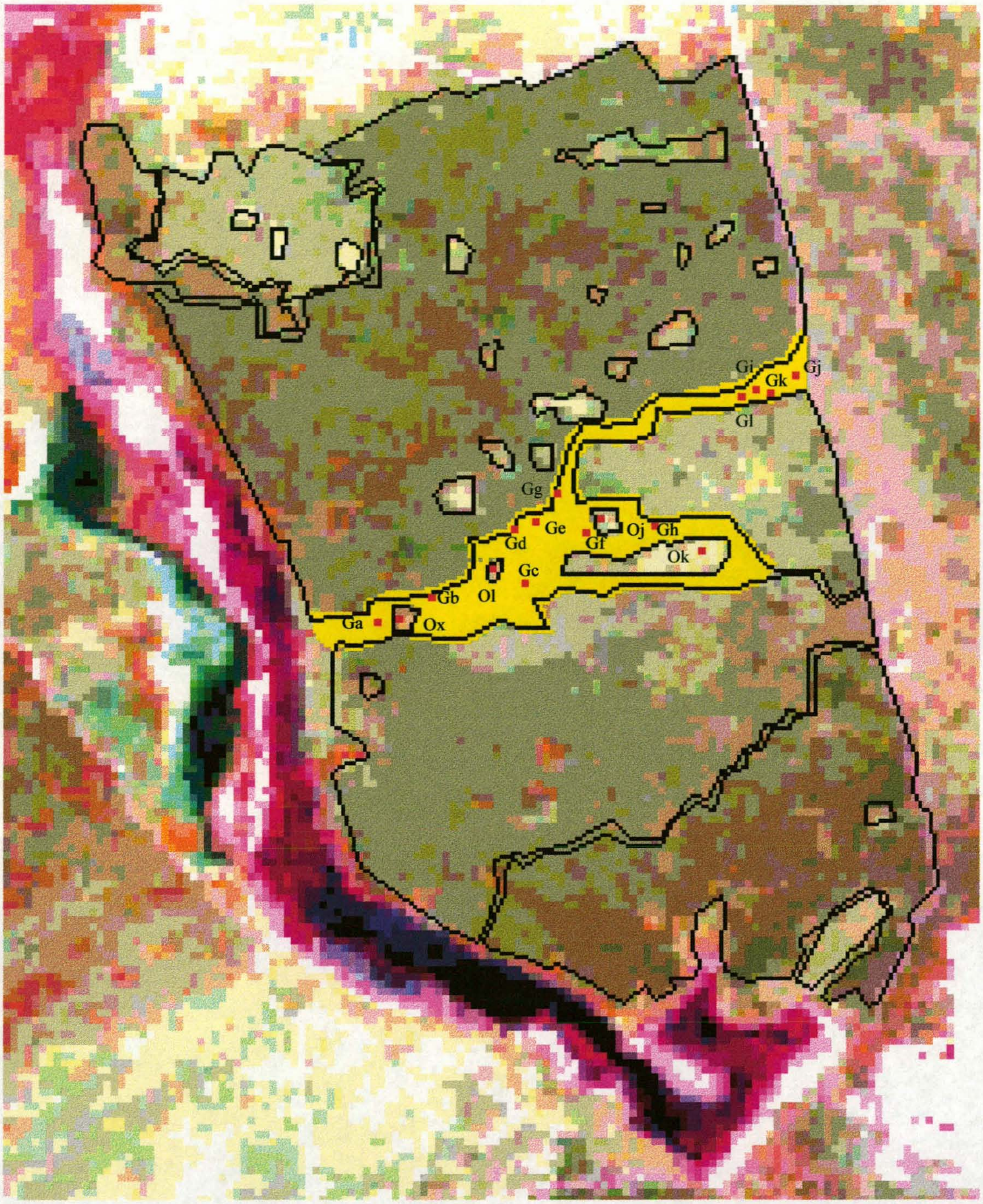

Figure 3.5 The possible ecotone area depicted in bright yellow as well as the applicable quadrats.

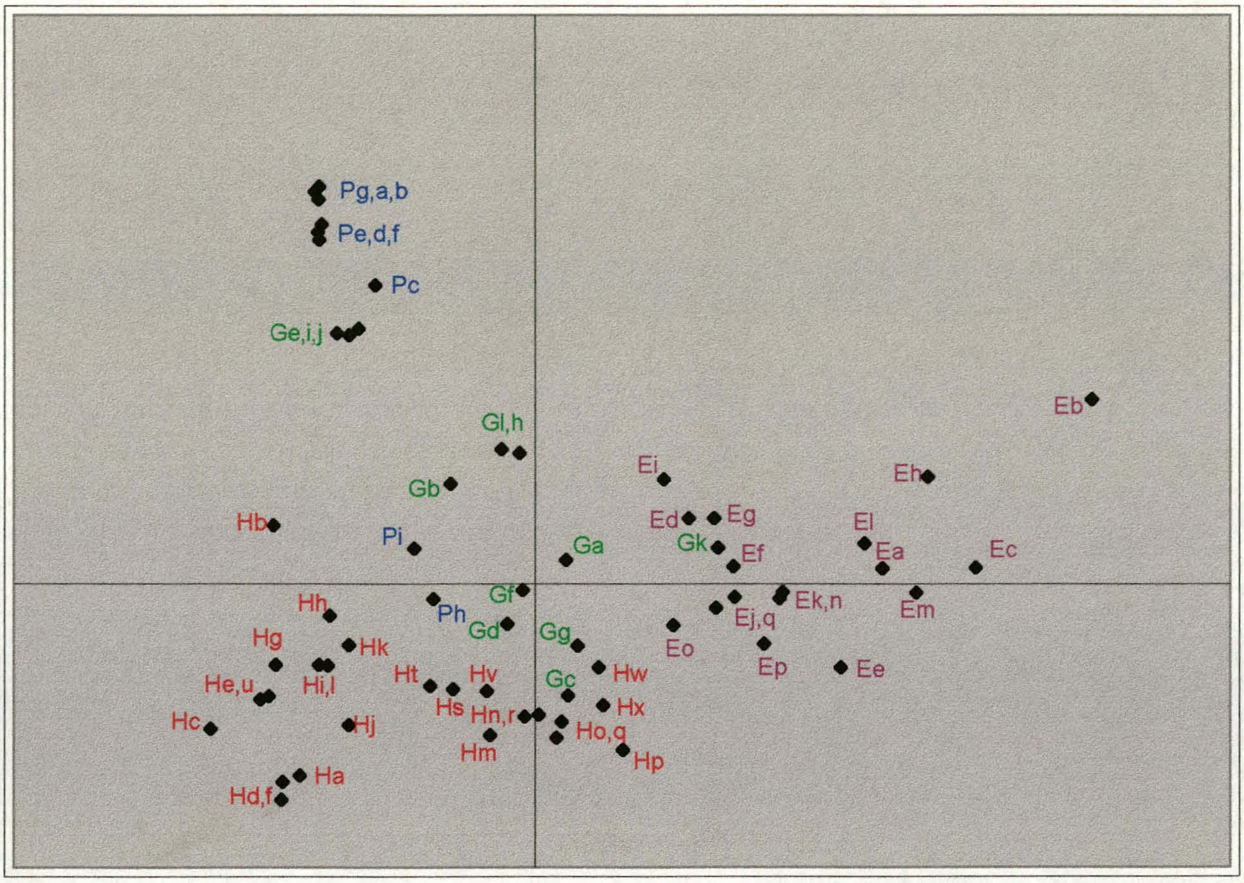

Figure 3.6 Simca ordination of the quadrats of the Passerina community (indicated by "P"), Euchaetis community (indicated by "E"), Erica community (indicated by "H") and the Border community (indicated by "G"). This ordination shows the spread of the Border community quadrats in relationship to its neigboring communities.

communities, but it is an area that has a long narrow strip of the Euchaetis community type vegetation within Passerina community vegetation. Following this, quadrats Gl and Gk were laid out in this narrow strip of vegetation within the Passerina community to determine to which community type it belongs. Quadrats Gi and Gj were laid out more to the north of this strip of vegetation to determine if this area belongs to the Passerina community. From Figure 3.6 it can be seen that quadrat Gk lies among the Euchaetis community quadrats. Quadrat Gl lies further away from the Euchaetis community, but based on the similar vegetation description to that of the Euchaetis community it was decided that both of these quadrats belong to the Euchaetis community. Quadrats Gi and Gj were included in the Passerina community. The final result of the further field visits, sampling and analysis of data led to the possible ecotone area in this section of the study area being included in the Passerina community with the acceptance that there is a long narrow strip of Euchaetis community vegetation occurring within this area.

The quadrats Gd, Ge, Gf, Gg and Gh lies between the Euchaetis, Passerina and Erica communities in the middle section of the study area (Figure 3.5). With further field visits it was found that a few small patchess and strips of Passerina community vegetation occurs within an area that consists of vegetation that is very similar to that of the Euchaetis community. It was therefore decided to put quadrat Ge in one of these patches or strips to determine if they actually are the same as the Passerina community and according to the SIMCA ordination, quadrat Ge belongs to the Passerina community. From Figure 3.6 it can be seen that quadrats Gd, Gf, Gg and Gh can possibly represent an ecotone area between the Euchaetis and Erica communities. Due to the fact that their vegetation descriptions are very similar to that of the Euchaetis community, they were included in the Euchaetis community. This section of the ecotone area was thus included in the Euchaetis community with the acceptance that there are a very few small patches and strips of the Passerina community vegetation that occur within the area.

If a line is to be drawn from the east to the west from quadrat Ok to Ol to Ox and then to the De Hoop Vlei it would represent a low lying area running from east to west along this line with the mentioned Old Lands along it (Figure 3.5). The Euchaetis community's southern most section has a fall in slope to the south and this fall reaches its lowest point at this low-lying area. The Erica community, which lies to the south of this low-lying area, has a rise in slope towards the south which starts at this low-lying area. It can therefore be said that this low-lying area represents the border between the Erica and Euchaetis community with a possible ecotone area on either side of it before it goes into the real Erica and Euchaetis communities. The ordination results (Figure 3.6) indicate quadrats Ga, Gb and Gc, that was laid out around this low-lying area, as being possible ecotone area quadrats. Considering this low lying area as a natural boundary between the two applicable communities, the vegetation description of the quadrats within this area, ordination results and the size of this possible ecotone area compared to the size of the communities surrounding it, it was decided to move the boundary between the communities to the low lying basin. This lead to quadrats Ga and Gb to be included in the Euchaetis community and quadrat Gc in the Erica community.

A summary of the final quadrat groupings within the seven different communities in the study area as obtained by means of classification and ordination is shown in Table 3.4. Using the classification and ordination results (Table 3.4) and information gathered with further fieldwork and visits a final ground map was drawn representing the perceived community boundaries within the study area as can be seen in Figure 3.7.

3.3.2 Community description

Through fieldwork and field visits seven different vegetation communities were identified within the study area. These seven communities were confirmed by means of classification and ordination. A short summary of each of these communities follows:

Renoster

Typical plants of this community are *Elytropappus rhinocerotus, Rhus glauca* and *Nylandtia spinosa.* Vegetation in the community covers about 75% of the area with an average height of not more than 50 cm. Twenty to twenty five percent of the area has been classified as bare ground with the possibility of being covered by small grasses and regrowth after good rains. The community occurs on very level terrain with a deep fertile brown soil and limestone rocks spread evenly over the whole area with very few limestone banks.

Table 3.4 A summary of the final quadrat groupings within the different vegetation communities obtained by means of classification and ordination. Quadrats laid out in the Renoster community is indicated by "Ra" to "Rj", Thatch community by "Ba" to "Bj", Passerina community by "Pa" to "Pi", Euchaetis community by "Ea" to "Eq", Erica community by "Ha" to "Hx", Old Lands community by "Oa" to "Ox", Vlei community by "Va" to "Ve" and the possible ecotone area by "Ga" to "Gl".

Community	Quadrat groupings
Renoster	R R R R R R R R R R a b c d e f g h i j
Thatch	B B B B B B B B B a b c d e f g i j
Passerina	P P P P P P P G G G a b c d e f g e i j
Euchaetis	E E E E E E E E E E E E E E E E E G G G G G G G G a b c d e f g h i j k l m n o p q a b d f g h k l
Erica	H H H H H H H H H H H H H H H H H H H H H H H H B P P G a b c d e f g h i j k l m n o p q r s t u v w x h h i c
Old Lands	O O O O O O O O O O O O O O O O O O O O O O O O a b c d e f g h i j k l m n o p q r s t u v w x
Vlei	V V V V V a b c d e

Thatch

This community is characterized by very dense *Thamnochortus insignis* and to a lesser extent by *Elytropappus rhinocerotus* and *Erica vernicosa*. Vegetation is very dense and there are almost no open spaces within the area. The dominating *Thamnochortus insignis* is more than a metre tall. The community has a slight slope falling towards the south. The soil is a very deep white sandy soil with no stones or banks.

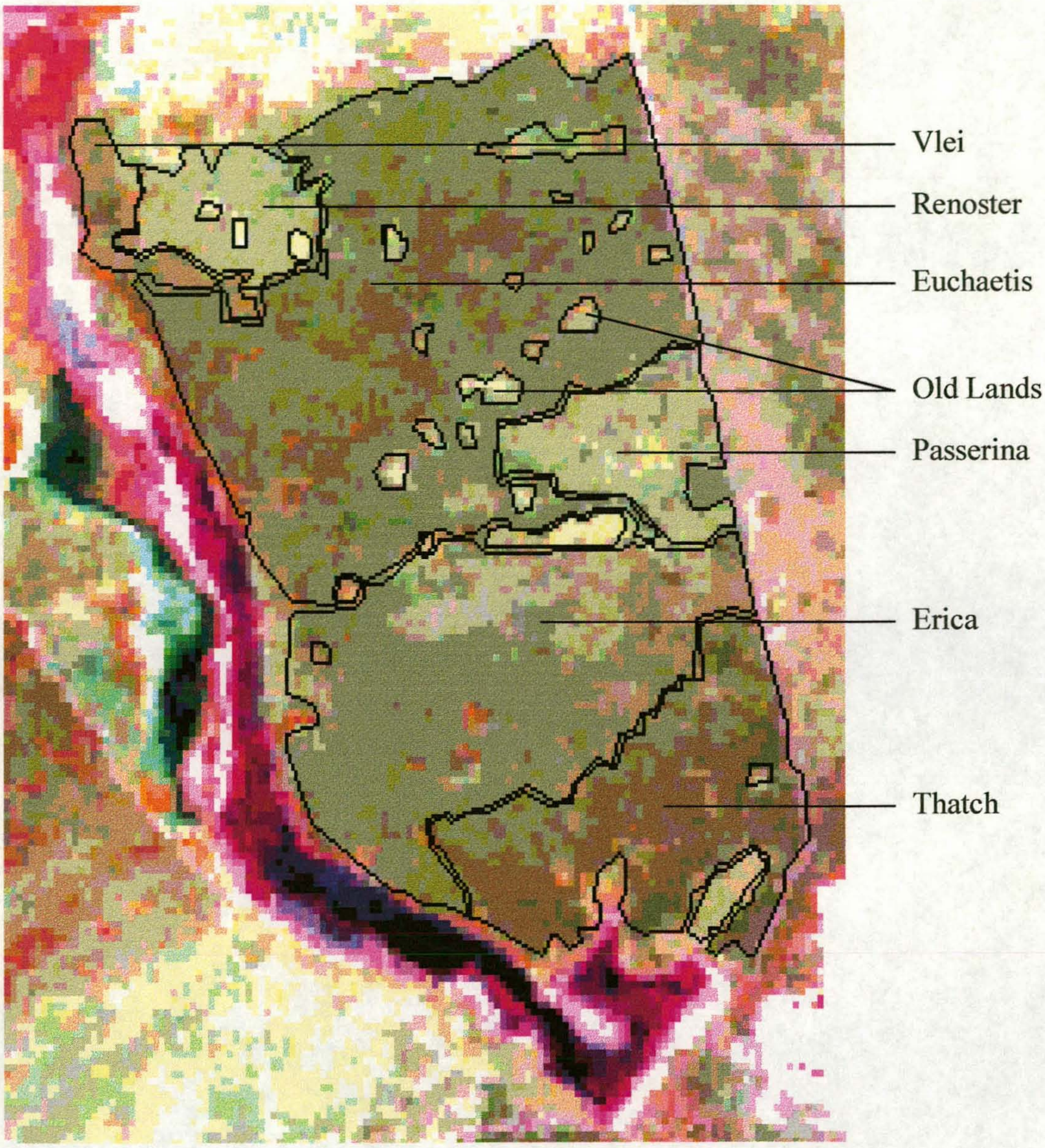

Figure 3.7 The final ground map representing the true community boundaries as they occur within the study area.

Passerina

Characteristic of the vegetation of this community is the large amount of *Passerina galpinii* and to a lesser extent *Rhus glauca* and *Nylandtia spinosa*. The vegetation is less than a metre tall with about 30% of the area being bare over dry periods and possibly covered with small grasses and regrowth after good rains. The area is on very level terrain with no slope. The soil is a deep brown and fertile soil with very few limestone rocks and banks, but with large amounts of white pebbles covering the area.

Euchaetis

This community covers the largest area of all the communities in the study area. Typical of it are the large amounts of *Thamnochortus fraternus, Passerina galpinii, Euchaetis meridionalis, Leucadendron murii, Chondropetalum microcarpum* and *Erica bruniifolia*. This community is typical of a limestone fynbos community. Average height of the vegetation is about 1 metre with taller leucadendron bushes and the density varies from 70% to very dense. Most of the community occurs on level terrain with the southern most section having a slight fall in slope towards the south. The soil of the area is a very shallow white sandy soil with large amounts of limestone rocks and banks.

Erica

This is the second largest community within the study area. Vegetation typical of the community is *Thamnochortus fraternus, Chondropetalum microcarpum, Erica vernicosa* and *Passerina galpinii*. The vegetation varies in height from very low growing *Erica vernicosa* to about 1 m tall *Thamnochortus fraternus* and covers the area with between 80-90%. A slight slope rising from the north and then falling again towards the south characterizes the area. The soil is a light sandy soil and ranges from being quite deep to very shallow with varying amounts of limestone banks and rock.

Old Lands (Old Fields)

The old land community consists of small patches and strips that are spread over the whole study area and occur within other community boundaries. Typical of this community is that all the areas are low lying basins with deep fertile brown soil with almost no limestone rocks and banks within them. Two main grass species, namely *Merxmuellera cincta* and *Cynodon dactylon* occur within these areas. Another typical species, to a lesser extent, is *Nylandtia spinosa*.

Vlei

The vlei community borders the De Hoop Vlei and is the community with the largest and tallest plants in the study area. Typical are *Sideroxylon inerme, Rhus glauca, Thamnochortus fraternus, Pterocelastrus tricuspidatus* and *Euryops linearis*. This is a fairly level area with a deep fertile brown soil and with limestone banks and rocks only located in certain areas.

3.3.3 Classification and ordination of the burnt area data

Quadrats Fa and Fb are in the burnt area adjacent to the Euchaetis community (Figure 3.8). The floristic and soil features (Appendix 2) of these two quadrats are very similar to that of the Euchaetis community and from fieldwork and visits these two areas appeared to be very similar. The summary of the TWINSPAN results (Table 3.5), obtained from Appendix 4, shows that quadrats Fa and Fb are included in the Euchaetis community and this is confirmed by the ordination results (Figure 3.9). A classification and ordination was done using the same input data set as used to obtain the results in Table 3.5 and Figure 3.9, with the only difference being that the soil data was excluded from this input data set. This was done to determine the floristic similarities or dissimilarities between the vegetation samples without it being influenced by factors such as the soil features. From these results (Appendix 5, Table3.6 and Figure 3.10) it can be seen that quadrats Fa and Fb are also included in the Euchaetis community. It can therefore be said that the area surrounding quadrats Fa and Fb are very similar to that of the Euchaetis community.

Quadrats Fc and Fd are situated adjacent to the Passerina community (Figure 3.8). *Passerina galpinii*, *Rhus glauca* and *Nylandtia spinosa* characterizes the Passerina community. Even though quadrats Fc and Fd contains fairly large amounts of *Passerina galpinii* it is basically dominated by *Thamnochortus fraternus* and also contains fairly

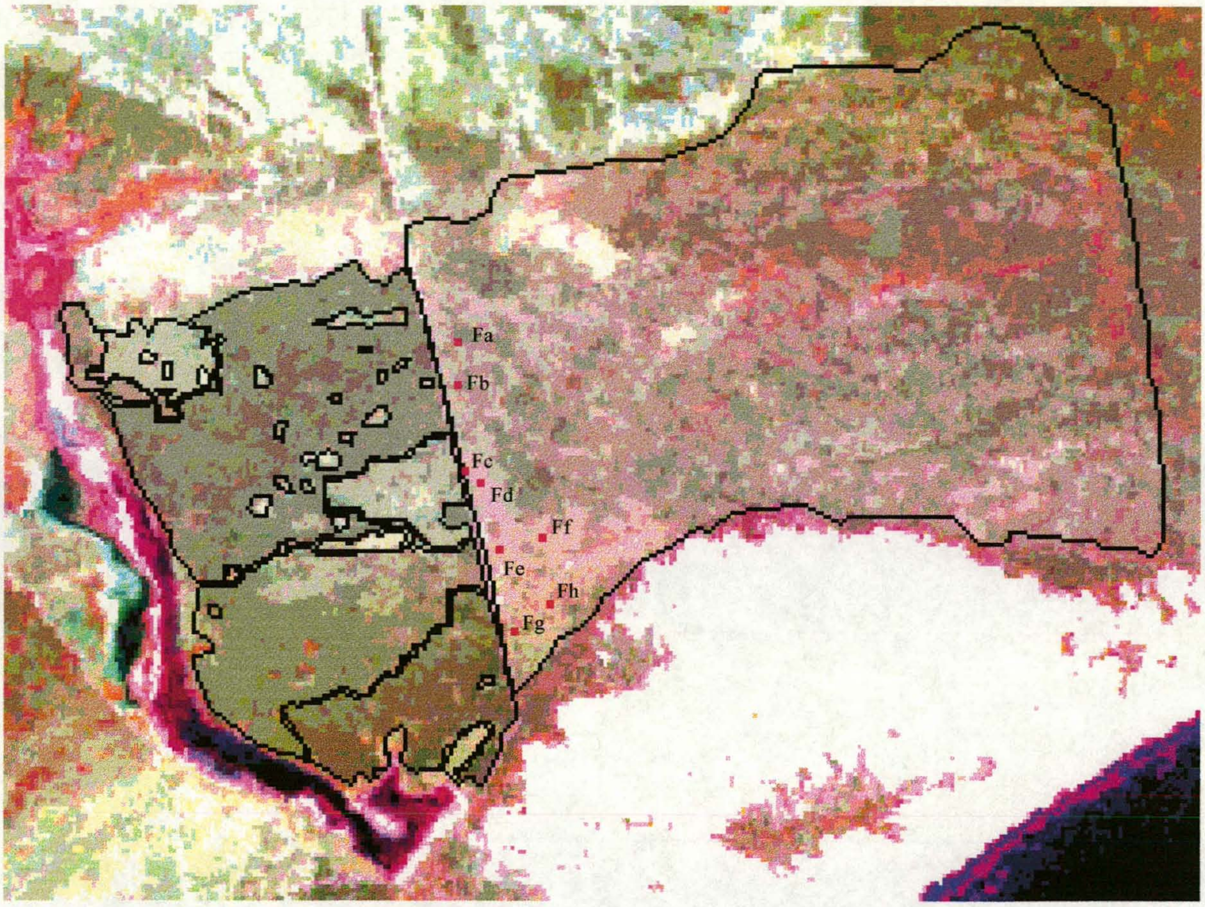

Figure 3.8 Final ground map with the burnt area as well as the burnt area quadrats.

Table 3.5 Summary of TWINSPAN results obtained from using the Euchaetis, Erica, Thatch, Passerina and Fire community quadrat data, including the Fire community quadrats' soil features, as input data to determine to which communities the Fire community quadrats belong. Quadrats laid out in the Euchaetis community is indicated by "Ea" to "Eq", Erica community by "Ha" to "Hx", Thatch community by "Ba" to "Bj", Passerina community by "Pa" to "Pi" and in the burnt area by "Fa" to "Fh".

Division of quadrats according to the TWINSPAN division obtained from Appendix 4 and including all quadrat information.

Division level 1	P P P P P P P E E E E E E E F F E E E E E E E E E F F E H H H H H H H H H H H B H H H H H H H H H H H H H F F P P B F F B B B B B B B B a e f g b d c a b c l i d g c d e f j k m n o p q a b h w n o p q x k s v m r h a b c f g h i j l t u d e e f h i f g h a c b g i j d e
Division level 2	P P P P P P P E E E E E E E F F E E E E E E E E E F F E H H H H H H H H H H H B H H H H H H H H H H H H H F F P P B F F B B B B B B B B a e f g b d c a b c l i d g c d e f j k m n o p q a b h w n o p q x k s v m r h a b c f g h i j l t u d e e f h i f g h a c b g i j d e
Division level 3	P P P P P P P E E E E E E E F F E E E E E E E E E F F E H H H H H H H H H H H B H H H H H H H H H H H H H F F P P B B B B B B B B a e f g b d c a b c l i d g c d e f j k m n o p q a b h w n o p q x k s v m r h a b c f g h i j l t u d e e f h i a c b g i j d e
Division level 4	P P P P P P P E E E E E E E F F E E E E E E E E E F F E H H H H H H H H H H H B H H H H H H H H H H H H H F F P P B B B B B B a e f g b d c a b c l i d g c d e f j k m n o p q a b h w n o p q x k s v m r h a b c f g h i j l t u d e e f h i a c b g i j
Division level 5	P P P P P P E E E F F E E E E E E E E E F F E H H H H H H H H H H B H H H H H H H H H H H H H F F a e f g b d i d g c d e f j k m n o p q a b h n o p q x k s v m r h a b c f g h i j l t u d e e f
Division level 6	E E E F F E E E E E E E E E F F E H H H H H H H B H H H H H H H H H H H i d g c d e f j k m n o p q a b h n o p q x m r h a b c f g h i j l t u

Community summary of the above data.

Community	Quadrat groupings	Quadrats not included in community	Quadrats included from other communities	Division level
Passerina	P P P P P P P a b c d e f g	P P h i		3
Euchaetis	E E E E E E E E E E E E E E E E E F F F F a b c d e f g h i j k l m n o p q a b c d		F F F F a b c d	3
Erica	H H H H H H H H H H H H H H H H H H H H H H H H B P P F F a b c d e f g h i j k l m n o p q r s t u v w x h h i e f		B P P F F h h i e f	2
Thatch	B B B B B B B B B F F a b c d e f g i j g h	B h	F F g h	1

Table 3.6 Summary of TWINSPAN results obtained from using the Euchaetis, Erica, Thatch, Passerina and Fire community quadrat data, excluding the Fire community quadrats' soil features, as input data to determine to which communities the Fire community quadrats belong. Quadrats laid out in the Euchaetis community is indicated by "Ea" to "Eq", Erica community by "Ha" to "Hx", Thatch community by "Ba" to "Bj", Passerina community by "Pa" to "Pi" and in the burnt area by "Fa" to "Fh".

Division of quadrats according to the TWINSPAN division obtained from Appendix 5, including all quadrat information except soil data.

Division level 1	E E E E E E E E E F F E P P P P P P P E E E E E E F F P E P B H H H H H H H H H H H H H H H H H H H H H H H H F F B F F B B B B B B B B a b c l h n m p e a b j b d e f a c g g i d f q k c d h o i h a b c e f g h i j k l s t u v p r w m n o q x d e f f g h a d e b c g i j
Division level 2	E E E E E E E E E F F E P P P P P P P E E E E E E F F P E P B H H H H H H H H H H H H H H H H H H H H H H H H F F B F F B B B B B B B B a b c l h n m p e a b j b d e f a c g g i d f q k c d h o i h a b c e f g h i j k l s t u v p r w m n o q x d e f f g h a d e b c g i j
Division level 3	E E E E E E E E E F F E P P P P P P P E E E E E E F F P E P B H H H H H H H H H H H H H H H H H H H H H H H H F F B B B B B B B B a b c l h n m p e a b j b d e f a c g g i d f q k c d h o i h a b c e f g h i j k l s t u v p r w m n o q x d e f a d e b c g i j
Division level 4	E E E E E E E E E F F E P P P P P P P E E E E E E F F P E P B H H H H H H H H H H H H H H H H H H H H H H H H F F B B B B B a b c l h n m p e a b j b d e f a c g g i d f q k c d h o i h a b c e f g h i j k l s t u v p r w m n o q x d e f b c g i j
Division level 5	E E E F F E P P P P P P P E E E E E E F F P E P B H H H H H H H H H H H H H H H H H H H H H H H m p e a b j b d e f a c g g i d f q k c d h o i h a b c e f g h i j k l s t u v p r w m n o q x
Division level 6	E E E F F E E E E E E F F P E P B H H H H H H H H H H H H H H H H H H H H H H H m p e a b g i d f q k c d h o i h a b c e f g h i j k l s t u v p r w m n o q x

Community summary of the above data.

Community	Quadrat groupings	Quadrats not included in community	Quadrats included from other communities	Division level
Passerina	P P P P P P P a b c d e f g	P P h i		4
Euchaetis group 1	E E E E E E E E E E F F a b c e h j l m n p a b	E E E E E E E d f g i k o q	F F a b	2
Euchaetis group 2	E E E E E E E P F F d f g i k o q h c d	E E E E E E E E E E a b c e h j l m n p	P F F h c d	4
Erica	H H H H H H H H H H H H H H H H H H H H H H H H B P F F a b c d e f g h i j k l m n o p q r s t u v w x h i e f		B P F F h i e f	3
Thatch	B B B B B B B B B F F a b c d e f g i j g h	B h	F F g h	1

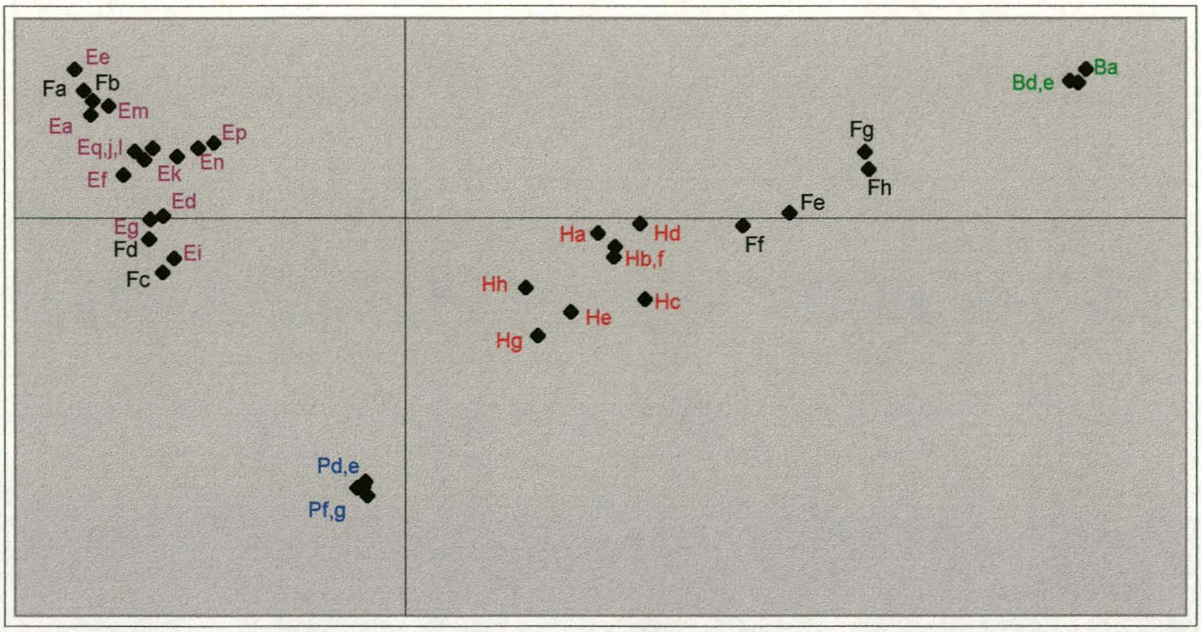

Figure 3.9 SIMCA ordination of the quadrats of the Passerina community (indicated by "P"), Euchaetis community (indicated by "E"), Erica community (indicated by "H"), Thatch community (indicated by "B") and the Fire community (indicated by "F"), including the soil features of the Fire community.

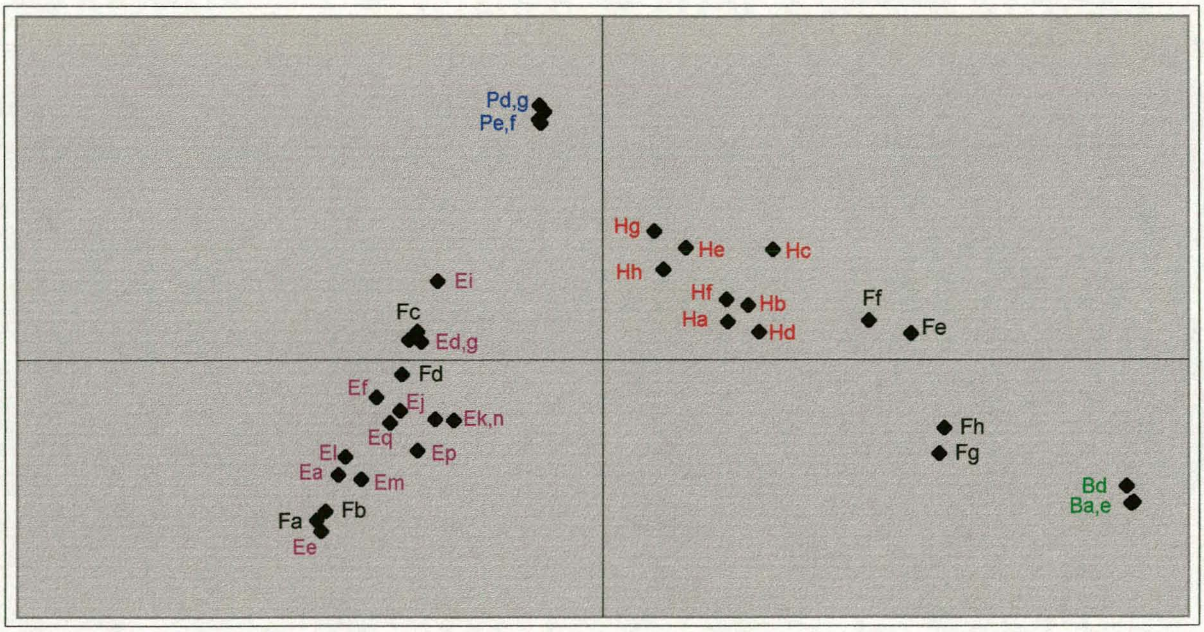

Figure 3.10 SIMCA ordination of the quadrats of the Passerina community (indicated by "P"), Euchaetis community (indicated by "E"), Erica community (indicated by "H"), Thatch community (indicated by "B") and the Fire community (indicated by "F"), excluding the soil features of the Fire community.

large amounts of *Euchaetis meridionalis* and *Erica bruniifolia*. Floristicly there are major differences between these two neighboring areas. The species composition of quadrats Fc and Fd are more similar to that of the Euchaetis community and this is also verified by the classification (Table3.5 and 3.6) and ordination (Figure 3.9 and 3.10) results. Even though these results strongly suggests that the area surrounding quadrats Fc and Fd are the same as that of the Euchaetis community, structurally there is a very big difference and certain key species such as *Leucadendron muirii* are absent within this area. It can therefore be concluded that quadrats Fc and Fd are not the same as the neighboring Passerina community and although there are certain similarities, they are not the same as the Euchaetis community.

Quadrats Fe and Ff are adjacent to the Erica community (Figure 3.8). Floristicly this area is similar to that of the Erica community by having large amounts of *Erica vernicosa* and fair amounts of *Chondropetalum microcarpum*, but it differs by lacking *Thamnochortus fraternus* and *Passerina galpinii* and having large amounts of *Erica inops*. Based on the difference in species composition between the two areas, it would be safe to say they are not the same communities even though according to the classification (Table 3.5 and 3.6) and ordination (Figure 3.9 and 3.10) results they are. The high level of similarity of the classification and ordination results can most probably be attributed to the large amounts of *Erica vernicosa* in quadrats Fe and Ff.

Quadrats Fg and Fh are located adjacent to the thatch community (Figure 3.8). The vegetation within these two quadrats and their surrounding area is characterized by *Thamnochortus insignis*, *Chondropetalum microcarpum*, *Erica vernicosa* and *Phylica axillaris*, while the Thatch community is mainly dominated by *Thamnochortus insignis* and *Erica vernicosa*. Even though there are similar species occurring in both areas, the percentage cover of these similar species differs greatly between the two areas and there are also various species that do not occur in both areas. There is also a big structural difference between the two areas. According to the classification results in Table 3.5 and 3.6 quadrats Fg and Fh can possibly belong to the Thatch community. These results can most probably be attributed to the occurrence of *Thamnochortus insignis* and *Erica* *vernicosa* in both areas. According to the ordination results (Figure 3.9) obtained for the same input data set as for Table 3.5, quadrats Fg and Fh fall halfway between the Erica and Thatch communities, indicating it as belonging to neither these communities and possibly being a community on its own. The same results were obtained from Figure 3.10 as for that obtained in Figure 3.9. Even though there are similarities between the Thatch community and quadrats Fg and Fh, which is confirmed by the classification results, there are still enough dissimilarities not to include these two quadrats within the Thatch community or any other community.

The possibility of the communities within the burnt area needing more time to mature is very doubtful since the vegetation in the burnt area is already eight years old. McDonald (1993) mentions a fire that occurred in the Boosmansbos wilderness area in the Langeberg in February 1988 and by April 1991 the communities in the burnt area had already recovered significantly enough to be described in a vegetation classification study. It can therefore be considered that the communities within the burnt area, bordering the study area are already mature enough to be described and to give reliable and interpretable classification and ordination results.

3.4 Discussion

Description of fynbos vegetation is a very complex process and much debate has surrounded this process (McDonald 1993). Various methods have been used in attempts to classify the floristically complex vegetation into meaningful and practical units that are interpretable by scientists and managers.

Two approaches to the classification of fynbos have been used, namely the floristic approach and the structural approach. The floristic approach has been based mainly on the methodology of the Zürich-Montpellier school of phytosociology (Braun-Blanquet 1932). However one of the problems facing phytosociologists in the fynbos of the Cape is the great diversity of habitats and plant species. Floristic techniques have demanded high skills in identifying plants in the field and this places high demands on the ecologist's ability in field taxonomy for limited returns in ecological understanding. This reduces the generality and usefulness of a formal phytosociological approach to local studies in small areas (Bond 1981, Campbell 1996).

A structural technique was thus used for the description of the vegetation within the study area (Campbell, Cowling, Bond and Kruger 1981). However, although this structural description method provides a comprehensive typology of the fynbos vegetation, it lacks the floristic information found in phytosociological studies, which is needed for the classification and ordination process of the quadrat data. It was therefore decided to include a floristic description of the vegetation within the quadrats in terms of species composition and percentage cover of the species. This floristic description of the quadrat data allowed for effective classification and ordination of the data, which lead to the effective description of the different communities within the study area.

The possible ecotone areas identified within the study area were included in the communities within the study area and not described as ecotone areas. This decision was based on the floristic and structural similarities between these communities and the possible ecotone areas. Scale also played an important role in this decision. The size of the possible ecotone areas is very small compared to the size of the surrounding communities.

Only after the final decision had been made that the possible ecotone areas must be included with the other communities within the study area, could a very accurate ground map be drawn. This ground map is based not only on the classification and ordination results, but also on fieldwork, field visits and numerous GPS readings and therefore represents the true community boundaries as they occur in the field. This final ground map would serve as the norm against which the effectiveness of the Landsat satellite imagery's ability to indicate fynbos vegetation communities would be measured.

The burnt area bordering the study area to the east delivered some surprising results. From the fieldwork, classification and ordination results it was concluded that only the two quadrats opposite the Euchaetis community are the same as the Euchaetis community. The other quadrats and their surrounding areas differ from the communities they border within the study area. The next step would be to determine through image processing if the communities in the study area were actually part of the communities within the burnt area before the fire. If this is proven to be right, it will lead to some very interesting questions to be answered such as does a fynbos community return to its original state after a fire? If not, how much does the species composition change within the community after the fire and do we actually lose some very important species within a specific community without even knowing it? Is it possible that the difference between a hot and cold fire within an area can lead to a total new community? It is well known that fynbos is driven by fire (Le Maitre and Midgley 1992), but isn't the process even more dynamic in terms of changes over time than we realize?

The definition of the study area in terms of its different vegetation communities and their boundaries has been very accurate and resulted in a ground map representing these study area communities as they occur in the field. It will be seen through the process of image processing if the Landsat images delivers the same community boundaries as that was found in this chapter.

Chapter 4

Image Processing

The only paradise we ever need – if only we had the eyes to see.

- Edward Abbey

4.1 Introduction

The purpose of this portion of the study is to determine if the vegetation communities that occur in the field can be defined by means of image processing. Seven annual Landsat images of the study area were available, the feasibility of using Principal Component Analysis (PCA) to reduce several years' Landsat satellite imagery to a smaller and more manageable set of imagery bands will therefore also be investigated. The objectives of such a smaller set of imagery data, representing several years imagery, will be to retain the essential elements included in the original input data sets that is necessary for effective vegetation description and classification by means of image processing, while reducing natural variation and noise included in the imagery. Such representative imagery of several years' data will serve as baseline imagery for a specific area and a specific time period. The objectives of such baseline imagery would be to serve as a norm for a specific area and time period in terms of the type of vegetation communities, community size, specific community location and borders that occurs in the applicable area. This baseline imagery would also serve as the norm against which all vegetation community change that occurs within the applicable area over time will be measured.

The representative imagery as well as 1997 imagery would then be used in supervised maximum likelihood classifications to determine the vegetation communities as defined by image processing within the study area. A classification accuracy assessment would then be done by comparing these supervised maximum likelihood classified images with the accurate ground map as obtained in Chapter 3. The accuracy assessment would indicate how effectively the vegetation communities are defined within the classified images compared to the actual vegetation communities as they occur in the field. The accuracy assessment would also indicate if the representative imagery obtained by means of PCA actually reduces the amount of natural variation and noise that occurs within the separate years' imagery. The results of the accuracy assessment would thus indicate the feasibility of using PCA to obtain representative imagery to be used in the future as baseline imagery for a specific area and time period.

The area that lies to the east of the study area and that burnt in 1991 would also be investigated by means of image processing. The objective was to determine if the communities within the study area and bordering the burnt area actually spread into the burnt area before the fire. If this is proven to be so, the assumption may be made that these communities in the burnt area would recover in time to their original state. The recovery of the burnt area would be measured against the neighboring study area by means of image processing.

4.2 Methods

4.2.1 Spatial data

Spatial data used in the study is Landsat Thematic Mapper (TM) data acquired in February of each of the following years, namely 1990, 1991, 1993, 1994, 1995, 1996 and 1997. The reason for acquiring TM data during the month of February for each year is due to the lack of cloud cover over the study area during this period.

Out of the seven spectral bands obtained by the Landsat TM scanner, only six were used in this study. These six spectral bands were from the blue (band 1), green (band 2), red (band 3), near infrared (band 4) and mid-infrared (bands 5 and 7) portion of the spectrum, excluding the thermal (band 6) portion of the spectrum. Band 6 was not included for the reason of the independent character of thermal data compared to the reflective data measured by Landsat and the characteristics of the thermal portion of the spectrum was not necessary to meet the objectives of the study. The dominant surface features contributing different thermal responses are not related to those contributing optical reflectance (Franklin 1992, Fox and Stuart 1994). The TM data used in the study have a spatial resolution of 30 m (Szekielda 1988).

TM data was georeferenced to the Latitude/Longitude spherical co-ordinate grid reference system and degrees were used as the reference units. The reason for this being so that the reference system of the TM imagery can coincide with that of the GPS that was used for the study and the 1:50 000 maps that cover the study area and were used for referencing purposes.

The study area as well as the burnt area next to it was selected from the larger TM data set and this selected area was used for further image processing. This section of the TM data was then spatially georeferenced to its exact known ground position by using 10 well distributed ground control points. This was done in order to minimize the positional error of the imagery. Registration error is decreased with an increase in the number of ground control points. Sixteen is recommended as a reasonable number of ground control points and these points must be well distributed throughout the image and must be of a very high accuracy (Colwell 1983). In this study it was possible to select ten very well distributed ground control points of a very high accuracy. Increasing the number of ground control points would have meant selecting points with lesser accuracy and this would have led to an overall decrease in accuracy. It was therefore decided to rather use fewer ground control points of a very high accuracy than to decrease the overall accuracy by selecting more ground control points of a low accuracy.

4.2.2 Representative image

Principal Component Analysis (PCA) is a commonly used technique in remote sensing (Ingebritsen and Lyon 1985, Davis 1986, Fung and LeDrew 1987, Eastman and Fulk 1993) and was used to isolate components within the multispectral data of the years 1990, 1991, 1993, 1994, 1995, 1996 and 1997 that were most useful in portraying the essential elements of these years' data to create a representative image of all these years. The representative imagery obtained by means of PCA reduces the amount of natural variation, noise and temporal variability that influences the Landsat TM data (Delcourt, Delcourt and Webb 1983, Forman and Gordon 1986). The components thus obtained enhance the contrast of the data set (Ahern and Sirdis 1989) and this allows for adequate discrimination between all communities present (Belward and Taylor 1986, Lo, Scarpace and Lillesand 1986). Spectral characteristics depend not only on the composition of the surface but also on the conditions under which they are measured (Szekielda 1988). This natural variation and noise can be caused by factors such as time of day data was obtained, wind velocity and direction, haze, topographic shadowing, air and soil temperature and moisture, sun angle, and the rainfall pattern of the weeks and even months before the TM data were obtained (Ayyad 1981, Talbot and Markon 1986, Dymond, Page and Brown 1996, Maxwell and Hoffer 1996).

In order to accomplish accurate detection of real changes in vegetation cover, some method of data normalization is required to remove unwanted changes in spectral reflectance (Jensen 1996). PCA was used to identify the optimum linear combination of the original bands that accounts for environmental variation and then to transform these image bands of the various years used in the study into new bands or components (Gould 1967). These components are uncorrelated with one another and therefore each carries seprate information. PCA provides a convenient method of data compression and removal of redundant correlation between bands (Taylor 1974, Lasserre, Malan and Turner 1983). They are ordered in terms of the amount of image variation they can explain and therefore the first component carries most of the real information in the original band set and the latter components only describe minor variations (Chavez and Kwarteng 1989, Loughlin 1991). The components are thus a statistical abstraction of the variability inherent in the original band set (Walsh, Cooper, Von Essen and Gallager 1990).

All six bands of the mentioned seven years were used to obtain a set of bands that could be used for interpretation purposes and to obtain one representative image of these seven years. Band 1 of every year was put into a PCA and this process was repeated for band series 2-6. By doing a PCA on band series 1-6 instead of the TM data for the various years a set of components was obtained for each band series. The results of the PCA done on these data sets can be seen in Appendix 6. Component 1 of each of these sets of components includes most of the environmental variation of that specific data set while temporal data is included from component 2 onwards (Yuan 1990). The component 1 obtained from the PCA done for instance on all bands 1 of all seven years thus include most of the environmental variation included in the separate bands 1 of all the years. In this manner six component 1's were obtained that included most of the environmental variation of the various years information that was available for this study and these components could be transformed back to bands for classification and interpretation purposes. Thus by using PCA, six bands were obtained that represents imagery of all seven years.

These six bands representing the seven mentioned years used in the study could not be used for image processing purposes for the reason that they were in a transformed format and had to be reconstructed in the original byte/binary format. This was done by means of eigenvector transformation. The average eigenvector for each component 1 from each PCA was obtained and each component 1 was multiplied by its average eigenvector. The result of this was then converted to byte/binary format and the bands could now be used for image processing purposes. The sequence that has been followed to obtain the above mentioned representative imagery of the applicable seven years is depicted in Figure 4.1.

4.2.3 Supervised classification

The use of supervised maximum likelihood classification for high resolution remotely sensed data is extremely widespread (Maselli, Conese and Petkov 1994) and has several advantages, mainly connected with its theoretical simplicity and its statistical stability and robustness (Swain and Davis 1978, Strahler 1980, Colwell 1983, Schowengerdt

1983, Yool, Star, Estes, Botkin, Eckhardt and Davis 1986). A set of seven classes, representing the seven different communities, as obtained in Chapter 3 were used for the classification process and training sites were obtained from these seven different communities. These different communities are summarized in Table 4.1, which shows the permanently recognizable dominant species and soil features of each community. Training sites were positioned within these seven different communities away from the edges of contrasting communities so that they do not include edge pixels. Data within each training site for each community were examined by obtaining a frequency histogram for the spectral signatures contained in each training site. These histograms all had a unimodal frequency distribution for each spectral band to be used and this indicated spectral homogeneity for the applicable training sites.

Table 4.1 The seven different communities with their dominant species and soil features, representing the seven different classes as used for the supervised classification.

Community	Dominant species	Soil
1. Renoster	*Elytropappus rhinocerotus, Rhus glauca, Nylandtia spinosa*	Deep fertile brown soil and limestone rocks spread evenly over area with very few limestone banks.
2. Thatch	*Thamnochortus insignis, Elytropappus rhinocerotus, Erica vernicosa*	Deep white sandy soil with no stones or banks.
3. Passerina	*Passerina galpinii, Rhus glauca, Nylandtia spinosa*	Deep fertile brown soil with very few limestone rocks and banks, but with large amounts of white pebbles.
4. Euchaetis	*Thamnochortus fraternus, Passerina galpinii, Euchaetis meridionalis, Leucadendron murii, Chondropetalum microcarpum, Erica bruniifolia*	Shallow white sandy soil with large amounts of limestone rocks and banks.
5. Erica	*Thamnochortus fraternus, Passerina galpinii, Chondropetalum microcarpum, Erica vernicosa*	White sandy soil, ranging from deep to very shallow with very few to large amounts of limestone rocks and banks.
6. Old Lands	*Merxmuellera cincta, Cynodon dactylon, Nylandtia spinosa*	Deep fertile brown soil with no stones or banks.
7. Vlei	*Sideroxylon inerme, Rhus glauca, Thamnochortus fraternus, Euryops linearis, Pterocelastrus tricuspidatus*	Deep fertile brown soil with limestone rocks and banks in certain areas.

The supervised maximum likelihood classification was based only on Landsat TM data and involved standard iterative training, classification and refinement until an acceptable

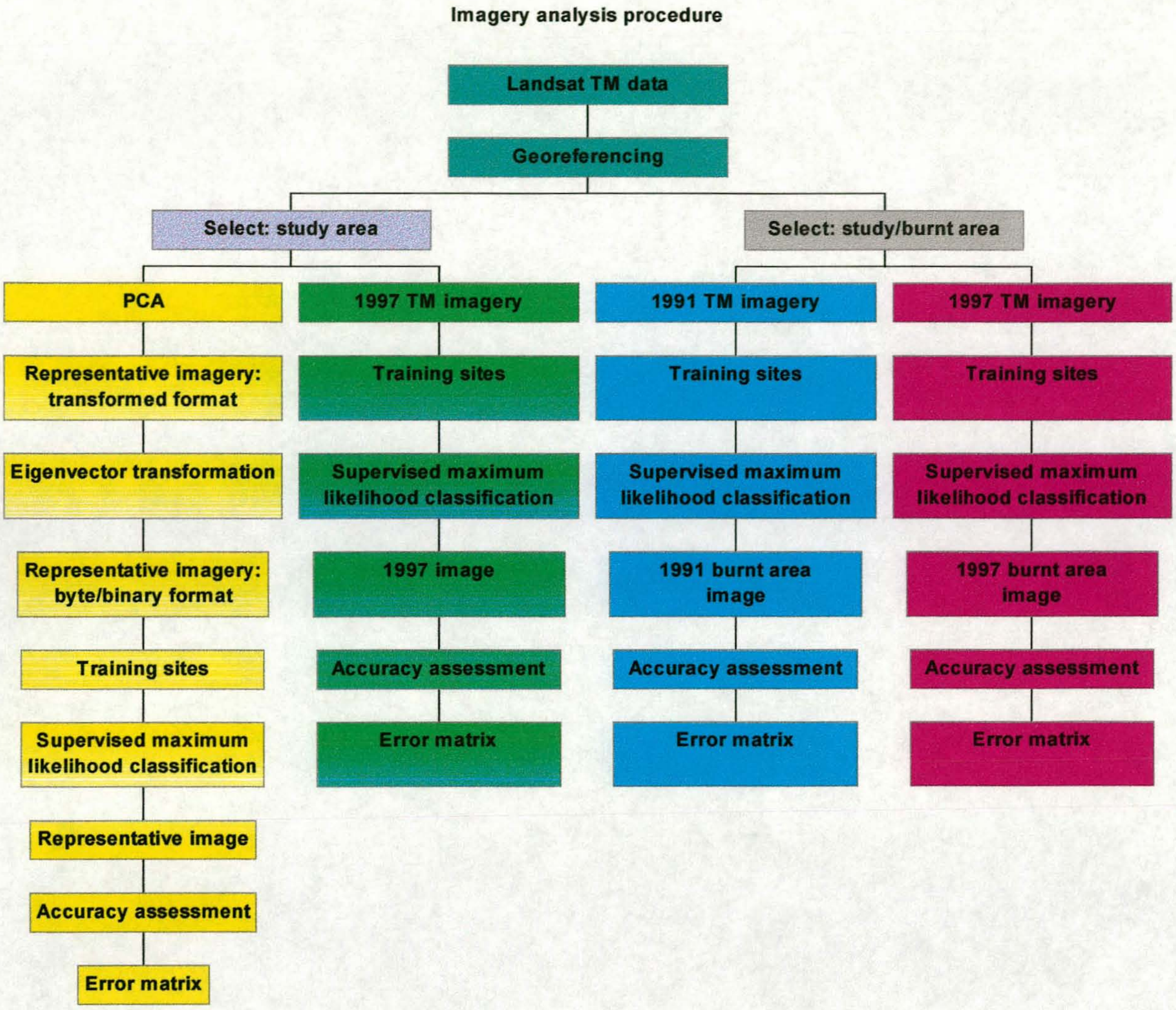

Figure 4.1 Indicated is the analysis procedures followed during image processing.

classification was reached (Richards 1986, Lillesand and Kiefer 1987). Six spectral bands were employed in the classification process, namely the blue, green, red, near infrared and the two mid-infrared bands. This combination of bands was used to capture nearly all the information contained in the TM data and to provide the best possible balance between processing efficiency and classification accuracy.

Two supervised maximum likelihood classifications were done on the TM data that contained the study area as well as the neighboring burnt area and the complete imagery analysis process is depicted graphically in Figure 4.1. The possibility that the communities within the study area bordering the burnt area actually spread into the burnt area before the fire is investigated by means of the supervised maximum likelihood classification done on the 1991 TM imagery. The 1991 TM imagery used in the supervised maximum likelihood classification were obtained before the fire in 1991. This classified image would be referred to as the 1991 burnt area image. If the study area communities bordering the burnt area actually do spread into the burnt area, the assumption is made that these communities would recover to their original state with time. This assumption is investigated by means of the supervised maximum likelihood classification done on the 1997 TM imagery. This classified image will be referred to as the 1997 burnt area image.

A supervised maximum likelihood classification was done on a selected area that contained only the study area. TM imagery of the year 1997 was used for the classification. The reason for classifying only the study area is to indicate the communities within this area and to compare these communities with those obtained in Chapter 3 by using the accurate ground map. TM data of 1997 were used because it was the latest data available for the study and the composite image that was used for referencing purposes during fieldwork was obtained by using the 1997 TM data. This classified image is referred to as the 1997 image and the procedures followed to obtain this image are shown graphically in Figure 4.1.

The six bands obtained by means of Principal Component Analysis were used in a supervised maximum likelihood classification to obtain the representative image of the seven applicable years. This image is referred to as the representative image in the future. The representative image contained the same selected area of the study area as that of the 1997 image to enable future comparisons between the two classified images.

4.2.4 Accuracy assessment

An accuracy assessment was done on the 1997 and representative images by means of determining the classification error (Gershmehl and Napton 1982). Classification error is based on the detailed assessment of the agreement between the 1997 and representative images and a reference map, which in this case is represented by the accurate ground map as obtained in Chapter 3. The units of comparison that were used in the accuracy assessment were pixels of the applicable images.

An error matrix was used to report the classification error (Belward and Valenzuela 1991, Congalton 1991, Sample 1994, Langford and Bell 1997). The left-hand side (y-axis) of the matrix is labeled with the vegetation categories on the reference map as follows: Renoster, Vlei, Euchaetis, Passerina, Erica, Thatch and Old Lands. The upper edge of the matrix (x-axis) is labeled with the same categories as that for the y-axis and these categories refer to those on the 1997 and representative images. The error matrix reveals the results of a comparison of the evaluated and reference images.

Each of the three images used for the accuracy assessment was georeferenced to the same co-ordinate grid reference system. These images were then finally spatially georeferenced to their exact known ground positions by using the same set of ground control points. This was done to minimize errors in the accuracy assessment.

The percentage of pixels correctly classified for each of the seven communities were used as a measure of the accuracy that was achieved by the supervised maximum likelihood classification that was used to obtain the 1997 and representative images. The overall percentage of correctly classified pixels were then determined for each of the 1997 and representative images by dividing the sum of correctly classified pixels by the total number of pixels examined (Hord and Brooner 1976, Congalton, Mead and Oderwald 1983, Story and Congalton 1986). For each of the seven applicable communities, errors of omission and errors of commission were determined. Errors of omission are, for example, the assignment of pixels of the Euchaetis community on the ground to the Erica community on the image, in other words, an area of "real" Euchaetis community on the ground has been omitted from the 1997 and representative images. An error of commission would be to assign an area of the Erica community on the ground to the Euchaetis community on either the 1997 or representative image. By examining the relationship between errors of omission and errors of commission, insight is gained into the varied reliabilities of communities identified in the 1997 and representative images and it is also an indication of the performance of the supervised maximum likelihood classification that was used to generate the 1997 and representative images (Campbell 1996).

4.3 Results

4.3.1 The 1997 image

The results of the supervised maximum likelihood classification of the 1997 TM imagery can be seen in Figure 4.2, the seven vegetation communities as obtained from fieldwork, classification and ordination in Chapter 3 are also indicated in Figure 4.2. The accuracy assessment done on the 1997 image was done using this figure and the results are indicated in Table 4.2.

From Table 4.2 it can be seen that 56.37% of the Renoster community was correctly classified. Most of the pixels that were omitted from the Renoster community were classified as Passerina pixels. The Renoster community is dominated by *Elytropappus rhinocerotus*, while the Passerina community is dominated by *Passerina galpinii*. These two plant species are very similar in their appearance, structure, leaf form and height and

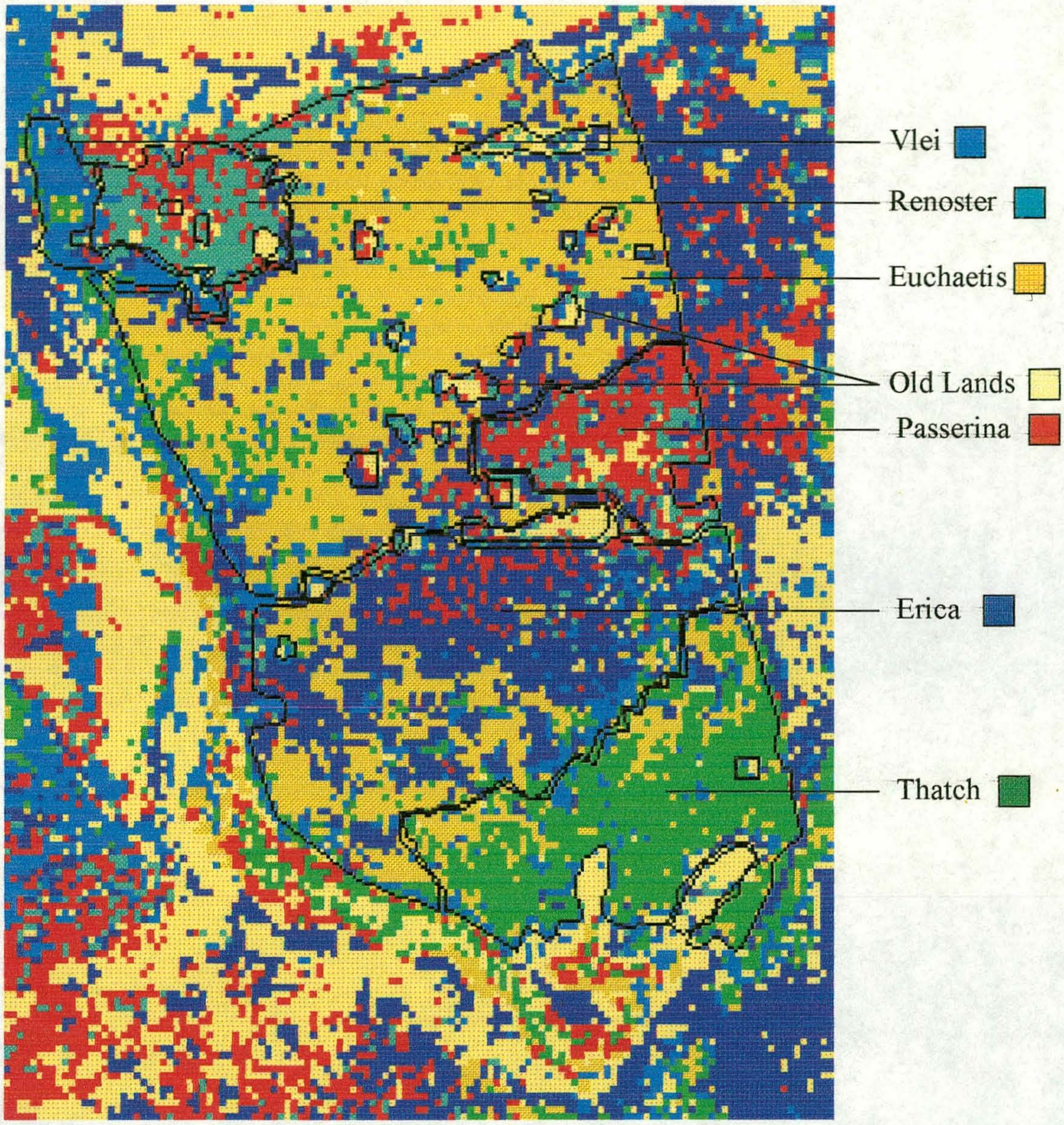

Figure 4.2 The supervised maximum likelihood classification of the 1997 TM imagery.

Table 4.2 Error matrix indicating the accuracy assessment done on the 1997 supervised maximum likelihood classified image, including the errors of omission and errors of commission.

Groundmap communities	Communities evaluated in the 1997 image										
	Renoster	Vlei	Euchaetis	Passerina	Erica	Thatch	Old Lands	Totals	A%	EO%	EC%
Renoster	239	19	1	110	26		29	424	56.37	43.63	80.90
Vlei	10	136	10	7	24	30	12	229	59.39	40.61	291.27
Euchaetis	110	205	2447	105	682	307	97	3953	61.90	38.10	23.65
Passerina	134	4	2	293	79		51	563	52.04	47.96	74.78
Erica	30	262	619	149	1120	131	61	2372	47.22	52.78	39.97
Thatch		153	274	1	64	927	48	1467	63.19	36.81	32.45
Old Lands	59	24	29	49	73	8	183	425	43.06	56.94	70.18
Totals	582	803	3382	714	2068	1403	481	9433			

Total number of pixels evaluated: 9433
Total number of pixels correctly classified: 5345
Percentage correctly classified pixels: 56.66%

Note. A%, accuracy percentage; EO, errors of omission; EC, errors of commission.

Table 4.3 Error matrix indicating the accuracy assessment done on the representative supervised maximum likelihood classified image, including the errors of omission and errors of commission.

Groundmap communities	Communities evaluated in the representative image										
	Renoster	Vlei	Euchaetis	Passerina	Erica	Thatch	Old Lands	Totals	A%	EO%	EC%
Renoster	269	12	1	116	15		11	424	63.44	36.56	58.96
Vlei	7	180	3	10	7	13	9	229	78.60	21.40	272.05
Euchaetis	74	213	2620	261	441	247	97	3953	66.28	33.72	7.92
Passerina	112	4	7	386	28		26	563	68.56	31.44	91.30
Erica	14	230	197	62	1624	185	60	2372	68.47	31.53	25.17
Thatch		131	84	2	65	1088	97	1467	74.16	25.84	30.88
Old Lands	43	33	21	63	41	8	216	425	50.82	49.18	70.59
Totals	519	803	2933	900	2221	1541	516	9433			

Total number of pixels evaluated: 9433
Total number of pixels correctly classified: 6383
Percentage correctly classified pixels: 67.67%

Note. A%, accuracy percentage; EO, errors of omission; EC, errors of commission.

both species cover most of the area within the specific community in which they occur. Both communities are also characterized by a deep fertile brown soil. These similarities between the two communities can lead to classification confusion when classifying them. The Passerina community has 52.04% correctly classified pixels, while the biggest percentage of pixels omitted from the Passerina community is classified as Renoster pixels. This serves as a verification of the above mentioned explanation of confusion that arises with the classification of the Renoster and Passerina communities.

According to Table 4.2, the Euchaetis community has 61.90% correctly classified pixels. Most of the pixels omitted from the Euchaetis community are classified as either pixels of the Erica or Thatch communities. It can be seen from the field, classification and ordination results obtained in Chapter 3 that the Euchaetis and Erica communities are very similar. The soils of these two communities are also very similar in certain areas. This also probably led to a substantial amount of Euchaetis community pixels being classified as Erica pixels. Looking at the Erica community it can be seen that only 47.22% of the community were actually classified as Erica community. The biggest percentage of pixels omitted from the Erica community was classified as Euchaetis pixels. The reason for this being the same as mentioned with the classification of the Euchaetis community. Quite a substantial amount of the Euchaetis community pixels were classified as Thatch pixels. The Thatch community is dominated by *Thamnochortus insignis*, while large amounts of *Thamnochortus fraternus* occurs within the Euchaetis community. These two species are very similar in appearance and this is probably the reason why certain pixels within the Euchaetis community that contain large amounts of *Thamnochortus fraternus* have been classified as being Thatch. In the Thatch community 63.19% of the pixels were classified as being Thatch pixels and the largest percentage of pixels omitted from the Thatch community are classified as Euchaetis. This is probably because of the similarities between the *Thamnochortus insignis* and *Thamnochortus fraternus* species that occurs in these two communities.

The Vlei community is indicated as having 59.39% correctly classified pixels as can be seen from Table 4.2. Most of the pixels omitted from the Vlei community are classified as being either Erica or Thatch. The reason for so many Vlei pixels being classified as Erica pixels can be attributed to most of these pixels being on or near the Vlei community boundary and thus possibly being mixed pixels. These mixed pixels consist of vegetation typical of the transition area between communities and thus in this case of Vlei and possibly Renoster and/or Euchaetis vegetation. These mixed pixels lead to classification confusion and therefore they are classified as something totally different from the Vlei community they are supposed to be. These mixed pixels thus lead to a decrease in classification accuracy which also effects the accuracy assessment (Campbell 1981, Campbell 1996). The same explanation as was used for Vlei pixels being classified as Erica pixels can be applied to some of the omitted pixels within the Vlei community being classified as Passerina pixels. From fieldwork done in the Vlei community it was found that the small patch (Figure 4.2) of pixels that has been classified as being Thatch and Euchaetis pixels is a patch that is dominated by *Elytropappus rhinocerotus* and *Rhus glauca* within the Vlei community. A very important aspect of training sites is that all cover types in the scene must be adequately represented (Scholz, Fuhs and Hixson 1979). This specific area occurred as a very small patch only within the Vlei community and was thus not regarded, treated and described as a separate community. This resulted in this small patch being forceably classified into one of the other communities. Due to the fact that the spectral signature received from this area is most probably the closest to the Thatch or Euchaetis communities it was classified as being part of these communities. The Renoster community borders the Vlei community (Figure 4.2) and the pixels that are classified as being Renoster within the Vlei community lie on this border and it is thus more a border effect, than pixels within the Vlei community actually being classified as Renoster.

The Old Land community consists of small, normally circular areas that are included within other communities and almost form small islands within these communities, it is not therefore a contiguous community as is the case with the other communities. The purpose of describing and classifying such small areas in such fine detail within the study area is to be able to make more precise statements about any given point in the image (Webster and Beckett 1968). Classification accuracy decreased by the increase of precision by trying to classify these small Old Land areas into detailed classes. The Old Lands community has a 43.06% classification accuracy (Table 4.2). Due to the small size and shape of the Old Land areas, much confusion developed with the classification of these areas and many of these Old Land areas consists out of pixels that includes Old Land features as well as neighboring community features. Some of these Old Land areas are so small that they consist mostly of these mixed pixels and the accuracy of allocation is thus affected (Campbell 1981, Campbell 1996). These Old Lands are mostly low lying basins with deep fertile brown soil which are waterlogged after good rains, because of this, no large species such as *Sideroxylon inerme* (Milkwood) occurs within them. Very large *Sideroxylon inerme* trees do occur on many of the edges of these Old Land patches where it is drier and the soil is still deep and fertile. This leads to a further increase in the mixed pixel affect, which plays a very important role in the classification accuracy of the Old Lands. Either the species *Cynodon dactylon* or *Merxmuellera cincta* dominates the Old Land areas. Even though these two grass species differ structurally from each other they give the same reflectance due to their colour and thus the same classification results are achieved (Graetz and Gentle 1982). The *Cynodon dactylon* is not such a densely growing species as *Merxmuellera cincta* and in certain Old Land patches this could lead to classification confusion due to exposed soil (Miller and Pearson 1971, Tucker 1977, Rao, Brach and Mack 1978, Huerte, Jackson and Post 1985). Some of these Old Land patches have got various densities of *Nylandtia spinosa* and/or *Relhania uniflora* in them and this might also influence the classification process. It can thus be seen that classification errors do occur in the case of the Old Land community mainly because of the small size of these areas. Even though there is much variation in the classification results of the Old Land community these areas can still be recognized on the classified image (Figure 4.2). The boundaries of these Old Land patches in the 1997 image (Figure 4.2) might differ slightly from those on the ground map, but they can still be identified.

A total of 56.66% of the 1997 image has been classified correctly according to the accuracy assessment (Table 4.2) done on Figure 4.2. Reasons have been given in the above paragraphs for obtaining the percentage correctly classified pixels for each community as well as explaining each communities' omitted pixel composition. By using a pixel-by-pixel comparison to determine classification accuracy, the border areas between communities were included as well. Pixels that fall on these boundaries between communities often contain features of both the communities and thus have digital values unlike either of the two communities represented and are then misclassified (Campbell 1981, Campbell 1996). These mixed boundary pixels were thus included in the error assessment and this led to a decrease in perceived classification accuracy as obtained from the error matrix.

Not all the differently classified pixels within a particular community are misclassified due to classification confusion and the effect of mixed pixels. The communities within the study area are not completely homogeneous and contain small areas that are not truly representative of the applicable community. This is because of physical and botanical differences that occur between the major part of the community area and these small areas that are included within the community boundaries. Due to these differences, different spectral signatures are obtained for these pixels. This results in these pixels either being classified as belonging to one of the other communities because they actually do belong to another community or as being forceably classified into one of the seven possible communities because they do not have a representative spectral signature. Pixels that have been classified differently within a community as belonging to another community are thus classified differently because they contain different physical and botanical features than the majority of pixels within the community they occur in. This results in the overall classification accuracy of a particular community being perceived lower than the actual classification accuracy of such a community. The Renoster community for instance is not completely homogeneous and in certain areas species such as *Relhania uniflora* occur in quite big patches within the Renoster community (Appendix 1 and 2). Spectral signatures obtained from such areas within the Renoster community has resulted in the applicable pixels being classified as belonging to another community. This led to an increase in the percentage pixels classified differently in the Renoster community, but not necessarily wrongly classified. The effect of these pixels being classified differently due to the community not being totally homogeneous is applicable to all study area communities.

The 56.66% accuracy obtained for the 1997 image could thus have been higher if these border areas as well as the different smaller areas within the larger communities had been excluded from the accuracy assessment, but it could have introduced bias. The character of the study area thus contributes to the potential classification error of the image (Campbell 1996). It was therefore decided not to change or adapt the error assessment approach used in the study.

4.3.2 The representative image

The representative image obtained by means of the supervised maximum likelihood classification done on the representative imagery obtained from the Principal Component Analysis can be seen in Figure 4.3. The results of the accuracy assessment done on the representative image is summarized in the error matrix in Table 4.3.

From Table 4.3 it can be seen that 63.44% of the Renoster community were classified correctly in Figure 4.3. This is an improvement of 7.07% compared to the Renoster community of the 1997 image. Most of the pixels omitted from the Renoster community were classified as Passerina pixels. The same pattern were observed with the 1997 image, the reason being the similarities between the *Elytropappus rhinocerotis* that dominates the Renoster community and the *Passerina galpinii* that dominates the Passerina community and the similarities between the two communities' soils. In the Passerina community 68.56% were classified correctly and most of the pixels that were omitted were classified as Renoster community pixels. The same pattern was observed in the 1997 image except that in the representative image there is a classification improvement of 16.52% compared to the Passerina community in the 1997 image.

From Table 4.3 it can be seen that 66.28% of the Euchaetis community were classified correctly compared to the 61.90% of the Euchaetis community in the 1997 image. This is a classification improvement of 4.38% compared to the 1997 image. Very much the same pattern is observed in the representative image as in the 1997 image in terms of omitted pixels. In the Erica community 68.47% of the community has been correctly classified,

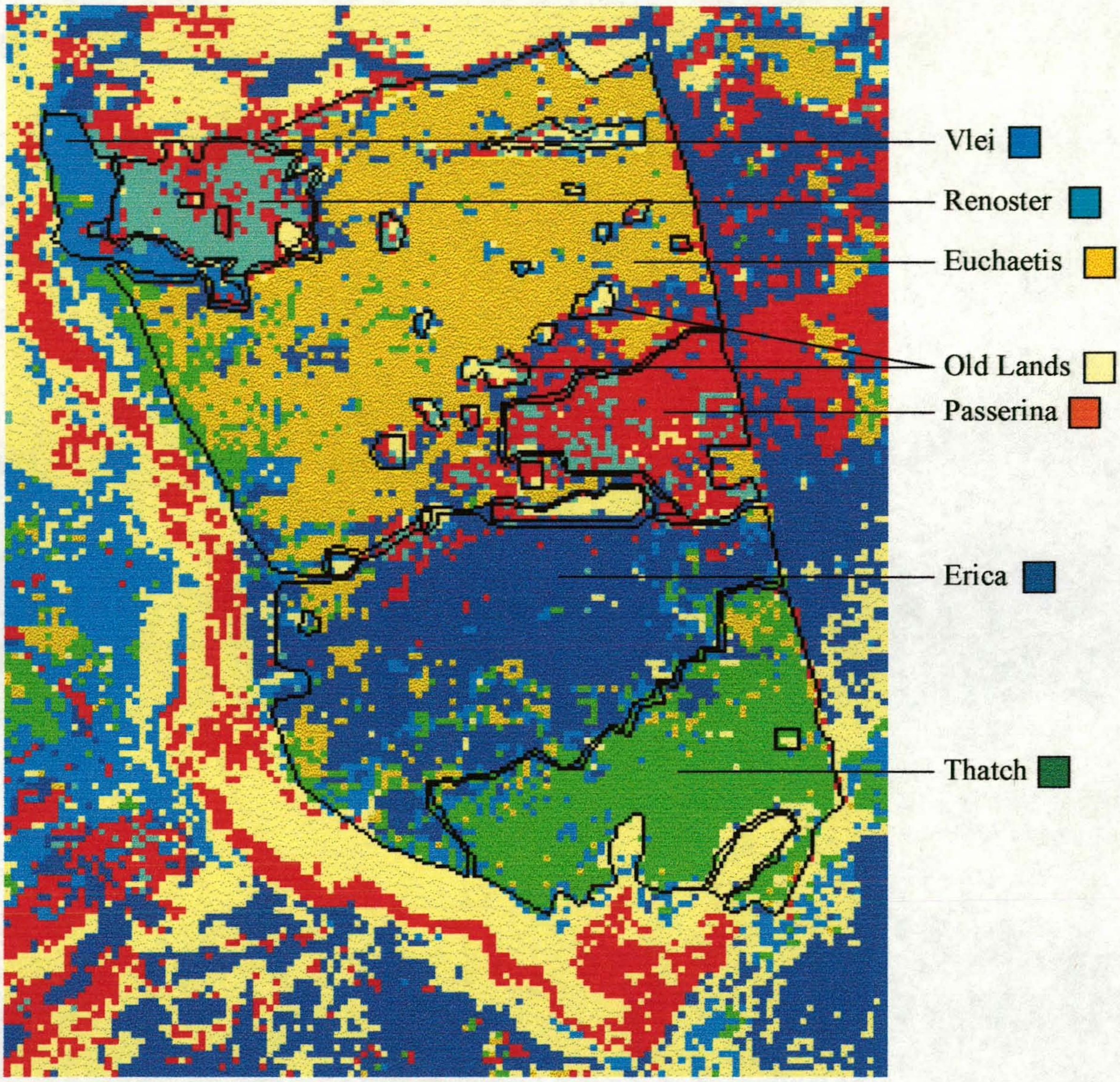

Figure 4.3 The representative image obtained by means of supervised maximum likelihood classification of the six Principal Component Analysis bands.

this is a classification improvement of 21.25% compared to the Erica community in the 1997 image. Most of the pixels wrongly classified from the Erica community has been classified as either belonging to the Vlei, Euchaetis or Thatch communities, but none of these dominates the percentage omitted pixels of the Erica community.

The Thatch community has 74.16% correctly classified pixels. Comparing these results with those obtained for the Thatch community in the 1997 image it can be seen that there is a classification improvement of 10.97% in the representative image. The omitted pixels has been classified as either being Vlei, Euchaetis, Erica or Old Land pixels with none of these groups dominating.

The correctly classified pixels in the Vlei community cover 78.60% of the community on the ground. This is a classification improvement of 19.21% compared to the Vlei community in the 1997 image. The small area within the Vlei community that is dominated *by Elytropappus rhinocerotus* and *Rhus glauca* and classified as being Thatch or Euchaetis pixels is still visible on the representative image even though it is smaller. The decrease in size of this area in the representative image can be attributed to several reasons. Boundary pixels of this area could have been classified differently over the various years. In some years these same pixels could have been classified as being Vlei pixels and in other years as either being Thatch or Euchaetis pixels and this could have led to them being classified as Vlei pixels in the representative image that was obtained by means of Principal Component Analysis. Another possible reason for the decrease in size of this patch within the Vlei community is the possibility that the size of this area is actually increasing and it is therefore bigger in the 1997 image than in the representative image.

The objective of the study is to identify the communities, if possible, within the study area. Considering the objective it is thus very important to be able to identify such small areas as this area within the Vlei community and other small areas such as the Old Land areas. It has thus been possible to identify fairly small areas even though it is not always possible to define the size and actual boundaries of such small areas accurately. The

21.40% omitted pixels from the Vlei community have been classified as either being Renoster, Passerina, Thatch, Old Lands or Erica pixels with none of these groups dominating.

The Old Land community has been classified 50.82% correctly. This is an improvement of 7.76% compared to the Old Land community in the 1997 image. Even though the accuracy assessment shows a classification improvement of 7.76, the total percentage of 50.82% correctly classified pixels for the Old Land community for the representative image is still not very high. The reasons for this being the same as mentioned for the classification results of the Old Land community in the 1997 image. The conclusion drawn from these results is once again that the Old Land community's classification success rate is lower than with other communities due to their small size. Even though the percentage correctly classified pixels for the Old Land community in both images is low it is still very important to describe and classify these areas. The reason for this being that the Old Land community is a community that is well spread throughout the study area and thus representative of the study area. By describing such small representative areas within the study area will enable one to make well judged precise statements with confidence about any given point in the study area.

The overall percentage of correctly classified pixels for the representative area is 67.67%. This is an improvement of 11.01% compared to the 1997 image. All the communities within the representative image showed a classification improvement compared to the 1997 image. The purpose of the representative image was not only to create an image that is representative of the study area for several years but also to minimize the amount of image variation and noise. If the percentage improvement in classification results is considered in the representative image compared to the 1997 image the objective of minimizing image variation and noise has been achieved. An image portraying the communities within the study area and that is truly representative of the study area has thus been obtained in the form of the representative image and by using Principal Component Analysis. Considering the scale at which the analysis was done, this representative imagery can thus serve effectively as baseline imagery for an area to be used for comparison purposes with imagery of the same area, but obtained for a different time period to detect vegetation change and thus community change over time.

4.3.3 Burnt area

The results of the supervised maximum likelihood classification done on the 1991 and 1997 TM imagery that contains the study area as well as the burnt area can be seen in Figure 4.4 and Figure 4.5. These two images indicate the seven described communities in the study area, the boundary of the burnt area that is to the east of the study area as well as the position of the quadrats laid out in the burnt area.

From Figure 4.4 it can be seen that the communities within the study area bordering the burnt area are the Euchaetis, Passerina, Erica and Thatch communities. It can clearly be seen that the Euchaetis, Erica and Thatch communities did spread very well into the burnt area before the fire. The Passerina community did not spread into the neighboring burnt area, although some of the pixels within this area have been classified as being Passerina pixels (Figure 4.4). This area opposite the Passerina community is more a mixture of the Euchaetis, Thatch, Erica and Passerina communities combined.

A possible reason for the Passerina community not spreading into the burnt area is the fact that man, by means of agriculture, has changed the Passerina community within the study area. From Table 4.1 it can be seen that the Passerina community has a very deep fertile brown soil with very few limestone rocks and banks. In terms of soil features this area was one of the few suitable areas on the previous De Hoop farm to be used for agricultural purposes before the area became a nature reserve. The Passerina community was ploughed in previous years and after that intensively used for the grazing of livestock (Van der Merwe 1977). It can thus be seen that this area underwent intensive unnatural changes and has only been given a chance to recover to a more natural state for the past twenty years. From the description of the Passerina community in Appendix 1 and 2 it can be seen that this area is now dominated by *Passerina galpinii* and also contains small amounts of *Rhus glauca* and *Nylandtia spinosa* which are all fynbos pioneer species. A

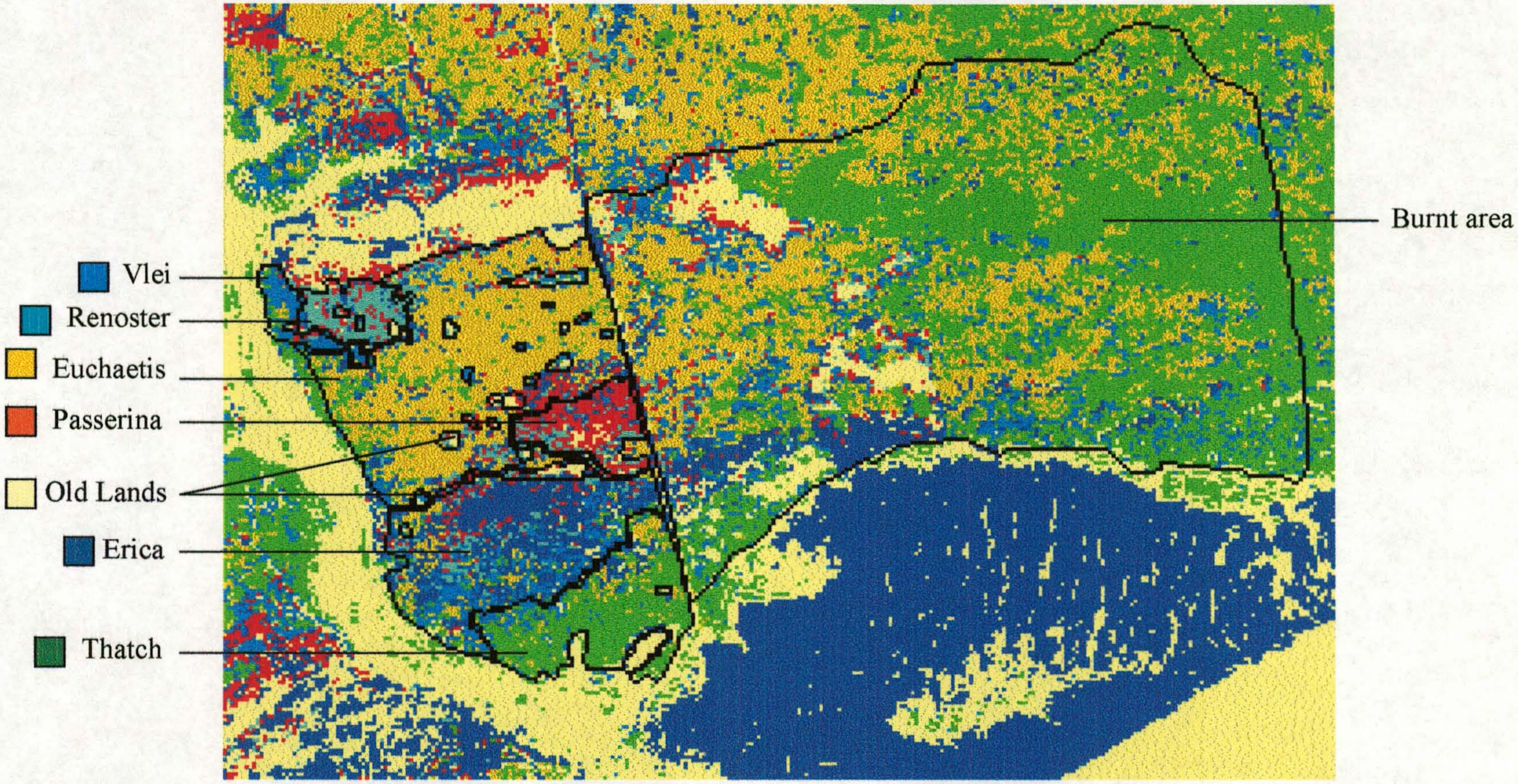

Figure 4.4 The 1991 burnt area image obtained by means of the supervised maximum likelihood classification of the 1991 TM imagery. Included in the image is the study area as well as the burnt area.

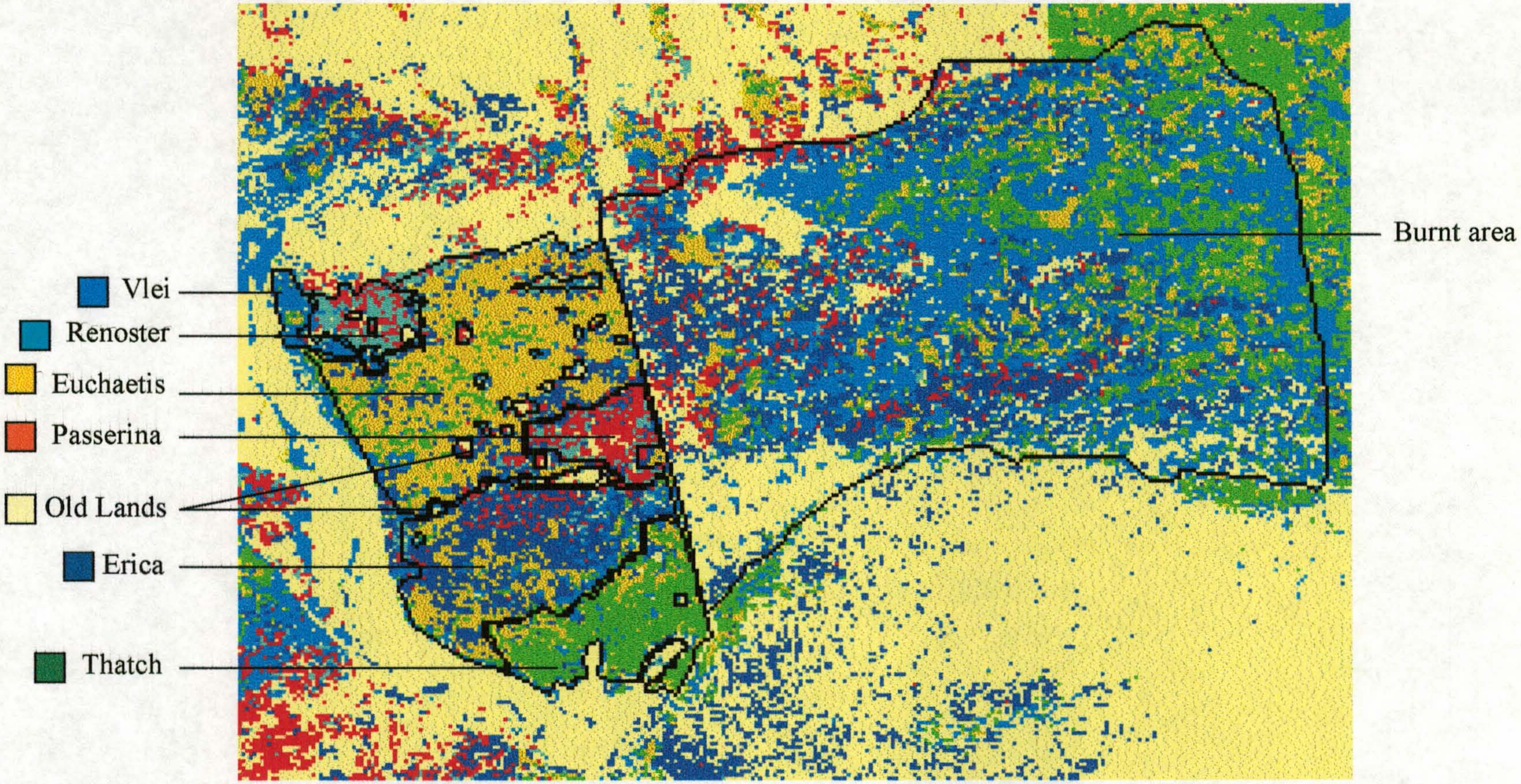

Figure 4.5 The 1997 burnt area image obtained by means of the supervised maximum likelihood classification of the 1997 TM imagery. Included in the image is the study area as well as the burnt area.

large percentage of the area is also described as being bare ground, which is only covered with small grasses and regrowth after good rains (Appendix 1 and 2). Considering these pioneer plant species and the percentage uncovered area within the Passerina community, it can be seen that this area has not fully recovered after the unnatural changes it underwent and is still in a development or maturing stage. If one considers these unnatural changes to the Passerina community in previous years it is most probably the reason for the difference between this area and the neighboring unchanged natural area within the burnt area before the fire.

According to the 1997 burnt area image (Figure 4.5) none of the areas within the burnt area bordering the communities in the study area recovered after the fire to their original state. Quadrats Fa and Fb were laid out in the burnt area adjacent to the Euchaetis community and according to the description of these two quadrats and the classification and ordination results obtained in Chapter 3, these two quadrats as well as their surrounding area are the same as the Euchaetis community. Theoretically the classification results of the burnt area adjacent to the Euchaetis community should thus be classified as being part of the Euchaetis community within the study area. According to the 1997 burnt area image (Figure 4.5) this area within the burnt area adjacent to the Euchaetis community has been classified as being part of the Erica community. A possible explanation for this being the similarities between the Erica and Euchaetis communities as described in Chapter 3. The burnt area has only recovered for seven years after the fire and the possibility exists that this area would still mature further. The classification confusion of this area can thus be ascribed to the similarities that exist between the Euchaetis and Erica communities and the maturity of the vegetation in the burn opposite the Euchaetis community. The possibility does therefore exist that this area could be classified as being part of the neighboring Euchaetis community in the future.

Quadrats Fc and Fd were laid out adjacent to the Passerina community. According to the description, classification and ordination results obtained in Chapter 3 these two quadrats have certain similarities with the Euchaetis community. Even though these similarities do exist it has been concluded in Chapter 3 that this area bordering the Passerina community is not the same as the Euchaetis community or the neighboring Passerina community. According to the results obtained in Figure 4.5 the area opposite the Passerina community consists of a mixture of pixels that has been classified as either belonging to the Euchaetis community or the Passerina community. A possible explanation for these classification results is that there is not a defined training site for this specific area and it has thus been forcibly classified as belonging to either the Euchaetis or Passerina communities. The reason for the community change within this area from before the fire until after the fire is unknown.

Quadrats Fe and Ff were laid out in the burnt area adjacent to the Erica community. According to the results obtained in Chapter 3, the area within and around quadrats Fe and Ff is not the same as the Erica community. The classification results obtained in Figure 4.5 verifies this and this area has been classified as being part of the Old Land community. The explanation for the classification results obtained is that this area is different to any of the seven described communities for which there are training sites and has thus been forcibly classified as belonging to one of these communities. The reason for the community change within this area from before the fire till after the fire is unknown.

Man has modified the Thatch community within the study area and the neighboring burnt area. The earliest objective of De Hoop being managed as a nature reserve was the breeding of antelope for restocking purposes in depleted areas. Overgrazing by domestic animals while De Hoop was still a farm and the large population of dune moles (*Barthyergus suillus*) had denuded much of the vegetation at De Hoop. The dune mole populations only occurred in areas where the soil was suitable for their extensive burrow system and one such area was the Thatch community. A full time mole catcher was employed by nature conservation to catch these dune moles by means of traps. Thousands of dune moles were caught in the Thatch community. Without any competition from the dune moles *Thamnochortus insignis* started to dominate this area. From the results obtained from fieldwork done in this area (Appendix 1 and 2) it can be seen that *Thamnochortus insignis* now dominates the Thatch community. After the departure of the dune mole catcher, a policy was established whereby mechanical bush cutting instead of fire was used to keep the vegetation biomass levels low at De Hoop (Hey 1995). This bush cutter approach of vegetation management at De Hoop stimulated the growth of *Thamnochortus insignis* even more before it was realized that fire is the driving force of fynbos. This lead to implementation of a burning plan for De Hoop and since then the area next to the study area has been burnt, but the study area itself is still due for a controlled burn. This creates the ideal situation for the monitoring of the recovery of fynbos communities after a fire by means of remote sensing. Quadrats Fg and Fh are situated in the burnt area adjacent to the Thatch community. According to the results obtained in Chapter 3 the area in and around these two quadrats does not belong to the neighboring study area Thatch community. The classification results (Figure 4.5) verify this. From Figure 4.5 it can be seen that this area has been classified as either belonging to the Old Land or Erica community. The reason for this being that there is not a specific signature for this area and therefore the area was forceably classified as belonging to the Old Land and Erica communities. The reason why the area within the burnt area did not recover to the original Thatch community is that man has been taken out of the equation and nature has been allowed to recover. This area is probably recovering to a vegetation community that is the same or very similar to the community it used to be before the dune moles were taken out and vegetation biomass levels were controlled mechanically.

4.4 Discussion

The objective of this chapter has been to determine the feasibility of Landsat TM imagery being used at a very detailed scale to effectively detect and quantify vegetation communities within a fynbos area. The feasibility of using TM imagery to identify and quantify fynbos vegetation communities has been measured on a pixel basis against the accurate ground map and the results have been portrayed in the form of an error matrix. Based on these results the conclusion has been made that TM imagery can be used effectively to detect and measure fynbos vegetation communities at a reasonably detailed scale within a particular area.

Even though the vegetation communities within the study area are clearly defined by means of the supervised maximum likelihood classification procedure used to obtain them, the potential exists for the classification results to be better. The lower accuracy than potentially obtainable can be attributed to the fact that this accuracy assessment was a total enumeration and not just a sample of the map. When sampling for accuracy assessment, it is common to pick homogeneous sites and locate your sample in the middle of the site. Using this approach tends to inflate the accuracy by avoiding boundaries that may be off by a pixel or two because of a combination of factors including misregistration and variability in interpretation. (Macleod and Congalton 1998). The mixed pixel effect encountered at boundaries between communities as well as communities not being completely homogeneous and classification confusion also represents a significant contribution to the omitted classified pixels within a community and thus results in a perceived lower classification accuracy.

Intra seasonal variation and noise also results in a significant contribution to the classification errors obtained for the 1997 imagery. PCA has been shown to be an effective method to minimize the effect of short term natural variation and noise. One of the requirements for using PCA to obtain better classification results is the necessity to have TM imagery of several time periods for the same area. Several sets of TM imagery must thus be obtained for a specific area to be able to use PCA to obtain effective baseline imagery of such an area. The positive side of using PCA is that very accurate imagery for a specific area for a specific time period is obtained with the minimum short term natural variation and noise. This imagery can serve as effective and very accurate baseline imagery for the applicable area for comparisons with imagery of the same area, but of a different time period to allow for vegetation change detection. The feasibility of using Landsat TM imagery and specifically baseline imagery obtained by means of PCA for change detection purposes and thus long term monitoring of vegetation communities will be investigated in the next chapter.

The effectiveness of Landsat TM imagery to detect fynbos vegetation communities has been shown without any doubt in this chapter and has been verified by a very accurate ground map. The potential exists to improve the classification results obtained by using only homogeneous areas within the applicable communities for the classification accuracy process. This would lead to the exclusion of mixed pixels and areas of classification confusion and thus bias. The classification accuracy results obtained in this chapter is a true representation of the actual classification results obtained for the applicable imagery.

With the possible future use of Landsat TM imagery for the quantification of fynbos vegetation communities the classification results and thus classification accuracy can be improved by the incorporation of complementary spatial data (Stow and Estes 1981, Hutchinson 1982). These techniques involve the use of non image thematic or other spatial information either before, during or after the spectral-based classification to complement spectral information contained in satellite imagery. Information may be used prior to classification to stratify a geographic region into separate groups, which are then independently classified using satellite image data. Strata are then combined after classification and misclassifications between strata are thus avoided. Thematic data can also be used post classification to resolve spectrally defined classes into finer categories. Finally, spatial data may be incorporated at classification, either as an additional "logical channel," or embedded in more complex decision schemes (Richards, Landgrebe and Swain 1982). Using these methods, many erroneous decisions based on spectral data alone can be avoided, because the collateral thematic data aid in class distinction. For example, categorical distinction may be enhanced through the integration of non-image spatial data in the classification process, e.g., elevation data may allow more accurate differentiation between vegetation communities (Strahler, Estes, Mertz and Stow 1980, Frank 1988, Teply and Green 1991). Thematic data such as soil maps, when combined with knowledge of the relationships between thematic variables and vegetation, may significantly improve vegetation community classification (Bolstad and Lillesand 1992). The potential of improving classification accuracy thus does exist, but will not be further investigated in this study.

Chapter5

Vegetation Change Detection Over Time

I do not know how the parts are interconnected,
and how each part accords with the whole;
for to know this it would be necessary
to know the whole of nature and all of
its parts.

- Baruch Spinoza 1632-1677

5.1 Introduction

The objective of the study is to determine the feasibility of using Landsat TM imagery for long term monitoring in the fynbos biome. The first part of the study entailed a detailed vegetation and vegetation community study of the study area to obtain a detailed ground based vegetation map. The aim of the second part of the study was to determine the feasibility of using Landsat TM imagery to quantify vegetation communities within a fynbos area at the applicable scale as explained in Chapter 1. By comparing the image processing results with the detailed ground map by means of image overlaying, it has been shown that Landsat TM imagery can be used effectively to obtain a detailed fynbos community description within a specific fynbos area.

Pricipal Component Analysis (PCA) has been used effectively to obtain representative imagery of the study area for a seven year time period. The major objective of such representative imagery is to reduce the amount of natural variation and noise that occurs within TM imagery. This objective has effectively been met by the use of PCA and this enabled the use of such representative imagery as baseline imagery. The purpose of such baseline imagery is to serve as a norm for a specific fynbos area in terms of the vegetation communities and community spread and boundaries that occur within this area for a specific time period.

Change detection is a technique used to determine the change between two or more time periods of a particular object of study (Singh 1989). Change detection is an important process in monitoring and managing natural resources because it provides quantitative analysis of the spatial distribution in the population of interest (Macleod and Congalton 1998). The baseline imagery obtained for a specific area and time period can thus be used for comparisons with imagery of the same area, but obtained at a different time period to determine any change over time. Based on the latter, the aim of this chapter is to determine the feasibility of the use of Landsat TM imagery to determine vegetation community change over time at the proposed scale. The results of this will determine the feasibility of using Landsat TM imagery for the long term monitoring in the fynbos biome.

5.2 Methods

5.2.1 Area to be used for detecting vegetation change over time

The area to be used to determine vegetation community and boundary changes over time is an area that includes the study area as well as the area to the east of the study area that burnt in 1991.

A detailed community description, ground map and baseline imagery has been obtained for the study area in previous chapters. This thorough knowledge can thus be used effectively to determine detailed change within the specific vegetation communities over time within the study area and is thus the reason for including the study area within the change detection process.

The burnt area to the east of the study area was not studied in such fine detail as the study area in terms of fieldwork and final community description. The main aim for considering the burnt area within the study was to determine if the areas within the burnt area bordering the study area formed part of the same system as the study area before the fire and if so, would these burnt areas recover to their original state with time. It has been shown in Chapter 4 that it is feasible to use Landsat TM imagery to quantify fynbos vegetation communities and based on this it has been shown that the communities within the burnt area adjacent to the study area actually formed part of the study area system before the fire in 1991. By means of fieldwork and further image processing it has also been shown that most of the burnt area did not recover to its original state with time after the fire. The reason for including the burnt area in the change detection process is thus not to determine specific detailed community change within the area as in the case of the study area, but rather to determine and quantify the vegetation community change within the area as a whole after the fire.

5.2.2 Imagery

Prior to any change detection, it is imperative that the imagery be geometrically rectified so that the same pixel at one date overlaps the same pixel for the other date (Townshend, Justice, Gurney and McManus 1992). The two sets of spatial data therefore used in this chapter for comparison purposes are the same as the selected and spatially georeferenced data as used in Chapter 4. The only difference is that only the 1990, 1991, 1996 and 1997 TM imagery data sets were used instead of all the imagery available. The reason for this being that 1990 and 1991 were the only two years of imagery available before the fire occurred in 1991 and the 1996 and 1997 data sets were the two available data sets that allowed for the most recovery of the burnt area after the fire.

PCA was used in exactly the same manner as in Chapter 4 except for a difference in input data as explained in the previous paragraph. PCA thus served as an effective tool for data compaction of the applicable imagery and to obtain essential elements of the various applicable years' imagery. The main objective of using PCA in the study was to minimize the amount of natural variation and noise that occurs within the imagery. To minimize such natural variation and noise as far as possible it is necessary to use as much TM imagery as possible within the PCA process. Unfortunately only two data sets were available for each period (1990/1991 and 1996/1997) in this study and the possibility therefore exists that the natural variation and noise is not reduced as effectively as it possibly could have been if more TM imagery would have been available.

The 1996/1997 imagery was used as the baseline because all the fieldwork and detailed community description within the area was done during this period. The 1996/1997 baseline imagery would thus serve as the fynbos vegetation community norm imagery for the applicable area against which all other imagery of the same area, but from a different time period would be compared to determine any vegetation changes over time. In this manner six PCA components representing six spectral bands were obtained for the years 1990 and 1991 to serve as representative imagery as well as for the period 1996/1997 to serve as baseline imagery.

These two sets of six bands each had to be transformed by using eigenvector transformation and converted to byte/binary format before image processing. This was done in exactly the same manner as in Chapter 4 in the case of the representative imagery.

5.2.3 Supervised classification

A supervised maximum likelihood classification was done on the 1990/1991 representative imagery and the 1996/1997 baseline imagery. The spectral signatures used for the classification were exactly the same as those used in the supervised maximum likelihood classification done in Chapter 4. Only the study area communities were thus covered in the development of the spectral signatures and no spectral signatures were obtained from the burnt area.

Using spectral signatures obtained only from the study area in a supervised maximum likelihood classification that included the burnt area as well, could cause communities in the burnt area that are different from the communities within the study area to be forcibly classified as being one of the study area communities. The same is possible for the burnt area in the 1996/1997 baseline imagery, only here the possibility exists that the whole of the burnt area can be forced into the communities within the study area due to a possible complete community change after the burn.

5.2.4 Accuracy assessment

An accuracy assessment was done on the study area of the 1990/1991 representative and 1996/1997 baseline supervised classified images by determining the classification error as was done in Chapter 4. A distinction was made between the study area and burnt area in both the 1990/1991 representative and 1996/1997 baseline images. The reason for this being that an accurate ground map was available for the study area and not the burnt area. An accuracy assessment was thus done for the study area part of each of the applicable images by comparing it with the accurate ground map. For each of the 1990/1991 representative and 1996/1997 baseline images an assessment was done in terms of how many pixels of each of the study area communities is represented in the burnt area in each of the two applicable images.

An error matrix was used to report the classification errors as was done in Chapter 4. The communities indicated in the error matrix were Renoster, Vlei, Euchaetis, Passerina, Erica, Thatch and Old Lands. An assessment matrix was obtained for the burnt area in each of the 1990/1991 representative and 1996/1997 baseline images and indicated the number of pixels in the burnt area that represent communities within the study area.

The reason for doing a classification accuracy assessment and an assessment of the burnt area of each of the classified 1990/1991 representative and 1996/1997 baseline images is to allow for effective and very accurate comparisons between these two time periods in terms of vegetation composition. By determining the difference between the two images by comparing on a pixel by pixel basis within each of the communities, the actual vegetation, vegetation community, community area and boundary differences could be determined.

5.2.5 Image comparison

An increasingly popular application of remotely sensed data is for change detection (Macleod and Congalton 1998). Four aspects of change detection are important when monitoring natural resources: (1) detecting that changes have occurred, (2) identifying the nature of the change, (3) measuring the areal extent of the change, and (4) assessing the spatial pattern of the change (Brothers and Fish 1978, Malila 1980). Techniques to perform change detection with satellite imagery have become numerous because of increasing versatility in manipulating digital data and increasing computing power (Jensen 1996).

Post classification change detection and image differencing (Howarth and Wickware 1981, Nelson 1983, Pilon, Howarth, Bullock and Adeniyi 1988, Jensen, Cowen, Althausen, Narumalani and Weatherbee 1993) are the most common means of detecting change between images from different time periods. The basic principle of all change detection techniques is that the digital number of a specific pixel of one date is different from the digital number of the same pixel, but of another date. This principle, that both the post classification and image differencing techniques is based on led to both of them being discarded as change detection techniques for this study.

Simply subtracting the digital pixel numbers of one image or spectral band from those of a second image or spectral band fails to produce an image showing real changes in land cover. The same pixel for different time periods was not always classified as being the same and this theoretically means a vegetation change that occurred within the particular pixel over the applicable time period. It was found that these changes were mostly not correlated with changes in vegetation cover. The reason for this being that the same pixel for different time periods could be classified differently due to classification confusion and not due to vegetation change, for example as occurs between the Renoster and Passerina communities. Another reason for classification differences is due to the mixed pixel effect. These given reasons are based on the very similar classification results obtained for all the study area communities in the 1997 (Figure 4.2 and Table 4.2) and representative (Figure 4.3 and Table 4.3) images in Chapter 4 and the preliminary results obtained in this chapter. The final classifications could have been filtered to eliminate some of the classification confusion and mixed pixel effects to obtain results that could have been used effectively in the post classification and image differencing techniques (Lo and Shipman 1990, Macleod 1994, Walsh and Townsend 1995). This would have meant being biased towards the true classification results and it was therefore decided not to apply a filter to the final classification results.

Based on the above, it was decided to compare the classification results that would be obtained for the 1990/1991 representative imagery directly with that obtained for the 1996/1997 baseline imagery by means of a matrix (Jakubauskas, Lulla and Mausel 1990, Ringrose, Matheson, Tempest and Boyle 1990, Muchoney and Haack 1994) to determine vegetation community change over time. By means of this direct classification comparisons between the two time periods, the four aspects of change detection as described earlier would be adhered to effectively.

The classification accuracy results for both the 1990/1991 representative and 1996/1997 baseline images are compared by means of a matrix. Included in this comparison matrix is the percentage correctly classified pixels for each community for the two applicable time periods. The percentage contribution of the omitted pixels within each of the communities within the study area in the 1990/1991 and 1996/1997 images is indicated in the comparison matrix. The reason for including the correctly classified and omitted pixels' percentages for each community for each year instead of indicating the direct difference between these percentages within the same matrix is to allow for effective comparisons between the different time periods. This will allow for effective comparisons to be made between the classification results obtained for the two time periods and thus to detect any vegetation community changes that possibly occurred over time. The percentage correctly classified pixels for the burnt area could not be determined for the reason that an accurate ground map was not available for this area as in the case of the study area. The burnt area was thus described as a whole and the difference between the 1990/1991 representative and 1996/1997 baseline images' burnt areas was determined in terms of percentage differently classified pixels.

5.3 Results

5.3.1 The 1990/1991 representative and 1996/1997 baseline images

The results of the supervised maximum likelihood classification using the 1990/1991 representative imagery can be seen in Figure 5.1 and that obtained for the 1996/1997 baseline imagery can be seen in Figure 5.2. The study area as well as the seven

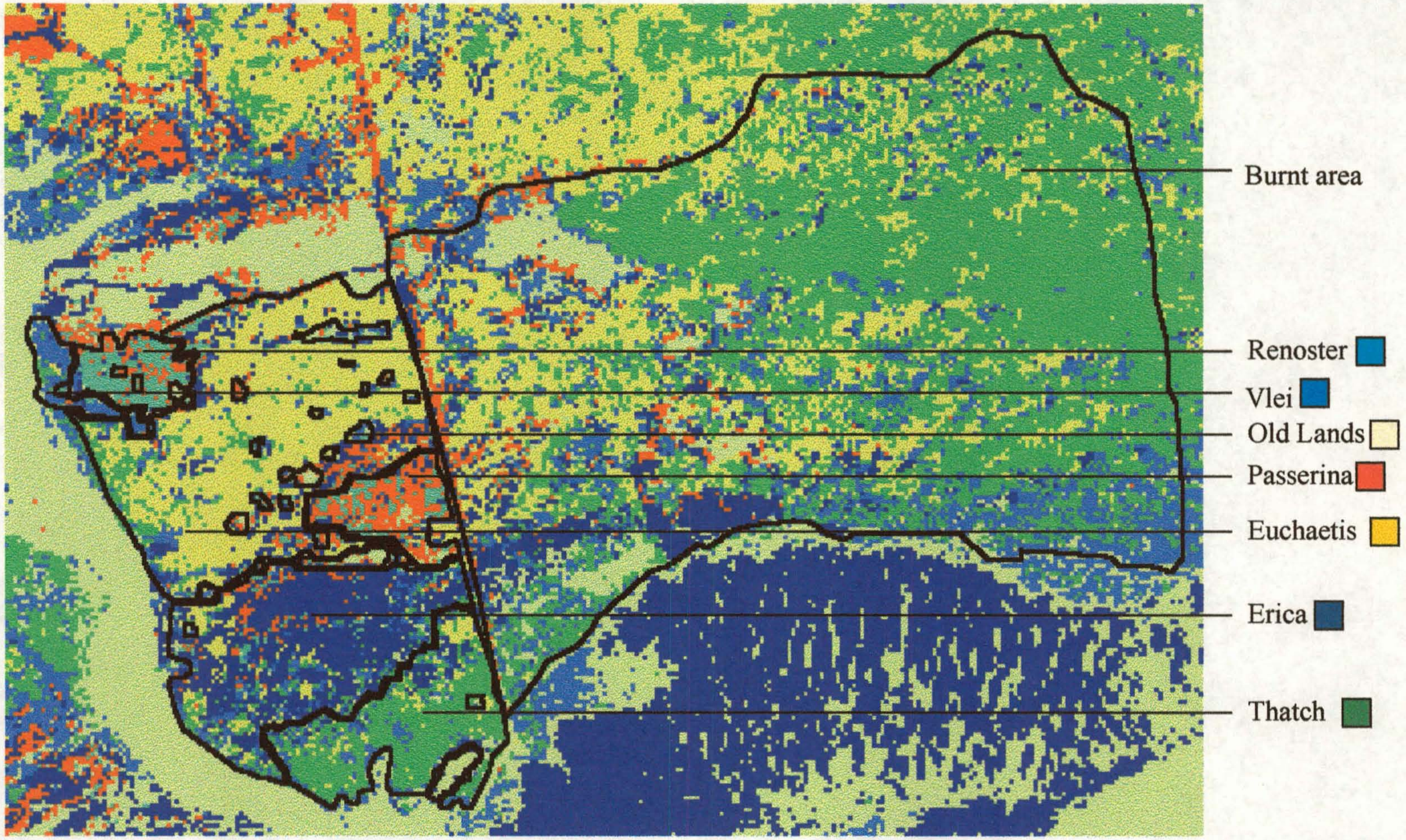

Figure 5.1 The 1990/1991 representative image. Shown in the image is the study area, the various communities in the study area as well as the burnt area to the east of the study area.

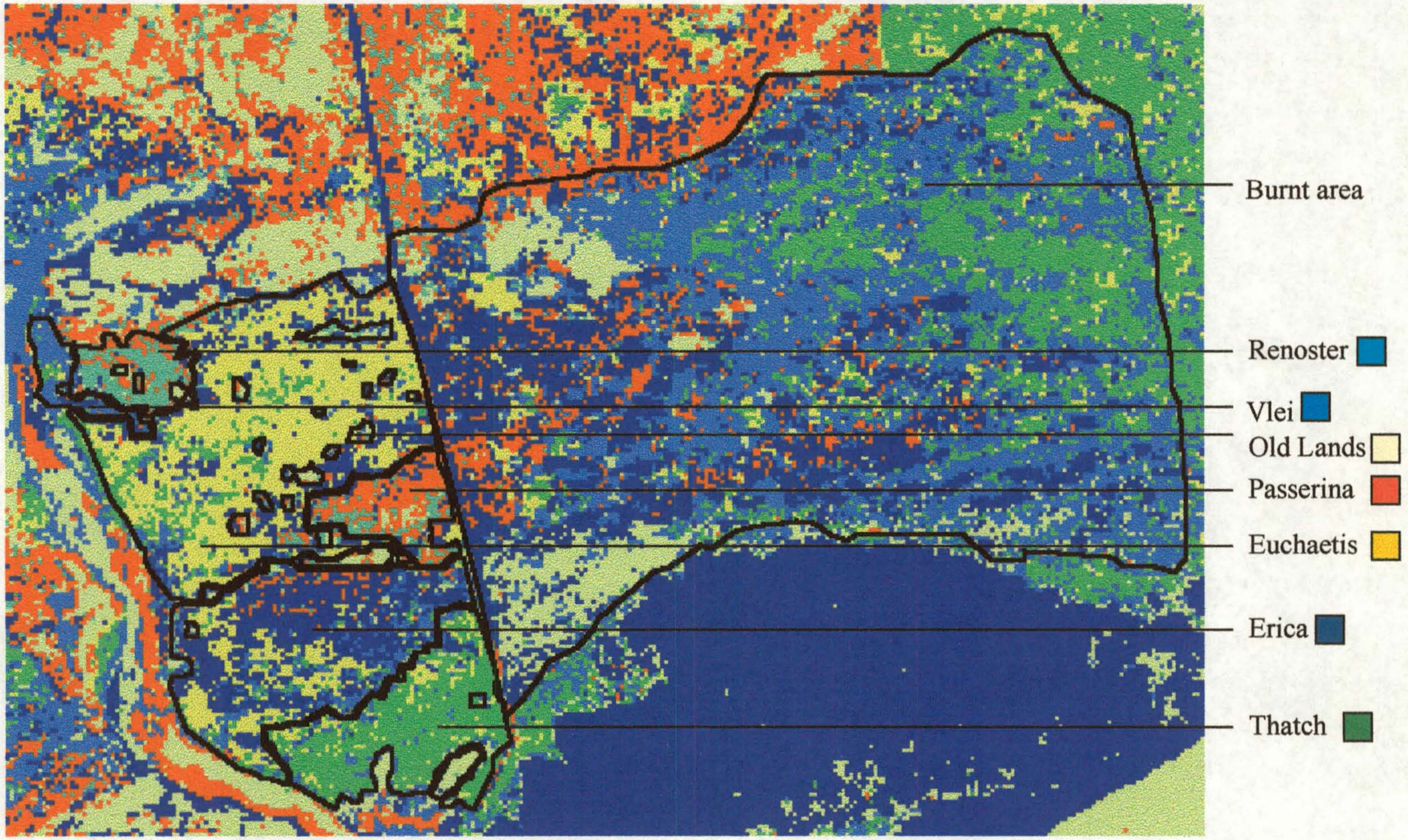

Figure 5.2 The 1996/1997 baseline image. Shown in the image is the study area, the different study area communities as well as the burnt area to the east of the study area.

different vegetation communities that occurs within it and the burnt area to the east of the study area is indicated in both images. The accuracy assessment done on the study area communities and the classification results of the burnt area is indicated in Table 5.1 for the 1990/1991 representative image and Table 5.2 for the 1996/1997 baseline image.

From Table 5.1 and 5.2 it can be seen that 60.16% and 57.06% of the study area within Figure 5.1 and 5.2 have been correctly classified respectively. Even though the different vegetation communities in Figure 5.1 and 5.2 are clearly defined by means of supervised maximum likelihood classification, the potential exists for the classification accuracy results to have been better. PCA was used specifically to reduce the amount of natural variation and noise within the imagery and thus to obtain higher classification accuracy results. Compared to the classification results obtained in the representative image (Figure 4.3) that was obtained by means of PCA in Chapter 4, the overall classification accuracy for the 1990/1991 representative and 1996/1997 baseline images was not as high. The reason for not achieving such high accuracy, results from the fact that only two data sets for each the 1990/1991 and 1996/1997 time periods was available.

Another factor that must be considered for the lower than potentially possible classification results is that the same method to determine classification accuracy was used as in Chapter 4. A total enumeration was thus done for both the 1990/1991 representative and 1996/1997 baseline images to determine their classification accuracy results. Using this method tends to lead to lower perceived classification accuracies, but prevents bias (Macleod and Congalton 1998). Boundary pixels containing features of both the applicable communities as well as the effect of the different communities not being completely homogeneous in terms of vegetation composition contributed significantly to the classification accuracy results obtained. Considering these factors, the classification accuracy obtained for the applicable imagery is significantly higher as indicated in Table 5.1 and 5.2. The classification results obtained in this chapter is thus a true representation of the actual classification results, while the objectives of the classification are still met, thus to define the vegetation communities within the applicable areas.

Table 5.1 Error matrix indicating the accuracy assessment done on the 1990/1991 representative image obtained by means of Principal Component Analysis.

Study area communities	Communities evaluated in the 1990/1991 representative image										
	Renoster	Vlei	Euchaetis	Passerina	Erica	Thatch	Old Lands	Totals	A%	EO%	EC%
Renoster	278	11		92	25		18	424	65.57	34.43	96.00
Vlei	7	145	7	5	14	25	26	229	63.32	36.68	334.50
Euchaetis	110	220	2513	233	456	332	89	3953	63.57	36.43	10.98
Passerina	158	4	11	284	57		49	563	50.44	49.56	91.30
Erica	83	272	232	121	1373	206	85	2372	57.88	42.12	30.27
Thatch		215	156		113	900	83	1467	61.35	38.65	38.79
Old Lands	49	44	28	63	53	6	182	425	42.82	57.18	82.35
Totals	685	911	2947	798	2091	1469	532	9433			

Total number of pixels evaluated: 9433
Total number of pixels correctly classified: 5675
Percentage correctly classified pixels: 60.16%

Note. A%, accuracy percentage; EO, errors of omission; EC, errors of commission.

Burnt area	Study area communities that the burnt area was classified as belonging to							
	Renoster	Vlei	Euchaetis	Passerina	Erica	Thatch	Old Lands	Totals
Burnt area	109	2893	4596	551	1440	9583	1421	20593
% Burnt area	0.53	14.05	22.32	2.68	6.99	46.54	6.90	100.00

Table 5.2 Error matrix indicating the accuracy assessment done on the 1996/1997 baseline image obtained by means of Principal Component Analysis.

Study area communities	Communities evaluated in the 1996/1997 baseline image										
	Renoster	Vlei	Euchaetis	Passerina	Erica	Thatch	Old Lands	Totals	A%	EO%	EC%
Renoster	259	8	1	102	30		24	424	61.10	38.90	82.08
Vlei	6	142	9	9	28	26	9	229	62.01	37.99	334.50
Euchaetis	111	226	2335	120	710	376	75	3953	59.10	40.90	19.15
Passerina	149	5	4	289	70		46	563	51.33	48.67	69.98
Erica	29	345	517	114	1164	145	58	2372	49.07	50.93	40.64
Thatch		150	204	1	57	999	56	1467	68.10	31.90	37.76
Old Lands	53	32	22	48	69	7	194	425	45.65	54.35	63.06
Totals	607	908	3092	683	2128	1553	462	9433			

Total number of pixels evaluated: 9433
Total number of pixels correctly classified: 5382
Percentage correctly classified pixels: 57.06%

Note. A%, accuracy percentage; EO, errors of omission; EC, errors of commission.

Burnt area	Study area communities that the burnt area was classified as belonging to							
	Renoster	Vlei	Euchaetis	Passerina	Erica	Thatch	Old Lands	Totals
Burnt area	97	8062	861	1354	4872	3428	1919	20593
% Burnt area	0.47	39.15	4.18	6.58	23.66	16.65	9.32	100.00

Comparing the classification results obtained for the study area communities as illustrated in Tables 5.1 and 5.2 with those obtained for the 1997 (Figure 4.2 and Table 4.2) and representative images (Figure 4.3 and Table 4.3) in Chapter 4, similar trends between these results can be observed. Comparing the classification results obtained for the Renoster community in the above mentioned images it can be seen that most of the pixels not classified as being Renoster have been classified as Passerina. Most of the Passerina community pixels not classified as being Passerina have been classified as belonging to the Renoster community within all four images. Omitted pixels from the Vlei community have been classified as belonging to a variety of other study area communities, but are dominated by Erica and Thatch pixels in the applicable images. The largest percentage of omitted pixels in the Euchaetis community has been classified as being Erica and Thatch pixels. Pixels not classified as being Erica pixels in the Erica community have mostly been classified as Vlei, Euchaetis and Thatch pixels. Omitted pixels within the Thatch community have mostly been classified as being Vlei, Euchaetis and Erica pixels. The omitted pixels from the Old Land community has been classified largely according to the surrounding communities and the mixed pixel effect that is obtained with the Old Land areas' boundaries. As already mentioned the classification results obtained for the 1990/1991 representative and 1996/1997 baseline images (Tables 5.1 and 5.2) in terms of the omitted pixels for each of the study area communities is very similar to each other and is also very similar to the classification results obtained for the 1997 and baseline images (Tables 4.2 and 4.3). The same explanations as given in Chapter 4 can thus be applied to the classification results obtained in this chapter as well. These similarities in classification results between the four images serve as a verification of the application of Landsat TM imagery to detect and quantify different fynbos vegetation communities.

The classification results of the burnt area are indicated in Tables 5.1 and 5.2. From Table 5.1 it can be seen that the burnt area in the 1990/1991 representative image has mostly been classified as belonging to the Vlei, Euchaetis and Thatch communities. The Vlei classified pixels within the 1990/1991 representative image's burnt area contributes 14.05% to the total burnt area and the Euchaetis classified pixels 22.32% and the Thatch classified pixels 46.54%.

From Table 5.2 it can be seen that most of the pixels within the 1996/1997 baseline image's burnt area (Figure 5.2) were classified as Vlei, Erica and Thatch pixels. The Vlei pixels contributed 39.15% to the total of burnt area, while the contribution of the Erica and Thatch communities was 23.66% and 16.65% respectively.

5.3.2 Vegetation community change detection over time

The actual vegetation change over the applicable time period in terms of amount and percentage change is indicated in Table 5.3. Considering the separate classification accuracy results obtained for the Renoster community it can be seen that 65.57% of the Renoster community in the 1990/1991 representative image has been classified as being Renoster vegetation and 61.10% in the 1996/1997 baseline image. The percentage omitted pixels in the 1990/1991 representative image is 34.43% and that for the 1996/1997 baseline image is 38.90%. When comparing the detailed omitted pixels' classification results obtained for the Renoster community for the 1990/1991 and 1996/1997 time periods with each other it will be seen that the results are very similar. Included in the percentage omitted pixels for the applicable time periods are the pixels differently classified within the Renoster community because of true physical and botanical differences that occur between them and the Renoster community. The similarity in omitted pixels percentages for the Renoster community between the applicable time periods serves as a verification of these differently, but not wrongly classified pixels within the Renoster community not changing over the applicable time period. These separate classification results for the two applicable time periods thus shows fairly similar classification results obtained for the Renoster community and thus the classification accuracy is quite high. Based on these classification results, as well as the detailed omitted pixels classification results obtained for the Renoster community for the 1990/1991 and 1996/1997 time periods respectively, it can be said that no vegetation and thus community change occurred within the Renoster community between the two applicable time periods.

It can be seen in Table5.3 that no or very little vegetation change occurred in the Renoster, Vlei, Euchaetis, Passerina, Thatch and Old Land communities. In the Erica community the percentage omitted pixels being classified as Euchaetis pixels is

Table 5.3 Comparison of the 1990/1991 representative image (Figure 5.1) and the 1996/1997 baseline image (Figure 5.2) to determine vegetation change over time.

Communities and areas evaluated	Total pixels classified	Pixels classified differently	% Classification difference	% Correctly classified pixels		% Contribution of differently classified pixels within the different communities													
						Renoster		Vlei		Euchaetis		Passerina		Erica		Thatch		Old Lands	
				1990/1991	1996/1997	1990/1991	1996/1997	1990/1991	1996/1997	1990/1991	1996/1997	1990/1991	1996/1997	1990/1991	1996/1997	1990/1991	1996/1997	1990/1991	1996/1997
Renoster	229	185	80.79	65.57	61.10			2.59	1.89		0.24	21.70	24.06	5.90	7.08			4.25	5.66
Vlei	424	84	19.81	63.32	62.01	3.06	2.62			3.06	3.93	2.18	3.39	6.11	12.23	10.92	11.35	11.35	3.93
Euchaetis	3953	1422	35.97	63.57	59.10	2.78	2.81	5.57	5.72			5.89	3.04	11.54	17.96	8.40	9.51	2.25	1.90
Passerina	563	290	51.51	50.44	51.33	28.06	26.47	0.71	0.89	1.95	0.71			10.12	12.43			8.70	8.17
Erica	2372	1153	48.61	57.88	49.07	3.50	1.22	11.47	14.54	9.78	21.79	5.10	4.81			8.68	6.11	3.58	2.45
Thatch	1467	565	38.51	61.35	68.10			14.66	10.22	10.63	13.91		0.07	7.70	3.89			5.66	3.82
Old Lands	425	164	38.59	42.82	45.65	11.53	12.47	10.35	7.53	6.59	5.18	14.82	11.29	12.47	16.24	1.41	1.65		
Study area	9433	4072	43.17	60.16	57.06	4.31	3.69	8.12	8.12	4.60	8.03	5.45	4.18	7.61	10.22	6.03	5.87	3.71	2.84
Burnt area	20593	14349	69.68			0.53	0.47	14.05	39.15	22.32	4.18	2.68	6.58	6.99	23.66	46.54	16.65	6.90	9.32

9.78% in the 1990/1991 representative image and 21.79% in the 1996/1997 baseline image and pixels being correctly classified as Erica are 57.88% and 49.07% respectively. These classification differences in the Erica community classification results between the two time periods might not show much vegetation change in the Erica community, but it still serves as a good indication of change over time within the specific community. This slight difference in the omitted pixel classification results serve as motivation for the field visits to such an area.

The position of the possible vegetation change within an area is determined by using the georeferenced and baseline imagery in conjunction with the comparison matrix. In the case of the Erica community it has been determined by using Table 5.3 that there was an increase in Euchaetis pixels within the Erica community from the 1990/1991 period to the 1996/1997 period and a decrease in the Erica classified pixels. These classification differences can be visually compared by means of the baseline and representative imagery (Pilon, Howarth, Bullock and Adeniyi 1988). The spread of change within a specific community might be random over the total community area. Such random spread of change will most probably indicate the fragmentation of the community.

If the positional vegetation change is clumped it serves as an indication of the development of new vegetation within a community such as alien vegetation. Positional vegetation change that develops from the boundary of a specific community is a strong indication of the spread of the neighboring community into the applicable community. Positional boundary changes might also serve as an indication of the spread of alien vegetation into an area or the spread of human activities such as agriculture. By referring to the comparison matrix and comparing the applicable georeferenced imagery, the position of vegetation change can be obtained and used together with a GPS. The exact position of the possible vegetation change within the field can thus be visited and an explanation for the vegetation change can be obtained.

A possible explanation for the specific difference in classification results between the two time periods is that the Erica community matured more from the 1990/1991 time period to the 1996/1997 time period. Due to the more mature Erica community and the floristic and structural similarities between the Erica and Euchaetis communities described in Chapter 3, more of the Erica community has been classified as being of the Euchaetis community, because of classification confusion. Based on this explanation it is postulated that there is no actual vegetation change within the Erica community over time.

These explanations for the differences in classification accuracy results obtained for the same area, but for different time periods reiterates the importance of effective and accurate fieldwork and ground truthing.

Comparing the overall classification accuracies and omitted pixels results obtained for the study areas of both the 1990/1991 representative and 1996/1997 baseline images it can be seen that no significant vegetation changes occurred between the two time periods.

Burnt area communities were obtained and located by means of image processing and their distribution is not based on an accurate ground map. Therefore the communities within the burnt area were compared directly with each other in terms of the total amount of the burnt area being classified as belonging to one of the seven specific study area communities.

Table 5.3 indicates substantial classification differences between 1990/1991 representative and 1996/1997 baseline images respective burnt areas. In the 1990/1991 image 14.05% of the burnt area was classified as belonging to the Vlei community compared to the 39.15% of the 1996/1997 baseline image. This represents a classification difference of 25.10% in the burnt area being classified as Vlei community pixels. Comparing the percentage Euchaetis classified pixels within the burnt area it can be seen that 22.32% within the 1990/1991 representative image has been classified as Euchaetis compared to the 4.18% in the 1996/1997 baseline image. Within the 1990/1991 representative image's burnt area only 6.99% has been classified as Erica pixels compared to the 23.66% within the 1996/1997 baseline imagery. Pixels being classified as Thatch within the 1990/1991 representative image contributed 46.54% to the burnt area compared to the 16.65% in the 1996/1997 baseline. These classification differences represent very large changes in community structure that occurred from before the fire in 1991 till 1996/1997.

No detailed fieldwork was done in the burnt area and there are thus no feasible explanations for the differences in vegetation within the burnt area from before the fire until after the fire. It can however be said conclusively that definite vegetation changes occurred from the time period before the fire until after the fire based on image processing. It is also possible to determine effectively the amount of vegetation change within the area as well as the exact geographical position and spread of these changes.

5.4 Discussion

Those who would successfully manage the fynbos biome require management orientated information. Fynbos vegetation is similar to many other vegetation types in that it is subject to change. These changes are the result of management, of long term vegetation succession, or are the result of catastrophic events that produce changes in a very short time. Managers often lack information about changes upon which they can, with reasonable confidence, base management decisions. In the past, this information has been derived from either sporadic or intensive but costly field sampling procedures. In this age of intense information acquisition and transfer there is still a need for more accurate approaches to data acquisition, storage and retrieval. Remote sensing based on satellite imagery offers a potentially strong data base from which to work.

The overall aim of the study was to determine the possible use of Landsat TM imagery to identify the various vegetation communities occurring within a specific fynbos area and the possibility of measuring change for the long term monitoring of fynbos.

The first objective of the study was thus to determine what occurs within study area in terms of different vegetation communities. This objective was met in Chapter 3.

The objective of Chapter 4 was to determine the feasibility of the use of Landsat TM imagery to detect and quantify vegetation communities within the study area at the proposed scale. Signatures obtained from the accurate ground map were used in a supervised classification to obtain the study area communities by means of image processing. In Chapter 4 it was shown that Landsat TM imagery can be used effectively to quantify the vegetation communities that occur in a fynbos area at the proposed scale.

The feasibility of using Principal Component Analysis (PCA) to lessen the effect of natural variation and noise within imagery was also determined in Chapter 4. Based on these results it can be seen that it is possible to use PCA effectively to reduce the effect of natural variation and noise in imagery and still retain the environmental variation.

Included in the study was an area to the east of the study area that burnt in 1991. The objective of including the burnt area in the study was to determine if the communities within the burnt area were the same as those it bordered in the study area and if these communities would recover to their original state after the fire. It has been determined in Chapter 3 and 4 that the burnt area communities bordering the study area were in most areas the same as the neighboring study area communities before the fire and that these burnt area communities did not recover to their original state after the fire. These results led to some very interesting unanswered questions which resulted in the broadening of the potential future use of Landsat TM imagery in the fynbos biome.

The objective of this chapter was to determine the possible use of Landsat TM imagery to determine vegetation change over time and is based on the work done in Chapters 3 and 4. Based on the results obtained in this chapter it has been shown that it is possible to use Landsat TM imagery to determine vegetation community change over time at the proposed scale of the study. It is important to stress that these results are based on the fact that extensive fieldwork and analysis was done for the study area and a thorough record in the form of a detailed ground map is available for the area. This detailed ground map gave a comprehensive description of the vegetation communities of the area and thus served as the norm against which vegetation change was measured. It can thus be seen that Landsat TM imagery can not be used as a quick and easy method to firstly determine the vegetation communities within an area and secondly to use these results to determine vegetation community change over time. It is necessary to do a certain amount of small scale fieldwork to obtain accurate results. The amount of fieldwork done in this study does not serve as an indication or norm for the amount and effort that must be put into fieldwork for further studies or use of these methods for management, research and planning purposes.

The amount of fieldwork and ground truthing done in the potential future applications of the results obtained in this study will be determined by the features of the specific area and will most probably be far less than the work done in this initial study.

The results reported in this study are restricted to the vegetation types, soils and terrain conditions of the study area. Although they should be extrapolated with caution, the conditions of the study area are representative of those found in much of the fynbos biome. Thus, the potential exists for their application across a wider geographical scale. It must be stressed that this is a preliminary evaluation of the technique and many questions remain. The results, however, look promising and if accurate repeatability can be achieved, this scale of monitoring holds much promise as a method that can be applied by managers, researchers and strategic planners. Further application is warranted, both in different areas and with additional thematic data.

List of References

Acocks, J.P.H. 1988. Veld types of South Africa. Third edition. *Mem. Bot. Surv. S. Afr.* 57: 1-146.

Ahern, H.J. and Sirdis, J. 1989. Reflectance enhancements for the Thematic Mapper: an efficient way to produce images of consistently high quality. *Photogramm. Eng. and Remote Sens.* 55(1): 61-67.

Allen, T.F.H. and Hoekstra, T.W. 1988. The critical role of scaling in land modelling. In: *Gelinas, R., Bond, D. and Smit, B. (eds.) Perspectives on land modelling*. Polyscience Publications, Montreal, 9-13.

Apan, A.A. 1997. Land cover mapping for tropical forest rehabilitation planning using remotely sensed data. *Int. J. Remote Sensing* 18(5): 1029-1049.

August, P.V. 1993. GIS in Mammalogy: Building a database. In: *McLaren, S.B and Braun, J.K. (eds.) GIS Applications in Mammalogy*. Oklahoma Museum of Natural History, Oklahoma, 11-26.

Austin, M.P. 1985. Continuum concept, ordination methods and niche theory. *Annual Review of Ecology and Systematics* 16:39-61.

Ayyad, M.A. 1981. Soil-vegetation-atmosphere interactions. In: *Goodall, D.W., Perry, R.A. and Hones, K.M.W. (eds.). Arid-land ecosystems: structure, function and management.* Cambridge Univ. Press, Cambridge, England, 9-31.

Belward, A.S. and Taylor, J.C. 1986. The influence of resampling method and multitemporal Landsat imagery on crop classification accuracy in the United Kingdom. *Proceedings of IGARSS 1986 Symposium, 8-11 September, Zurich, Switzerland.* ESA Ref. #SP-254, ESA Publications Division, 529-534.

Belward, A.S. and Valenzuela, C.R. 1991. *Remote sensing and geographical information systems for resource management in developing countries*. Kluwer Academic Publishers, Netherland.

Berry, B.J.L. and Marble, D.F. 1968. *Spatial analysis: a reader in statistical geography.* Prentice-Hall, New Jersey.

Bolstad, P.V. and Lillesand, T.M. 1992. Improved classification of forest vegetation in Northern Wisconsin through a rule-based combination of soils, terrain and Landsat Thematic Mapper data. *For. Sci.* 38(1): 5-20.

Bond, W.J. 1981. *Vegetation gradients in Southern Cape mountains. M.Sc. Thesis*. University of Cape Town.

Bossi, L. 1984. Mapping Cape fynbos vegetation with the aid of Landsat imagery. *Veld and Flora* 70(1): 31-33.

Braun-Blanquet, J. 1932. *Plant Sociology: the Study of Plant Communities*. (English translation), McGraw-Hill, New York.

Brothers, G.L. and Fish, E.B. 1978. Image enhancement for vegetation pattern change analysis. *Photogramm. Eng. and Remote Sens*. 44(5): 607-616.

Cain, S.A. 1938. The species-area curve. Am. *Midland Naturalist* 19:573-581.

Campbell, B.M. 1986. Vegetation classification in a floristically complex area: the Cape Floristic Region. *S. Afr. J. Bot.* 52: 129-140.

Campbell, B.M., Cowling, R.M., Bond, W. and Kruger, F.J. 1981. Structural characterization of vegetation in the Fynbos Biome. *South African Natural Scientific Programmes Report* 52:1-18.

Campbell, J.B. 1981. Spatial correlation effects upon accuracy of supervised classification of land cover. *Photogramm. Eng. and Remote Sens.* 47: 355-363.

Campbell, J.B. 1996. *Introduction to remote sensing. 2nd ed.* Taylor and Francis, London.

Chavez, P.S. and Kwarteng, A.Y. 1989. Extracting spectral contrast in Landsat Thematic Mapper image data using selective Principal Component Analysis. *Photogramm. Eng. and Remote Sens.* 55(3): 339-348.

Coates Palgrave, K. 1991. *Trees of Southern Africa.* Struik Publishers, Cape Town.

Colwell, R.N. (ed.) 1983. *Manual of Remote Sensing. 2nd. ed.* Falls Church, Va.: American Society for Photogrammetry and Remote Sensing.

Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sens. Environ.* 37: 35-46.

Congalton, R.G., Mead, R.A. and Oderwald, R.G. 1983. Assessing Landsat classification accuracy using discrete multivariate analysis statistical techniques. *Photogramm. Eng. and Remote Sens.* 49: 1671-1678.

Cowling, R.M. and Richardson, D.M. 1995. *Fynbos: South Africa's Unique Floral Kingdom.* Fernwood Press, Cape Town.

Cowling, R.M., Holmes, P.M. and Rebelo, A.G. 1992. Plant diversity and endemism. In: *Cowling, R.M. (ed.) The ecology of fynbos: nutrients, fire and diversity.* Oxford University Press, Cape Town, 62-112.

Cressie, N.A.C. 1993. *Statistics for Spatial Data: Revised Edition.* Wiley, New York.

Curtis, J.T. 1959. *The Vegetation of Wisconsin: an ordination of plant communities.* Madison, Wisconsin.

Dahl, E. 1960. Some measures of uniformity in vegetation analysis. *Ecology* 41:805-808.

Daubenmire, R.F. 1968. *Plant communities: A textbook of plant synecology.* Harper and Row, New York.

Davis, J.C. 1986. *Statistics and data analysis in geology.* Wiley, New York.

Deckert, C. and Bolstad, P.V. 1994. Terrain and canopy influence on code-phase GPS position accuracy. Ninth Annual Symposium on Geographical Information Systems. Vancouver, British Columbia. *GIS Modelling and Analysis in Resource Environments*, 241-251.

Delcourt, H.R., Delcourt, T.A. and Webb, T. 1983. Dynamic plant ecology: the spectrum of vegetative change in space and time. *Quant. Sci. Rev.* 1: 153-175.

Di Castri, F. and Hansen, A.J. 1992. The environment and development crises as determinants of landscape dynamics. In: *Hansen, A.J. and Di Castri, F. (eds.) Landscape boundaries. Consequences for biotic diversity and ecological flows.* Springer-Verlag, New York, 3-18.

Dymond, J.R., Page, M.J. and Brown, L.J. 1996. Large area vegetation mapping in the Gisborne district, New Zealand, from Landsat TM. *Int. J. Remote Sens.* 17(2): 263-275.

Eastman, J.R. and Fulk, M. 1993. Long sequence time series evaluation using standardized principal components. *Photogramm. Eng. and Remote Sens.* 59(6): 991-996.

Edwards, D. 1983. A broad-scale structural classification of vegetation for practical purposes. *Bothalia* 14,3 and 4: 705-712.

Forman, R.T.T. and Gordon, M. 1986. *Landscape Ecology*. Wiley, New York.

Forsyth, G.G. and Van Wilgen, B.W. 1993. The incorporation of monitoring programmes into geographical information systems. In: *Marais, C. and Richardson, D.M. (eds) Monitoring requirements for fynbos management. FRD Programme Report Series.* No. 11: 98-102.

Fox, L. III. and Stuart, J.D. 1994. Detecting changes in forest condition. Following wildfire, using image processing and GIS. *ASPRS/ACSM. Annual convention and exposition. ASPRS Technical papers. Reno, Nevada* 1: 177-206.

Frank, T.D. 1988. Mapping dominant vegetation communities in the Colorado Rockey Mountain front range with Landsat Thematic Mapper and digital terrain data. *Photogramm. Eng. and Remote Sens.* 54: 1727-1734.

Franklin, S.E. 1992. Satellite remote sensing of forest type and landcover in the Subalpine Forest Region, Kananaskis Valley, Alberta. *Geocarto International* 4: 25-35.

Fuggle, R.F. and Ashton, E.R. 1979. Climate. In: *Day, J., Siegfried, W.R., Louw, G.N. and Jarman, M.L. (eds.) Fynbos ecology: a preliminary synthesis. South African National Science Progress Report* 40: 7-15.

Fuls, E.R., Bredenkamp, G.J. and Van Rooyen, N. 1992. The plant communities of the undulating grassland of the Vredefort-Kroonstad-Lindley-Heilbron area, northern Orange Free State. *S. Afr. J. Bot.* 58: 224-230.

Fung, T. and LeDrew, E. 1987. Application of principal component analysis to change detection. *Photogramm. Eng. and Remote Sens.* 53(12): 1649-1658.

Gauch, H.G. 1982. *Multivariate Analysis in Community Ecology.* Cambridge University Press. Cambridge.

Gauch, H.G. and Whittaker, R.H. 1981. Hierarchical classification of community data. *J. Ecol.* 69: 537-557.

Georgiadou, Y. and Doucet, K.D. 1990. The issue of selective availability. *GPS World* 1:53-56.

Gershmehl, P.J. and Napton, D.E. 1982. Interpretation of resource data: Problems of scale and transferability. *Practical applications of computers in government, papers from the annual conference of the Urban and Regional Information Systems Association*, 471-482.

Goodall, D.W. 1954. Objective methods for the classification of vegetation: III. An essay in the use of factor analysis. *Australian Journal of Botany* 2:302-324.

Gould, P. 1967. On the geographical interpretation of eigenvalues. *Transactions, Institute of British Geographers* 42: 53-86.

Graetz, R.D. and Gentle, M.R. 1982. The relationship between reflectance in the Landsat wavebands and the composition of an Australian semi-arid shrub rangeland. *Photogramm. Eng. and Remote Sens.* 48(11): 1721-1730.

Greenacre, M.J. 1984. *Theory and Applications of Correspondence Analysis*. Academic Press, New York.

Greenacre, M.J. 1986. SIMCA: a program to perform simple correspondence analysis. *American Statistician* 40(3):230-231.

Haining, R. 1990. *Spatial data analysis in the social and environmental sciences.* Cambridge University Press, Cambridge.

Hardcastle, P. 1996. *De Hoop management plan*. Internal document, Cape Nature Conservation.

Hendey, Q.B. 1983. Cenozoic geology and palaeogeography of the fynbos region. In: *Deacon, H.J., Hendey, Q.B. and Lambrechts, J.J.N. (eds.) Fynbos palaeoecology: a preliminary synthesis. South African National Scientific Programmes Report No. 75*, 35-60.

Hey, D. 1995. *A Nature Conservationist Looks Back.* Cape Nature Conservation, Cape Town.

Hill, M.O. 1973. Reciprocal averaging: an eigenvector method of ordination. *J. Ecol.* 61:237-250.

Hill, M.O. 1974. Correspondence analysis. A neglected multivariate method. *Journal of the Royal Statistical Society – Series C* 23:340-354.

Hill, M.O. 1979. *TWINSPAN – a FORTRAN Program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes.* Cornell University, New York.

Holland, M.M. 1988. SCOPE/MAB Technical consultations on landscape boundaries. Report of a SCOPE/MAB workshop on ecotones, 5-7 January 1987, Paris, France, *Biol. Int. Spec.* 17: 47-106.

Holz, R.K. 1985. *The surveillant science: remote sensing of the environment, 2nd. ed.* Wiley, New York.

Hopkins, P.J., MaClean, A.L. and Lillesand, T.M. 1988. Assessment of Thematic Mapper imagery for forestry applications under Lakes States conditions. *Photogramm. Eng. and Remote Sens.* 54: 61-68.

Hord, R.M. and Brooner, W. 1976. Land use map accuracy criteria. *Photogramm. Eng. and Remote Sens.* 42: 671-677.

Horler, D.N.H. and Ahern, F.J. 1986. Forestry information content of Thematic Mapper data. *Int. J. Remote Sens.* 7: 405-428.

Howarth, P.J. and Wickware, G.M. 1981. Procedures for change detection using Landsat digital data. *Int. J. Remote Sens.* 2(3): 277-291.

Huerte, A.R., Jackson, R.D. and Post, D.F. 1985. Spectral response of a plant canopy with different soil backgrounds. *Remote Sens. Environ.* 17(1): 37-53.

Hutchinson, C.F. 1982. Techniques for combining Landsat and ancillary data for digital classification improvement. *Photogramm. Eng. and Remote Sens.* 48: 123-130.

Ingebritsen, S.E. and Lyon, J.P. 1985. Principal component analysis of multitemporal image pairs. *Int. J. Remote Sens.* 6(5): 687-696.

Jakubauskas, M.E., Lulla, K.P. and Mausel, P.W. 1990. Assessment of vegetation change in a fire altered forest landscape. *Photogramm. Eng. and Remote Sens.* 56(3): 371-377.

Jarman, M.L. 1985. Computer-aided vegetation mapping. *S. Afr. J. For.* 132: 40-45.

Jensen, J.R. 1996. *Introductory digital image processing: a remote sensing perspective, 2nd. ed.* Prentice-Hall, New York.

Jensen, J.R., Cowen, D.J., Althausen, J.D., Narumalani, S. and Weatherbee, O. 1993. An Evaluation of the CoastalWatch Change Detection Protocol in South Carolina: *Photogramm. Eng. and Remote Sens.* 59(6): 1039-1046.

Kenkel, N.C. and Podani, J. 1991. Plot size and estimation efficiency in plant community studies. *J. Veg. Sci.* 2:539-544.

Kent, M. and Ballard, J. 1988. Trends and problems in the application of classification and ordination methods in plant ecology. *Vegetatio* 78: 109-124

Kent, M. and Coker, P. 1992. *Vegetation Description and Analysis: A Practical Approach.* Wiley, New York.

Kruger, F.J. 1979. Plant Ecology. In: *Day, J., Siegfried, W.R., Louw, G.N. and Jarman, M.L. (eds.) Fynbos ecology: a preliminary synthesis. South African National Science Progress Report 40*, 88-126.

Lambrechts, J.J.N. 1979. Geology, geomorphology and soils. In: *Day, J., Siegfried, W.R., Louw, G.N. and Jarman, M.L. (eds.) Fynbos ecology: a preliminary synthesis. South African National Science Progress Report 40*, 16-26.

Langford, M. and Bell, W. 1997. Land cover mapping in a tropical hillsides environment: a case study in the Cauca region of Colombia: *Int. J. Remote Sens.* 18(6): 1289-1306.

Lasserre, M., Malan, O.G. and Turner, B. 1983. The application of principal component analysis to Landsat MSS data. *Proceedings of seminar on principal component analysis in the atmospheric and earth sciences,* Pretoria.

Le Maitre, D.C. and Midgley, J.J. 1992. Plant reproductive ecology. In: *Cowling, R.M. (ed.) The ecology of fynbos: nutrients, fire and diversity.* Oxford University Press, Cape Town, 135-174.

Lillesand, T.M. and Kiefer, R.W. 1987. *Remote sensing and image interpretation. 2nd ed.* Wiley, New York.

Lo, C.P. 1986. *Applied remote sensing*. Longman, New York.

Lo, C.P. and Shipman, R.L. 1990. A GIS approach to land-use change dynamics detection. *Photogramm. Eng. and Remote Sens*. 56(11): 1483-1491.

Lo, T.H.C., Scarpace, F.L. and Lillesand, T.M. 1986. Use of multitemporal spectral profiles in agricultural land-cover classification. *Photogramm. Eng. and Remote Sens.* 52(4): 535-544.

Loughlin, W.P. 1991. Principal Component Analysis for Alteration Mapping. *Photogramm. Eng. and Remote Sens.* 57(9): 1163-1169.

Low, A.B. and Rebelo, A.G. (eds.) 1996. *Vegetation of South Africa, Lesotho and Swaziland.* Department of Environmental Affairs and Tourism, Pretoria.

Ludwig, J.A. and Reynolds, J.F. 1988. *Statistical Ecology: A Primer in Methods and Computing*. Wiley, New York.

Lulla, K. and Mausel, P. 1983. Ecological applications of remotely sensed multispectral data. In: *Richason, B.F., Jr. (ed.) Introduction to remote sensing of the environment, 2nd ed.* Kendall/Hunt, Dubuque, Iowa. 354-377.

Macleod, R.D. 1994. *Using a quantitative accuracy assessment to compare various change detection techniques for eelgrass distributions in Great Bay, NH, with Landsat Thematic Mapper data, M.S. Thesis*, University of New Hampshire, Durham, New Hampshire.

Macleod, R.D. and Congalton, R.G. 1998. A quantitative comparison of change-detection algorithms for monitoring eelgrass from remotely sensed data. *Photogramm. Eng. and Remote Sens.* 64(3): 207-216.

Malila, W.A. 1980. Change vector analysis: an approach for detecting forest changes with Landsat, *Proceedings of the 6th Annual Symposium on Machine Processing of Remotely Sensed Data*, Purdue University, 326-335.

Maselli, F. Conese, C. and Petkov, L. 1994. Use of probability entropy for the estimation and graphical representation of the accuracy of maximum likelihood classifications. *ISPRS J. Photogramm. and Remote Sens.* 49(2): 13-20.

Maxwell, S.K. and Hoffer, R.M. 1996. Mapping agricultural crops with multi-date landsat data. *Proceedings of the National ASPRS/ACSM 1996 Annual Convention, Baltimore, MD*, 433-443.

McDonald, D.J. 1993. The vegetation of the southern Langeberg, Cape Province. 1. The plant communities of the Boosmansbos Wilderness Area. *Bothalia* 23(1): 129-151

Meentemeyer, V. and Box, E.O. 1987. Scale effects in landscape studies. In: *Turner, M.G. (ed.) Landscape heterogeneity and disturbance*. Springer-Verlag, New York, 15-34.

Miller, L.D. and Pearson, R.L. 1971. Areal mapping program of the IBP grassland biome: Remote sensing of the productivity of the short grass prairie as input into biosystem models. Proc. 7th Int. Symp. *Remote Sens. Environ.* 1:175-205.

Moll, E.J. and Bossi, L. 1984. Assessment of the extent of the natural vegetation of the fynbos biome of South Africa. *S. Afr. J. Sci.* 80: 355-358.

Moore, M.M. and Bauer, M.E. 1990. Classification of forest vegetation in north-central Minnesota using Landsat Multispectral Scanner and Thematic Mapper data. *For. Sci.* 36: 330-342.

Morin, R.L., Derenyi, E.E., Wein, R.W. and Yazdani, R. 1988. Up-dating landscape data for natural resource management through Landsat imagery. In: *Gelinas, R., Bond, D. and Smit, B. (eds.) Perspectives on land modelling*. Polyscience Publications, Montreal, 17-20.

Muchoney, D.M. and Haack, B.N. 1994. Change detection for monitoring forest defoliation. *Photogramm. Eng. and Remote Sens.* 60(10):1243-1251.

Mucina, L. 1997. Classification of vegetation: Past, present and future. *J. Veg. Sci.* 8: 751-760.

Mucina, L. and Van der Maarel, E. 1989. Twenty years of numerical syntaxonomy. *Vegetatio* 81:1-15.

Mustart, P., Cowling, R.M. and Albertyn, J. 1997. *Southern Overberg: South African Wild Flower Guide 8.* Botanical Society of South Africa and the Institute for Plant Conservation, Cape Town.

Nelson, R.F. 1983. Detecting forest canopy change due to insect activity using Landsat MSS. *Photogramm. Eng. and Remote Sens*. 49:1303-1314.

Nelson, R.F., Latty, R.S. and Mott, G. 1984. Classifying northern forests with Thematic Mapper Simulator data. *Photogramm. Eng. and Remote Sens.* 50: 607-617.

O'Neill, R.V., Milne, B.T., Turner, M.G. and Gardner, R.H. 1988. Resource utilization scales and landscape pattern. *Landscape Ecology* 2: 63-69.

Peterson, D.L., Westman, W.E., Stephenson, N.J., Ambrosia, V.G., Brass, J.A. and Spanner, M.A. 1986. Analysis of forest structure using Thematic Mapper simulator data. *I.E.E.E. Transactions on Geoscience and Remote Sensing* 24:113-121.

Pilon, P.G., Howarth, P.J., Bullock, R.A. and Adeniyi, P.O. 1988. An enhanced classification approach to change detection in semi-arid environments. *Photogramm. Eng. and Remote Sens.* 54(12): 1709-1716.

Poore, M.E.D. 1955. The use of phytosociological methods in ecological investigations. *J. Ecol.* 43:226-269.

Quatitrochi, D.A. and Pelletier, R.E. 1991. *Remote sensing for analysis of landscapes: an introduction. Quantitative methods in landscape ecology. The analysis and interpretation of landscape heterogeneity.* Springer-Verlag, New York.

Rao, V.R., Brach, E.J. and Mack, A.R. 1978. Crop discriminability in the visible and near infrared regions. *Photogramm. Eng. and Remote Sens. 44(9): 1179-1184.*

Richards, J.A. 1986. *Remote sensing digital image analysis*. Springer-Verlag, Berlin.

Richards, J.A., Landgrebe, D.A. and Swain, P.H. 1982. A means for utilizing ancillary information in multispectral classification. *Remote Sens. Environ.* 12: 463-477.

Richardson, D.M. and Van Wilgen, B.W. 1992. Ecosystems, community and species response to fire in mountain fynbos: conclusions from the Swartboskloof experiment. In: *Van Wilgen, B.W., Richardson, D.M., Kruger, F.J. and Van Hensbergen, H.J. (eds.) Fire in South African mountain fynbos: ecosystem, community and species response at Swartboskloof.* Springer-Verlag, Berlin, 273-284.

Richason, B.F., Jr. (ed.) 1983. *Introduction to remote sensing of the environment, 2nd ed.* Kendall/Hunt, Dubuque, Iowa.

Ringrose, S., Matheson, W., Tempest, F. and Boyle, T. 1990. The development and causes of range degradation features in southeast Botswana using Multi-temporal Landsat MSS imagery. *Photogramm. Eng. and Remote Sens.* 56(9): 1253-1262.

Roy, P., Ranganath, B., Diwakar, P., Vohra, T., Bhan, S., Singh, I. and Pandian, V. 1991. Tropical forest type mapping and monitoring using remote sensing. *Int. J. Remote Sens.* 12: 2205-2225.

Russel-Smith, J. 1991. Classification, species richness and environmental relations of monsoon rain forest in northern Australia. *J. Veg. Sci.* 2:259-278.

Sample, V.A. (ed.) 1994. *Remote sensing and GIS in ecosystem management.* Island Press, Washington.

Schloms, B.H.A., Ellis, F. and Lambrechts, J.J.N. 1983. Soils of the Cape Coastal Platform. In: *Deacon, H.J., Hendey, Q.B. and Lambrechts, J.J.N. (eds.) Fynbos palaeoecology: a preliminary synthesis. South African National Scientific Programmes Report No. 75,* 70-86.

Scholz, D. Fuhs, N. and Hixson, M. 1979. An evaluation of several different classification schemes, their parameters and performance. In: *Proceedings, Thirteenth International Symposium on Remote Sensing of the Environment.* Ann. Arbor: University of Michigan, 1143-1149.

Schowengerdt, R.A. 1983. *Techniques of Image Processing and Classification in Remote Sensing.* Academic Press, New York.

Schulze, E., Theron, G.K. and Van Hoven, W. 1994. The vegetation and identification of management units of the Imberbe Game Lodge in the mixed bushveld of the north-western Transvaal. *S. Afr. J. Bot.* 60(2): 85-93.

Shen, S.S., Badhwar, G.D. and Carnes, J.G. 1985. Separability of boreal forest species in the Lake Jennette area, Minnesota. *Photogramm. Eng. and Remote Sens.* 51(11): 1775-1783.

Shimwell, D.W. 1971. *Description and Classification of Vegetation.* Sidgewick and Jackson, London.

Short, N.M. 1982. *The Landsat tutorial workbook.* NASA Reference Publication 1078. Washington, D.C.: NASA Scientific and Technical Information Branch.

Short, N.M. and Blair, R.W., Jr. 1986. *Geomorphology from space: a global overview of regional landforms.* NASA SP-486. Washington, D.C.: NASA Scientific and Technical Information Branch.

Short, N.M. and Stuart, L.M., Jr. 1982. *The heat capacity mapping mission (HCMM) arthology.* NASA SP-465. Washington, D.C.: NASA Scientific and Technical Information Branch.

Singh, A. 1989. Digital change detection techniques using remotely sensed data. *Int. J. Remote Sensing* 10(6): 989-1003.

Smartt, P.F.M. 1978. Sampling for vegetation survey: a flexible systematic model for sample location. *Journal of Biogeography* 5:43-56.

Specht, R.L. 1979. *Heathlands and Related Shrublands: Descriptive Studies: Ecosystems of the World 9a Vol. 1 of 2*, Amsterdam.

Story, M. and Congalton, R.G. 1986. Accuracy assessment; a user's perspective. *Photogramm. Eng. and Remote Sens.* 52: 397-399.

Stow, D.A. and Estes, J.E. 1981. Landsat and digital terrain data for county-level resource management. *Photogramm. Eng. and Remote Sens.* 47: 215-222.

Strahler, A.H. 1980. The use of prior probabilities in maximum likelihood classification of remotely sensed data. *Remote Sensing Environ.* 10: 135-163.

Strahler, A.H., Estes, J.E., Mertz, F.C. and Stow, D.A. 1980. Incorporating collateral data in Landsat classification and modeling procedures. *Proc. 14th Internat. Symp. on Remote Sens. of the Environ. Environ. Res. Inst. of Michigan,* 1009-1026.

Swain, P.H. and Davis, S.M. 1978. *Remote Sensing: The Quantitative Approach.* McGraw-Hill, New York.

Szekielda, K.-H. 1988. *Satellite Monitoring of the Earth.* Wiley, New York.

Talbot, S.S. and Markon, C.J. 1986. Vegetation mapping of Nowitna National Wildlife Refuge, Alaska, using Landsat MSS digital data. *Photogramm. Eng. and Remote Sens.* 52(6): 791-799.

Taylor, M.M. 1974. Principal component colour display of ERTS imagery. *Proc. Second Canadian Symposium on Remote Sensing, Guelph*, 296-305.

Teply, J. and Green, K. 1991. Old growth forest: how much remains? *GeoInfo Syst.* 1:22-31.

Theron, J.N. 1983. Geological setting of the Fynbos. In: *Deacon, H.J., Hendey, Q.B. and Lambrechts, J.J.N. (eds.) Fynbos palaeoecology: a preliminary synthesis. South African National Scientific Programmes Report No. 75,* 21-34.

Thompson, M.W. 1993. Photographic and Landsat monitoring. Monitoring requirements for fynbos management. In: *Marais, C. and Richardson, D.M. (eds) Monitoring requirements for fynbos management. FRD Programme Report Series.* No. 11: 87-97.

Townshend, J.R.G., Justice, C.O., Gurney, C. and McManus, J. 1992. The impact of misregistration on change detection. *IEEE Transactions on Geoscience and Remote sensing* 30(5): 1054-1060.

Tucker, C.J. 1977. Asymptotic nature of grass canopy spectral reflectance. *Appl. Opt.* 16: 1151-1157.

Tucker, C.J. 1978. An evaluation of the first four Landsat Thematic Mapper reflective sensors for monitoring vegetation: A comparison with other satellite sensor systems. *NASA Tech. Memo.*, NASA TM-79617.

Tucker, C.J. and Maxwell, E.L. 1976. Sensor design for monitoring vegetation canopies. *Photogramm. Eng. and Remote Sens.* 24: 1399-1410.

Turner, M.G. and Gardner, R.H. (eds.) 1991. *Quantitative methods in landscape ecology. The analysis and interpretation of landscape heterogeneity.* Springer-Verlag, New York.

Turner, M.G., Dale, V.H. and Gardner, R.H. 1989. Predicting across scales: theory development and testing. *Landscape Ecology* 3:245-252.

Van der Maarel, E. 1975. The Braun-Blanquet approach in perspective. *Vegetatio* 30: 213-219.

Van der Maarel, E. 1990. Ecotones and ecoclines are different. *J. Veg. Sci.* 1: 135-138.

Van der Merwe, C.V. 1977. 'n Plantegroeiopname van die De Hoop Natuurreservaat. *Cape Department of Nature and Environmental Conservation Investigational report* 1: 1-29.

Van Wilgen, B.W., Everson, C.S. and Trollope, W.S.W. 1990. Fire management in Southern Africa: some examples of current objectives, practises and problems. In: *Goldammer, J.G. (ed.) Fire in the tropical biota: ecosystem processes and global challenges.* Springer-Verlag, Berlin, 179-215.

Vogelman, J.E. and Rock, B.N. 1986. Assessing forest decline in coniferous forests of Vermont using NS-001 Thematic Mapper data. *Internat. J. Remote Sens.* 7(10): 1303-1321.

Walsh, S.J. and Townsend, P.A. 1995. Comparison of change detection approaches for assessing a riverine flood hydroperiod. *ACSM/ASPRS Annual Convention and Exposition Technical Papers. American Congress on Surveying and Mapping and American Society for Photogrammetry. United States.* 134-143.

Walsh, S.J., Cooper, J.W., Von Essen, I.E. and Gallager, K.R. 1990. Image enhancement of Landsat Thematic Mapper data and GIS data integration for evaluation of resource characteristics. *Photogramm. Eng. and Remote Sens.* 56(8): 1135-1141.

Webster, R. and Beckett, P.H.T. 1968. Quality and usefulness of soil maps. *Nature* 219: 680-682.

Westfall, R.H. and Malan, O.G. 1986. A method for vegetation stratification using scale-related, vegetation enhanced satellite imagery. *Bothalia* 16(2): 263-268.

Williams, R.S. and Carter, W.D. (eds.) 1976. *ERTS-1: A new window on our planet. Geological Survey Profesianal Paper 929.* Washington, D.C.: U.S.G.P.O.

Woolley, J.T. 1971. Reflectance and transmittance of light by leaves. *Plant Physiol.* 47: 656-662.

Yool, S.R., Star, J.L., Estes, J.E., Botkin, D.B., Eckhardt, D.W. and Davis, F.W. 1986. Performance analysis of image processing algorithms for classification of natural vegetation in the mountains of Southern California. *Int. J. Remote Sensing* 7: 683-702.

Yuan, D. 1990. Higher order principal components: more information about lithological background. *Assn. Petrol. Geochem. Explor. Bull.* 6(1): 49-65.

Appendix 1

Included are the one page summaries of all the quadrat data as they were sampled and described within their various communities within the study area.

Also included is the summary of the description of the quadrats within the burnt area that is to the east of the study area.

Renoster

Quadrats

Species		Ra	Rb	Rc	Rd	Re	Rf	Rg	Rh	Ri	Rj
Definite effect:	*Elytropappus rhinocerotis*	65	60	80	70	35	60	35	70	50	50
	Rhus glauca	5	2	3	3	35	25	3	3	20	4
	Nylandtia spinosa	8	6	2	3	0.5	2	6	1	4	5
Possible effect:	*Aspalathus sanguineus ssp. Sanguineus*	2	8	0.5							5
	Relhania uniflora	0.5	2	0.5	0.5	2	3	15	2		
	Chrysanthemoides monilifera					0.5					
Slope:Flat area											
Stone: Plenty limestone rock											
Few limestone rock											
No limestone rock											
Plenty small pebbles											
Few small pebbles											
No small pebbles											
Banks: Plenty limestone banks											
Few limestone banks											
No limestone banks											
Bare ground: Covered with small grasses+regrowth		20	20	12	20	20	15	40	25	25	35
Soil: Deep 30cm+											
Medium depth 15-30cm											
Shallow 0-15cm											
Light leached colour											
Brown fertile clour											

Quadrat co-ordinates

	GPS:X	GPS:Y
Ra	20.40178	34.46228
Rb	20.4048	34.46285
Rc	20.40647	34.46235
Rd	20.3996	34.46103
Re	20.39841	34.46316
Rf	20.39905	34.45993
Rg	20.40584	34.46009
Rh	20.40385	34.46023
Ri	20.40093	34.46266
Rj	20.40454	34.46425

Colour key

- (red) Typical of quadrat and area.
- (green) Typical of area and if % than in plot as well.
- (yellow) Not typical of area or covered by other species, reckon plays no role.

Structural description of quadrats

Ra - Low Closed Small Leaved Shrubland with a Closed Grass Understorey.
Rb - Low Closed Small Leaved Shrubland with a Closed Grass Understorey.
Rc - Low Closed Small Leaved Shrubland with a Closed Grass Understorey.
Rd - Low Closed Small Leaved Shrubland with a Closed Grass Understorey.
Re - Low Closed Shrubland with a Closed Grass Understorey.
Rf - Low Closed Small Leaved Shrubland with a Closed Grass Understorey.
Rg - Low Middense Small Leaved Shrubland/Closed Grassland.
Rh - Low Closed Small Leaved Shrubland with a Closed Grass Understorey.
Ri - Low Closed Small Leaved Shrubland with a Closed Grass Understorey.
Rj - Low Middense Small Leaved Shrubland with a Closed Grass Understorey.

Thatch

Quadrats

Species		Ba	Bb	Bc	Bd	Be	Bf	Bg	Bh	Bi	Bj
Definite effect:	*Elytropappus rhinocerotis*	2	20	5	3	3	3	10			
	Thamnochortus insignis	80	95	90	60	60	30	95		100	100
	Erica vernicosa	60	3	40	60	50	50	10	25		
Possible effect:	*Thamnochortus fraternus*								30		
	Chondropetalum microcarpum						30		4		
	Passerina galpinii	0.5							60		
	Erica inops				10		2				
	Otholobium fruticans				5	5					
	Phylica axillaris								0.5		
	Pterocelastrus tricuspidatus										
	Sideroxylon inerme										
	Rhus glauca										
	Chrysanthemoides monilifera										
Slope:	Flat area										
	Basin										
Stone:	Plenty limestone rock										
	Few limestone rock										
	No limestone rock										
	Plenty small pebbles										
	Few small pebbles										
	No small pebbles										
Banks:	Plenty limestone banks										
	Few limestone banks										
	No limestone banks										
Bare ground:	Covered with small grasses+regrowth	5				2			10		
Soil:	Deep 30cm+										
	Medium depth 15-30cm										
	Shallow 0-15cm										
	Light leached colour										
	Brown fertile clour										

Quadrat co-ordinates

	GPS:X	GPS:Y
Ba	20.41783	34.48738
Bb	20.42335	34.48523
Bc	20.42564	34.48413
Bd	20.43206	34.48499
Be	20.42956	34.48269
Bf	20.43074	34.48011
Bg	20.42884	34.47916
Bh	20.41433	34.48772
Bi	20.42664	34.48884
Bj	20.43237	34.48254

Colour key

- (red) Typical of quadrat and area.
- (green) Typical of area and if % than in plot as well.
- (yellow) Not typical of area or covered by other species, reckon plays no role.

Structural description of quadrats

Ba - Mid-high Closed Restioid Dwarf Ericoid Shrubland with a Tall Open Shrub Overstorey.
Bb - Tall Closed Restioland with a Tall Open Shrub Overstorey.
Bc - Mid-high Closed Restioid Dwarf Ericoid Shrubland with a Tall Open Shrub Overstorey.
Bd - Low Closed Restioid Dwarf Ericoid Shrubland with a Low Open Small Leaved Shrub Overstorey.
Be - Mid-high Closed Restioid Dwarf Ericoid Shrubland.
Bf - Mid-high Closed Restioid Dwarf Ericoid Shrubland with a Low Sparse Shrub Overstorey..
Bg - Tall Closed Restioland with a Tall Very Sparse Shrub Overstorey.
Bh - Low Closed Restioid Low Small Leaved Shrubland/Dwarf Ericoid Open Shrubland.
Bi - Tall Closed Restioland.
Bj - Tall Closed Restioland.

Passerina

Quadrats

Species		Pa	Pb	Pc	Pd	Pe	Pf	Pg	Ph	Pi
Definite effect:	*Passerina galpinii*	45	50	50	60	60	60	45	40	40
	Rhus glauca	1.5	2	0.5			1	1	1	1
	Nylandtia spinosa	6	5	8	2	2	4	10		
Possible effect:	*Aspalathus sanguineus ssp. Sanguineus*	1.5	8		5			0.5		
	Erica vernicosa								1	3
	Erica bruniifolia								5	2
	Otholobium fruticans	0.5								
	Rhus lucida	0.5								
	Elytropappus rhinocerotis			0.5				0.5		
	Relhania uniflora							0.5		2
	Thamnochortus fraternus								30	30
	Chondropetalum microcarpum								60	15
	Merxmuellera cincta									2
Slope: Flat area										
Stone: Plenty limestone rock										
Few limestone rock										
No limestone rock										
Plenty small pebbles										
Few small pebbles										
No small pebbles										
Banks: Plenty limestone banks										
Few limestone banks										
No limestone banks										
Bare ground: Covered with small grasses+regrowth		35	30	35	30	30	30	40	10	10
Soil: Deep 30cm+										
Medium depth 15-30cm										
Shallow 0-15cm										
Light leached colour										
Brown fertile clour										

Quadrat co-ordinates

	GPS:X	GPS:Y
Pa	20.42781	34.46927
Pb	20.42326	34.46898
Pc	20.42135	34.46935
Pd	20.4186	34.47043
Pe	20.42137	34.4716
Pf	20.42619	34.4712
Pg	20.4275	34.47317
Ph	20.42904	34.47214
Pi	20.42993	34.47425

Colour key

- Typical of quadrat and area.
- Typical of area and if % than in plot as well.
- Not typical of area or covered by other species, reckon plays no role.

Structural description of quadrats

Pa - Low Middense Small Leaved Shrubland/Closed Grassland
Pb - Low Middense Small Leaved Shrubland/Closed Grassland
Pc - Low Middense Small Leaved Shrubland/Closed Grassland
Pd - Low Closed Small Leaved Shrubland/Closed Grassland
Pe - Low Closed Small Leaved Shrubland/Closed Grassland
Pf - Low Closed Small Leaved Shrubland/Closed Grassland
Pg - Low Middense Small Leaved Shrubland/Closed Grassland
Ph - Closed Restioid Small Leaved Shrubland
Pi - Closed Restioid Small Leaved Shrubland

Euchaetis

Quadrats

Species		Ea	Eb	Ec	Ed	Ee	Ef	Eg	Eh	Ei	Ej	Ek	El	Em	En	Eo	Ep	Eq
Definite effect:	*Thamnochortus fraternus*	70	40	45	50	35	40	50	30	40	50	50	50	30	20	60	40	50
	Rhus glauca	1		0.5	3		0.5	0.5	2	0.5	0.5	0.5			0.5	0.5	1	
	Chondropetalum microcarpum					10	0.5				15	15		15	50	30	40	15
	Passerina galpinii				20		30	25	15	30	10	10	15	3		20	4	15
	Erica spectabilis	10	60	10				0.5					20		5			
	Euchaetis meridionalis	4	2	40	7	20					3	40	25	50	30		50	0.5
	Leucadendron muirii	5	7	15	15	15	30	15	40	5	12		10	20	15			25
	Leucadendron meridianum	5	12						25									
	Protea obtusifolia								1	20				3				
	Erica scytophylla					40	20				10						2	30
	Erica bruniifolia	10	15	5			3	15		4	4					5	2	
Possible effect:	*Tarchonanthus camphoratus*	1		0.5														
	Pterocelastrus tricuspidatus																	
	Otholobium fruticans	0.5									0.5		0.5		0.5	0.5		
	Merxmuellera cincta																	
	Myrica quercifolia				3													
	Chrysanthemoides monilifera															0.5		
	Phylica axillaris			0.5						0.5		7				12		
	Relhania uniflora	3																
	Elytropappus rhinocerotis	1	0.5	1														
	Nylandtia spinosa							0.5										
	Aspalathus calcarea		0.5			3			15	3	2							
	Euryops linearis								3									
	Anthospernum spathulatum												10					
	Sideroxylon inerme																	
Slope: Flat area																		
Stone: Plenty limestone rock																		
Few limestone rock																		
No limestone rock																		
Plenty small pebbles																		
Few small pebbles																		
No small pebbles																		
Banks: Plenty limestone banks																		
Few limestone banks																		
No limestone banks																		
Bare ground: Covered with small grasses+regrowth					30		10	20		30	10	15			15			20
Soil: Deep 30cm+																		
Medium depth 15-30cm																		
Shallow 0-15cm																		
Light leached colour																		
Brown fertile clour																		

Quadrat co-ordinates

	GPS:X	GPS:Y
Ea	20.41263	34.45863
Eb	20.41549	34.45871
Ec	20.42086	34.45748
Ed	20.42369	34.45989
Ee	20.42594	34.46116
Ef	20.42376	34.46295
Eg	20.42287	34.46746
Eh	20.41752	34.46244
Ei	20.41394	34.46385
Ej	20.41447	34.46689
Ek	20.40625	34.46666
El	20.40118	34.46573
Em	20.40482	34.46893
En	20.40748	34.47102
Eo	20.40628	34.4739
Ep	20.41305	34.47272
Eq	20.41536	34.47141

Colour key

- (red) Typical of quadrat and area.
- (green) Typical of area and if % than in plot as well.
- (yellow) Not typical of area or covered by other species, reckon plays no role.

Structural description of quadrats

Ea - Closed Restioland with a Tall Open Shrub Overstorey with a Low Open Small Leaved Shrub Understorey.
Eb - Closed Restioland with an Low Ericoid Shrubland with a Midhigh Sparse Shrub Overstorey.
Ec - Closed Restioid Low Small Leaved Shrubland with a Tall Open Shrub Overstorey.
Ed - Closed Restioid Low Small Leaved Shrubland with a Proteoid Midhigh Sparse Overstorey.
Ee - Closed Restioid Low Ericoid Shrubland/Midhigh Open Proteoid Shrubland.
Ef - Closed Restioid Low Small Leaved Shrubland/Midhigh Open Proteoid Shrubland.
Eg - Closed Restioid Small Leaved Shrubland/Midhigh Open Proteoid Shrubland.
Eh - Closed Restioid/Midhigh Proteoid Shrubland/Low Middense Small Leaved Shrubland.
Ei - Closed Restioid Midhigh Proteoid Shrubland/Middense Small Leaved Shrubland.
Ej - Closed Restioid Low Small Leaved Shrubland with a Proteoid Midhigh Open Shrubland.
Ek - Closed Restioid Low Small Leaved Shrubland.
El - Closed Restioid Midhigh Small Leaved Shrubland with a Tall Open Shrub Overstorey.
Em - Closed Restioid Low Small Leaved Shrubland with a Midhigh Open Proteoid Overstorey.
En - Closed Restioid Low Small Leaved Shrubland.
Eo - Closed Restioid Low Small Leaved Shrubland.
Ep - Closed Restioid Low Small Leaved Shrubland.
Eq - Closed Restioid Low Ericoid Shrubland/Low Open Proteoid Shrubland.

Erica

Quadrats

Species		Ha	Hb	Hc	Hd	He	Hf	Hg	Hh	Hi	Hj	Hk	Hl	Hm	Hn	Ho	Hp	Hq	Hr	Hs	Ht	Hu	Hv	Hw	Hx
Definite effect:	*Thamnochortus fraternus*	20	20	1	30	3	0.5	3	10	15	30	2	1	50	40	40	60	30	50	25	40	20	30	60	60
	Chondropetalum microcarpum	20	3	3	6	32	60	40	40	15	35	25	35	25	40	30	15	3	20	60	60	10	60	50	3
	Erica vernicosa	60	70	75	80	45	50	40	40	30	40	25	20	20	15	20	10	20	10	20	10	60	20	10	10
	Passerina galpinii	7	11	35	10	50	25	70	35	60	35	45	25	20	15	3	20	10	40	50	40	60	20	25	25
	Erica scytophylla													30	25	37	50	60	40				0.5	10	40
Possible effect:	*Erica inops*				5	0.5								1	10	5									
	Elytropappus rhinocerotis						0.5																		
	Nylandtia spinosa				0.5		0.5	0.5			0.5														
	Rhus glauca					0.5																		1	
	Chrysanthemoides monilifera					0.5																			
	Phylica axillaris																						7		
	Rhus lucida				0.5	0.5																			
	Euchaetis meridionalis													1											
	Thamnochortus insignis																								
	Pterocelastrus tricuspidatus																								
	Sideroxylon inerme																								
Slope: Flat area																									
Stone: Plenty limestone rock																									
Few limestone rock																									
No limestone rock																									
Plenty small pebbles																									
Few small pebbles																									
No small pebbles																									
Banks: Plenty limestone banks																									
Few limestone banks																									
No limestone banks																									
Bare ground: Covered with small grasses+regrowth		15	20	20	10	10		10	20		5	15	20	10	15	20		30			5		20		10
Soil: Deep 30cm+																									
Medium depth 15-30cm																									
Shallow 0-15cm																									
Light leached colour																									
Brown fertile clour																									

Quadrat co-ordinates

	GPS:X	GPS:Y
Ha	20.42982	34.47601
Hb	20.42986	34.47673
Hc	20.42717	34.47507
Hd	20.42703	34.47783
He	20.42715	34.47869
Hf	20.42762	34.47958
Hg	20.42419	34.48028
Hh	20.41884	34.48336
Hi	20.42556	34.48096
Hj	20.42571	34.47713
Hk	20.42331	34.4754
Hl	20.42269	34.4782
Hm	20.41944	34.4776
Hn	20.41815	34.47573
Ho	20.41569	34.47739
Hp	20.41203	34.47974
Hq	20.41353	34.47793
Hr	20.41475	34.48175
Hs	20.42002	34.48055
Ht	20.41929	34.47933
Hu	20.41779	34.48445
Hv	20.41307	34.48695
Hw	20.40947	34.48368
Hx	20.41105	34.4802

Colour key

- Typical of quadrat and area. (red)
- Typical of area and if % than in plot as well. (green)
- Not typical of area or covered by other species, reckon plays no role. (yellow)

Structural description of quadrats

Ha - Closed Restioid Dwarf Ericoid Shrubland with a Low Sparse Shrub Overstorey.
Hb - Closed Restioid Dwarf Ericoid Shrubland with a Low Sparse Shrub Overstorey.
Hc - Dwarf Closed Ericoid Shrubland/Low Open Small Leaved Shrubland
Hd - Closed Restioid Dwarf Ericoid Shrubland/Low Middense Small Leaved Shrubland.
He - Closed Restioid Dwarf Ericoid Shrubland/Low Middense Small Leaved Shrubland.
Hf - Closed Restioid Dwarf Ericoid Shrubland/Low Middense Small Leaved Shrubland.
Hg - Closed Restioid Small Leaved Low Shrubland/Dwarf Ericoid Open Shrubland.
Hh - Closed Restioid Low Small Leaved Shrubland with a Dwarf Ericoid Shrub Understorey.
Hi - Closed Restioid Low Small Leaved Shrubland/Dwarf Middense Shrubland.
Hj - Closed Restioid Low Small Leaved Shrubland/Dwarf Closed Ericoid Shrubland.
Hk - Closed Restioid Low Small Leaved Shrubland/Open Dwarf Ericoid Shrubland.
Hl - Closed Restioid Low Small Leaved Shrubland/Dwarf Open Ericoid Shrubland.
Hm - Closed Restioid Low Small Leaved Shrubland/Dwarf Open Ericoid Shrubland.
Hn - Closed Restioid Low Small Leaved Shrubland with a Dwarf Sparse Ericoid Shrub Understorey.
Ho - Closed Restioid Low Small Leaved Shrubland with a Dwarf Sparse Ericoid Shrub Understorey.
Hp - Closed Restioid Low Small Leaved Shrubland.
Hq - Closed Restioid Low Small Leaved Shrubland with a Dwarf Open Ericoid Shrub Understorey.
Hr - Closed Restioid Low Ericoid Shrubland.
Hs - Closed Restioid Low Small Leaved Shrubland with a Dwarf Open Ericoid Shrub Understorey.
Ht - Closed Restioid Low Small Leaved Shrubland.
Hu - Closed Restioid Low Small Leaved Shrubland/Dwarf Middense Ericoid Shrubland.
Hv - Closed Restioid Low Small Leaved Shrubland with a Dwarf Sparse Ericoid Understorey with a Midhigh Sparse Shrub Overstorey.
Hw - Closed Restioid Low Ericoid Shrubland with a Open Dwarf Ericoid Shrub Understorey.
Hx - Closed Restioid Mid-High Ericoid Shrubland/Low Open Small Leaved Shrubland.

Old Lands

Quadrats

Species		Oa	Ob	Oc	Od	Oe	Of	Og	Oh	Oi	Oj	Ok	Ol	Om	On	Oo	Op	Oq	Or	Os	Ot	Ou	Ov	Ow	Ox
Definite effect:	*Nylandtia spinosa*				10	25	25	40	25	65	30	20	30	3	10	5	15	20	20	2	25			5	30
	Relhania uniflora				25	0.5								60	10	20	0.5	20			5				
	Merxmuellera cincta							60					40	30	80	70	70	60	75	85	60	100	100	95	80
	Cynodon dactylon	50	70	80	40	80	70		70	35	60	80								10					
	Carpobrotus edulis subsp. Edulis	25	20	20	1				5					2	1	2	2	0.5	2		2				
Possible effect:	*Elytropappus rhinocerotis*				30														2						
	Rhus glauca																	0.5							
	Aspalathus sanguineus ssp. Sanguineus					2					10														
	Passerina galpinii												30												
	Rhus lucida						5							2				0.5							
	Myrica quercifolia																10		2	3	5				
	Euryops linearis																								
	Sideroxylon inerme																								
	Thamnochortus insignis																								
Slope: Flat area																									
Basin																									
Stone: Limestone rocks spread evenly over area		5	5																						
Bare ground: Covered with small grasses+regrowth		25	30																						
Soil: Brown fertile clour																									

Quadrat co-ordinates

	GPS:X	GPS:Y
Oa	20.40272	34.46148
Ob	20.40417	34.46232
Oc	20.40749	34.46273
Od	20.41231	34.46257
Oe	20.41767	34.46844
Of	20.41611	34.47015
Og	20.4144	34.4701
Oh	20.4122	34.47174
Oi	20.41384	34.46613
Oj	20.41888	34.4726
Ok	20.42343	34.47382
Ol	20.41383	34.4743
Om	20.41991	34.45875
On	20.4211	34.4609
Oo	20.42637	34.46324
Op	20.42235	34.46269
Oq	20.42449	34.4617
Or	20.41887	34.46397
Os	20.42235	34.46555
Ot	20.41959	34.46679
Ou	20.42963	34.48812
Ov	20.43144	34.48357
Ow	20.40825	34.47849
Ox	20.40978	34.47624

Structural description of quadrats

Oa - Closed Grassland with a Closed Dwarf Succulent Shrub Overstorey.
Ob - Closed Grassland with a Closed Dwarf Succulent Shrub Overstorey.
Oc - Closed Grassland with a Closed Dwarf Succulent Shrub Overstorey.
Od - Low Middense Small Leaved Shrubland with a Closed Grass Understorey.
Oe - Closed Grassland with a Low Sparse Small Leaved Shrub Overstorey.
Of - Closed Grassland with a Low Open Small Leaved Shrub Overstorey.
Og - Closed Grassland with a Low Open Small Leaved Shrub Overstorey.
Oh - Closed Grassland with a Low Open Small Leaved Shrub Overstorey.
Oi - Low Middense Small Leaved Shrubland with a Closed Grass Understorey.
Oj - Closed Grassland/Low Open Small Leaved Shrubland.
Ok - Closed Grassland with a Low Sparse Small Leaved Shrub Overstorey.
Ol - Low Middense Small Leaved Shrubland/Closed Grassland.
Om - Low Closed Small Leaved Shrubland with a Closed Grass Understorey.
On - Closed Grassland with a Low Sparse Small Leaved Shrub Overstorey.
Oo - Closed Grassland with a Low Open Small Leaved Shrub Overstorey.
Op - Closed Grassland with a Low Sparse Small Leaved Shrub Overstorey.
Oq - Closed Grassland/Low Open Small Leaved Shrubland.
Or - Closed Grassland with a Low Sparse Small Leaved Shrub Overstorey.
Os - Closed Grassland.
Ot - Closed Grassland/Low Open Small Leaved Shrubland.
Ou - Closed Grassland.
Ov - Closed Grassland.
Ow - Closed Grassland.
Ox - Closed Grassland with a Low Open Small Leaved Shrub Overstorey.

Colour key

- Typical of quadrat and area.
- Typical of area and if % than in plot as well.
- Not typical of area or covered by other species, reckon plays no role.

Vlei

Quadrats

		Va	Vb	Vc	Vd	Ve
Species						
Definite effect:	*Rhus glauca*	20	20	5	20	20
	Thamnochortus fraternus	40	40		60	40
	Pterocelastrus tricuspidatus	30	30	70	20	15
	Euryops linearis	5	10		10	15
	Sideroxylon inerme	15	10	20	10	10
Possible effect:	*Elytropappus rhinocerotis*		7			
	Relhania uniflora		7			
	Merxmuellera cincta		3			
Slope: Flat area						
Stone: Plenty limestone rock						
Few limestone rock						
No limestone rock						
Plenty small pebbles						
Few small pebbles						
No small pebbles						
Banks: Plenty limestone banks						
Few limestone banks						
No limestone banks						
Bare ground: Covered with small grasses+regrowth		20	10	10	5	25
Soil: Deep 30cm+						
Medium depth 15-30cm						
Shallow 0-15cm						
Light leached colour						
Brown fertile clour						

Quadrat co-ordinates

	GPS:X	GPS:Y
Va	20.39688	34.45986
Vb	20.39829	34.46162
Vc	20.39624	34.46288
Vd	20.40122	34.46404
Ve	20.40363	34.46447

Colour key

- Typical of quadrat and area.
- Typical of area and if % than in plot as well.
- Not typical of area or covered by other species,

Structural description of quadrats

Va - Tall Middense Shrubland/Low Middense Restioland.
Vb - Tall Middense Shrubland/Low Middense Restioland.
Vc - Tall Closed Shrubland.
Vd - Middense Restioland/Low Open Shrubland with a Tall Sparse Shrub Overstorey.
Ve - Middense Restioland/Low Open Shrubland with a Tall Sparse Shrub Overstorey.

Border areas

Quadrats

Species		Ga	Gb	Gc	Gd	Ge	Gf	Gg	Gh	Gi	Gj	Gk	Gl
Definite effect:	*Passerina galpinii*	35	40	10	30	50	15	15	30	40	30		20
	Chondropetalum microcarpum	35	10	30	3		35	30	7			25	5
	Thamnochortus fraternus	15	20	30	50		30	30	30			30	35
	Euchaetis meridionalis	5		2	1			0.5				20	1
	Erica vernicosa			7									
Possible effect:	*Erica bruniifolia*				2		2	4					
	Rhus glauca	2	1	1	1		2	2	2	1	3	3	
	Nylandtia spinosa		1		0.5	4		0.5	0.5	2	1		2
	Phylica axillaris	1	1	1									
	Erica scytophylla			1									15
	Erica inops												
	Leucadendron muirii								10			2	20
Slope:	Flat area												
Stone:	Plenty limestone rock												
	Few limestone rock												
	No limestone rock												
	Plenty small pebbles												
	Few small pebbles												
	No small pebbles												
Banks:	Plenty limestone banks												
	Few limestone banks												
	No limestone banks												
Bare ground:	Covered with small grasses+regrowth	12	10	5	5	25	10	10	15	30	40	5	20
Soil:	Deep 30cm+												
	Medium depth 15-30cm												
	Shallow 0-15cm												
	Light leached colour												
	Brown fertile clour												

Quadrat co-ordinates

	GPS:X	GPS:Y
Ga	20.40874	34.47654
Gb	20.41113	34.47555
Gc	20.41533	34.47505
Gd	20.41495	34.47302
Ge	20.41584	34.4728
Gf	20.41817	34.47314
Gg	20.41696	34.47173
Gh	20.42126	34.47296
Gi	20.42583	34.46774
Gj	20.42773	34.46723
Gk	20.42658	34.46795
Gl	20.42522	34.46813

Colour key

- Red: Typical of quadrat and area.
- Green: Typical of area and if % than in plot as well.
- Yellow: Not typical of area or covered by other species, reckon plays no role.

Structural description of quadrats

Ga - Closed Restioid Small Leaved Shrubland.
Gb - Closed Restioid Small Leaved Shrubland.
Gc - Closed Restioid Small Leaved Shrubland.
Gd - Closed Restioid Small Leaved Shrubland.
Ge - Low Middense Small Leaved Shrubland.
Gf - Closed Restioid Small Leaved Shrubland.
Gg - Closed Restioid Small Leaved Shrubland.
Gh - Closed Restioid Low Small Leaved Shrubland.
Gi - Low Middense Small Leaved Shrubland/Closed Grassland
Gj - Low Middense Small Leaved Shrubland/Closed Grassland
Gk - Mid-dense Restioid Low Small Leaved Shrubland.
Gl - Mid-dense Restioland with a Mid-high Open Proteoid Shrub Overstorey.

Burnt area

Species		Fa	Fb	Fc	Fd	Fe	Ff	Fg	Fh
Definite effect:	*Leucadendron muirii*	20	10						
	Erica scytophylla	35	30						
	Thamnochortus fraternus	20	20	60	60				
	Chondropetalum microcarpum	5	5			10	15	20	15
	Thamnochortus insignis							20	20
	Passerina galpinii	5	5	30	15				
	Euchaetis meridionalis		5	10	20				
	Erica bruniifolia		2	20	5				
	Erica vernicosa					75	70	20	25
	Erica inops					25	10	3	5
	Phylica axillaris							20	10
Possible effect:	*Otholobium fruticans*	0.5	0.5					0.5	0.5
	Myrica quercifolia	0.5	0.5						
	Rhus glauca	0.5			0.5				
	Nylandtia spinosa				0.5				
	Merxmuellera cincta							2	4
Slope: Flat area									
Stone: Plenty limestone rock									
Few limestone rock									
No limestone rock									
Plenty small pebbles									
Few small pebbles									
No small pebbles									
Banks: Plenty limestone banks									
Few limestone banks									
No limestone banks									
Bare ground: Covered with small grasses+regrowth				25	20	15	15	5	10
Soil: Deep 30cm+									
Medium depth 15-30cm									
Shallow 0-15cm									
Light leached colour									
Brown fertile clour									

Quadrat co-ordinates

	GPS:X	GPS:Y
Fa	20.42902	34.46055
Fb	20.42914	34.46351
Fc	20.4298	34.46943
Fd	20.43121	34.47027
Fe	20.43273	34.47465
Ff	20.43629	34.47384
Fg	20.43399	34.48035
Fh	20.43701	34.47843

Colour key

- (red) Typical of quadrat and area.
- (green) Typical of area and if % than in plot as well.
- (yellow) Not typical of area or covered by other species, reckon plays no role.

Structural description of quadrats

Fa - Midhigh Closed Restioid Small Leaved Shrubland
Fb - Midhigh Closed Restioid Small Leaved Shrubland with a Midhigh Sparse Proteoid over storey
Fc - Low Middense Restioid Small Leaved Shrubland
Fd - Low Middense Restioid Small Leaved Shrubland
Fe - Dwarf Closed Restioid Small Leaved Ericoid Shrubland/Low Closed Small Leaved Shrubland
Ff - Dwarf Closed Restioid Small Leaved Ericoid Shrubland
Fg - Low Closed Restioid Small Leaved Shrubland/Dwarf Open Ericoid Shrubland
Fh - Low Closed Restioid Small Leaved Shrubland/Dwarf Open Ericoid Shrubland

Appendix 2

Included is the one page data matrix of all the areas sampled and described within the study area, including the burnt area.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
		E. rhinocerotus	N. spinosa	R. glauca	A. sanguineus	R. uniflora	Bare ground	C. monilifera	T. insignis	T. fraternus	C. microcarpum	E. verrucosa	P. galpinii	E. inops	O. fruticans	O. axillaris	R. lucida	M. cincta	P. tricuspidatus	T. camphoratus	E. spectabilis	E. meridionalis	L. muiri	L. meridianum	P. obtusifolia	E. bruniifolia	A. calcarea	M. quercifolia	E. scytophylla	E. linearis	A. spathulatum	C. dactylon	C. edulis	S. inerme	Limestone rock	Pebbles	Limestone banks	Soil deep	Soil med. depth	Soil shallow	Soil light	Soil brown	Flat area	Basins
1	Ra	65	8	5	2	0.5	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15									
2	Rb	60	6	2	8	2	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15									
3	Rc	80	2	3	0.5	0.5	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15									
4	Rd	70	3	3	0	0.5	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15									
5	Re	35	0.5	35	0	2	20	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15									
6	Rf	60	2	25	0	3	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15		5							
7	Rg	35	6	3	0	15	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15		15							
8	Rh	70	1	3	0	2	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15		5							
9	Ri	50	4	20	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15									
10	Rj	50	5	4	5	0	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15		15							
11	Ba	2	0	0	0	0	5	0	80	0	0	60	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
12	Bb	20	0	0	0	0	0	0	95	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
13	Bc	5	0	0	0	0	0	0	90	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
14	Bd	3	0	0	0	0	0	0	60	0	0	60	0	20	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
15	Be	3	0	0	0	0	2	0	60	0	0	50	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
16	Bf	3	0	0	0	0	0	0	30	0	30	50	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
17	Bg	10	0	0	0	0	0	0	95	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
18	Bh	0	0	0	0	0	10	0	0	30	4	25	60	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15		5							
19	Bi	0	0	0	0	0	0	0	99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
20	Bj	0	0	0	0	0	0	0	99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
21	Pa	0	6	1.5	1.5	0	35	0	0	0	0	0	45	0	0.5	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	15								
22	Pb	0	5	2	8	0	30	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	15	5							
23	Pc	0.5	8	0.5	0	0	35	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	5	15							
24	Pd	0	2	0	5	0	30	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	15	5							
25	Pe	0	2	0	0	0	30	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	15								
26	Pf	0	4	1	0	0	30	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	15								
27	Pg	0.5	10	1	0.5	0.5	40	0	0	0	0	0	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	15								
28	Ph	0	0	1	0	0	10	0	0	30	60	1	40	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	5	15	5							
29	Pi	0	0	1	0	2	10	0	0	30	15	3	40	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	5	15	5							
30	Ea	1	0	1	0	3	0	0	0	70	0	0	0	0	0.5	0	0	0	0	1	10	4	5	5	0	10	0	0	0	0	0	0	0	0	15		15							
31	Eb	0.5	0	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	60	2	7	12	0	15	0.5	0	0	0	0	0	0	0	5	15	15							
32	Ec	1	0	0.5	0	0	0	0	0	45	0	0	0	0	0	0.5	0	0	0	0.5	10	40	15	0	0	5	0	0	0	0	0	0	0	0	15		15							
33	Ed	0	0	3	0	0	30	0	0	50	0	0	20	0	0	0	0	0	0	0	0	7	15	0	0	0	0	3	0	0	0	0	0	0	15		15							
34	Ee	0	0	0	0	0	0	0	0	35	10	0	0	0	0	0	0	0	0	0	0	20	15	0	0	0	3	0	40	0	0	0	0	0	15		15							
35	Ef	0	0	0.5	0	0	10	0	0	40	0.5	0	30	0	0	0	0	0	0	0	0	0	30		0	3	0	0	20	0	0	0	0	0	15		15							
36	Eg	0	0.5	0.5	0	0	20	0	0	50	0	0	25	0	0	0	0	0	0	0	0.5	0	15	0	0	15	0	0	0	0	0	0	0	0	15		15							
37	Eh	0	0	2	0	0	0	0	0	30	0	0	15	0	0	0	0	0	0	0	0	0	40	25	1	0	15	0	0	3	0	0	0	0	15		15							
38	Ei	0	0	0.5	0	0	30	0	0	40	0	0	30	0	0	0.5	0	0	0	0	0	0	5	0	20	4	3	0	0	0	0	0	0	0	15		15							
39	Ej	0	0	0.5	0	0	10	0	0	50	15	0	10	0	0.5	0	0	0	0	0	0	3	12			4	2	0	10	0	0	0	0	0	15		15							
40	Ek	0	0	0.5	0	0	15	0	0	50	15	0	10	0	0	7	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	15		15							
41	El	0	0	0	0	0	0	0	0	50	0	0	15	0	0.5	0	0	0	0	0	20	25	10	0	0	0	0	0	0	0	10	0	0	0	15		5							
42	Em	0	0	0	0	0	0	0	0	30	15	0	3	0	0	0	0	0	0	0	0	50	20	0	3	0	0	0	0	0	0	0	0	0	15		15							
43	En	0	0	0.5	0	0	15	0	0	20	50	0	0	0	0.5	0	0	0	0	0	5	30	15	0	0	0	0	0	0	0	0	0	0	0	15		15							
44	Eo	0	0	0.5	0	0	0	0.5	0	60	30	0	20	0	0.5	12	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	15		15							
45	Ep	0	0	1	0	0	0	0	0	40	40	0	4	0	0	0	0	0	0	0	0	50	0	0	0	2	0	0	2	0	0	0	0	0	15		5							
46	Eq	0	0	0	0	0	20	0	0	50	15	0	15	0	0	0	0	0	0	0	0	0.5	25	0	0	0	0	0	30	0	0	0	0	0	15		15							
47	Ha	0	0	0	0	0	15	0	0	20	20	60	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15									
48	Hb	0	0	0	0	0	20	0	0	20	3	70	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15		5							
49	Hc	0	0	0	0	0	20	0	0	1	3	75	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15		5							
50	Hd	0	0.5	0	0	0	10	0	0	30	6	80	10	5	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5		5							
51	He	0	0	0.5	0	0	10	0.5	0	3	32	45	50	0.5	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5		5							
52	Hf	0.5	0.5		0	0	0	0	0	0.5	60	50	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5		5							
53	Hg	0	0.5	0	0	0	10	0	0	3	40	40	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5		5							
54	Hh	0	0	0	0	0	20	0	0	10	40	40	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15		15							
55	Hi	0	0	0	0	0	0	0	0	15	15	30	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15		15							
56	Hj	0	0.5	0	0	0	5	0	0	30	35	40	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5		5							
57	Hk	0	0	0	0	0	15	0	0	2	25	25	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			5							
58	Hl	0	0	0	0	0	20	0	0	1	35	20	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15									
59	Hm	0	0	0	0	0	10	0	0	50	25	20	20	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	30	0	0	0	0	0	15									
60	Hn	0	0	0	0	0	15	0	0	40	40	15	15	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	15		15							
61	Ho	0	0	0	0	0	20	0	0	40	30	20	3	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37	0	0	0	0	0	15		15							
62	Hp	0	0	0	0	0	0	0	0	60	15	10	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	15		15							
63	Hq	0	0	0	0	0	30	0	0	30	3	20	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0	0	0	0	0	15		15							
64	Hr	0	0	0	0	0	0	0	0	50	20	10	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	15		15							
65	Hs	0	0	0	0	0	0	0	0	25	60	20	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15		15							
66	Ht	0	0	0	0	0	5	0	0	40	60	10	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15									
67	Hu	0	0	0	0	0	0	0	0	20	10	60	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5								
68	Hv	0	0	0	0	0	20	0	0	30	60	20	20	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	15		15							
69	Hw	0	0	1	0	0	0	0	0	60	50	10	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	15		15							
70	Hx	0	0	0	0	0	10	0	0	60	3	10	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	15		15							
71	Oa	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	25	0	5									
72	Ob	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	20	0	5									
73	Oc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	20	0										
74	Od	30	10	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	1	0										
75	Oe	0	25	0	2	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	0	0										
76	Of	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	0	0										
77	Og	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
78	Oh	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	5	0										
79	Oi	0	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0										
80	Oj	0	30	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0	0										
81	Ok	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	0	0										
82	Ol	0	30	0	0	0	0	0	0	0	0	0	30	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
83	Om	0	3	0	0	60	0	0	0	0	0	0	0	0	0	0	2	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0										
84	On	0	10	0	0	10	0	0	0	0	0	0	0	0	0	0	0	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0										
85	Oo	0	5	0	0	20	0	0	0	0	0	0	0	0	0	0	0	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0										
86	Op	0	15	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	70	0	0	0	0	0	0	0	0	0	10	0	0	0	0	2	0										
87	Oq	0	20	0.5	0	20	0	0	0	0	0	0	0	0	0	0	0.5	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0										
88	Or	2	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2	0										
89	Os	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	85	0	0	0	0	0	0	0	0	0	3	0	0	0	10	0	0										
90	Ot	0	25	0	0	5	0	0	0	0	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0	5	0	0	0	0	2	0										
91	Ou	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
92	Ov	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
93	Ow	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
94	Ox	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
95	Va	0	0	20	0	0	20	0	0	40	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	5	0	0	0	15	15		15							
96	Vb	7	0	20	0	7	10	0	0	40	0	0	0	0	0	0	0	3	30	0	0	0	0	0	0	0	0	0	0	10	0	0	0	10	15		15							
97	Vc	0	0	5	0	0	10	0	0	0	0	0	0	0	0	0	0	0	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	15		15							
98	Vd	0	0	20	0	0	5	0	0	60	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	10	0	0	0	10	15		15							
99	Ve	0	0	20	0	0	25	0	0	40	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0		0	15	0	0	0	10	15		15							
100	Ga	0	0	2	0	0	12	0	0	15	35	0	35	0	0	1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	15		15							
101	Gb	0	1	1	0	0	10	0	0	20	10	0	40	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5							
102	Gc	0	0	1	0	0	5	0	0	30	30	7	10	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	15		15							
103	Gd	0	0.5	1	0	0	5	0	0	50	3	0	30	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	5		5							
104	Ge	0	4		0	0	25	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	15								
105	Gf	0	0	2	0	0	10	0	0	30	35	0	15	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	5	15	5							
106	Gg	0	0.5	2	0	0	10	0	0	30	30	0	15	0	0	0	0	0	0	0	0	0.5	0	0	0	4	0	0	0	0	0	0	0	0	15		15							
107	Gh	0	0.5	2	0	0	15	0	0	30	7	0	30	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	5	15	5							
108	Gi	0	2	1	0	0	30	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	15								
109	Gj	0	1	3	0	0	40	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	15								
110	Gk	0	0	3	0	0	5	0	0	30	25	0	0	0	0	0	0	0	0	0	0	20	2	0	0	0	0	0	0	0	0	0	0	0	15	15	15							
111	Gl	0	2	0	0	0	20	0	0	35	5	0	20	0	0	0	0	0	0	0	0	1	20	0	0	0	0	0	15	0	0	0	0	0	15	15	15							
112	Fa	0	0	0.5	0	0	0	0	0	20	5	0	5	0	0.5	0	0	0	0	0	0	0	20	0	0	0	0	0.5	35	0	0	0	0	0	15		15							
113	Fb	0	0	0	0	0	0	0	0	20	5	0	5	0	0.5	0	0	0	0	0	0	5	10	0	0	2	0	0.5	30	0	0	0	0	0	15		15							
114	Fc	0	0	0	0	0	25	0	0	60	0	0	30	0	0	0	0	0	0	0	0	10	0	0	0	20	0	0	0	0	0	0	0	0	5	15	15							
115	Fd	0	0.5	0.5	0	0	20	0	0	60	0	0	15	0	0	0	0	0	0	0	0	20	0	0	0	5	0	0	0	0	0	0	0	0	5	15	15							
116	Fe	0	0	0	0	0	15	0	0	0	10	75	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5		5							
117	Ff	0	0	0	0	0	15	0	0	0	15	70	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5		5							
118	Fg	0	0	0	0	0	5	0	20	0	20	20	0	3	0.5	20	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										
119	Fh	0	0	0	0	0	10	0	20	0	15	25	0	5	0.5	10	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0										

Appendix 3

TWINSPAN classification of the seven different communities as identified during fieldwork and the sampling process within the study area.

```
                 333443333334444436666675665614445555555566222222222         199999111112111888898887999987787778777
                 012153456890234679012307589487890123456867893124567123456897065789132790456345706897123424506891123

19 Tarc camp     1-1------------------------------------------------------------------------------------------------    000000
20 Eric spec     4545----1----3-------------------------------------------------------------------------------------    000000
21 Euch meri     2255535---2555-1----------1------------------------------------------------------------------------    000000
22 Leuc muri     3344-445434-54-55----------------------------------------------------------------------------------    000000
23 Leuc meri     34--------------5----------------------------------------------------------------------------------    000000
24 Prot obtu     ---------5--2---1----------------------------------------------------------------------------------    000000
25 Eric brun     443-2--2422---3---------------------------32-------------------------------------------------------    000000
26 Aspa calc     -1----2--22-----4----------------------------------------------------------------------------------    000000
30 Anth spat     ---4-----------------------------------------------------------------------------------------------    000000
15 Phyl axil     --1------1-3--4----------3--1----------------------------------------------------------------------    000001
9  Tham frat     55555555555555555555555255555551521244515555-----------------55-55---------------------------------    00001
39 Soil Shal     444--444444444444444444444---------------------------------4---------------------------------------    00001
10 Chon micr     ----5-41--444554-555422555552522355554555454------------------------------5------------------------    0001
28 Eric scyt     ----2-55--4----5-455555--155-----------------------------------------------------------------------    0001
38 Soil medi     ---44---------------------4444444444-44444444---------------4--------------------------------------    0001
11 Eric vern     -----------------445454555455555555555554512----------------------5524--555------------------------    0010
12 Pase galp     ---425-555442-544542545555555345455555555555555555---------------1---------------------5----------    0010
40 Soil leac     ------------------44444444444444444444444444----------------------444444444------------------------    0010
7  Chry moni     --------------1------------------1---------------------1-------------------------------------------    00110
13 Eric inop     ------------------43------1-----31--------------------------------------5-2------------------------    00110
34 Lime rock     4344444444444444444444-4444444444333344344334333333444444444444444---------------------------------    00110
42 Flat area     444444444444444444444444444444444444444444444444444444444444444444444444444------------------------    00110
36 Lime bank     4-444444444444444444444344-43-333333443---334-33--------33-4444444---------------------------------    00111
8  Tham insi     ------------------------------------------------------------------555555555------------------------    01000
14 Otho frut     1--1------1--11------------------------------1--------------------------33-------------------------    01000
35 Ston pebl     -4---------------------------------------3443444444------------------------------------------------    010010
3  Rhus glau     1-1-12-11111-11-21---------------1--------11112--11322255252255355------------1--------------------    010011
18 Pter tric     -------------------------------------------------------------55554---------------------------------    010011
29 Eury line     ----------------2--------------------------------------------43-44---------------------------------    010011
33 Side iner     -------------------------------------------------------------44544---------------------------------    010011
1  Elyt rhin     111-------------------------------1---------1-----155555555553----2354--222------2-------5---------    0101
6  Open area     -----5-45544-4-5--45-544-54-445544-45-353-44555555555545545555454353-----2----------------------55-    011
4  Aspa sang     ---------------------------------------------133--1231------3-----------------------------24-------    10
37 Soil deep     ------------------------------------4--------44444444444444--44444444444444444444444444444444444444    10
2  Nyla spin     --------1-----------------------1-11--1-----33322243322121233--------------243554525--3554555555---    110
41 Soil dark     444444444444444444--------------------------4444444444444444444444---------444444444444444444444444    110
17 Merm cinc     -------------------------------------------2-----------------2-------------5555555555555-----------    11100
27 Myri quer     -----2-------------------------------------------------------------------------3422----------------    11100
32 Carp edul     ---------------------------------------------------------------------------2121222-------1---3--555    11100
43 Low  basi     ---------------------------------------------------------------------------444444444444444444444444    11100
16 Rhus luci     --------------------------------11-----------1-----------------------------2--1-------------3------    11101
31 Cyno dact     ----------------------------------------------------------------------------------4------5555555555    11101
5  Relh unif     2------------------------------------------2------11211222-4-3-------------545531--------51--------    1111

                 000000000000000000000000000000000000000000000000000000000000000000000000000111111111111111111111111
                 000000000000000000000000000000000000000000001111111111111111111111111111111000000000000001111111111
                 000000000000000000111111111111111111111111110000000000000000000000111111111000000000000001000000111
                 000111111111111110000000001111111111111111110000000000000000011111000000111000000111111111 001111
                    00111111111111011111111000000000000000011000000011111111101111001111    00001000111111
                      000000000001  00000111001111111111111  011111110000000011                     000001
```

Appendix 4

TWINSPAN classification of the Euchaetis, Erica, Thatch, Passerina and Fire community quadrat data, including the Fire community quadrats' soil features.

```
                            11         11                           11   11
                22222223334333113334444441136666756656144455555566551122112111111211
                15672430121836564590234563479012307589487892345686701788969013279045

21 Euch meri    -------2255-3-455-2555-51-3----------1------------------------------   000000
22 Leuc muri    -------3344344--454-54--5545----------------------------------------   000000
24 Prot obtu    -----------5--------2------1----------------------------------------   000000
26 Aspa calc    --------1--2----2-2--------4----------------------------------------   000000
27 Myri quer    ------------2-------------------------------------------------------   000000
19 Tarc camp    -------1-1----------------------------------------------------------   000001
20 Eric spec    -------4545--1-------3----------------------------------------------   000001
23 Leuc meri    -------34------------------5----------------------------------------   000001
25 Eric brun    -------443-2-453-22---32--2----------------------------32-----------   000001
30 Anth spat    ----------4---------------------------------------------------------   000001
3  Rhus glau    1-112-11-1-121-1-111-111-1-21-----------------------1--11-----------   00001
41 Soil dark    44444444444444444444444444444---------------------------------------   00001
2  Nyla spin    3224323------1-1---------------------------11--1---1----------------   0001
4  Aspa sang    1--133--------------------------------------------------------------   0001
35 Ston pebl    4444443-4-----44----------------------------------3----44-----------   0001
39 Soil shal    -------444-444444444444-4444444444444-------------------------------   001
7  Chry moni    ----------------------1-----------------------------1---------------   01000
28 Eric scyt    ----------------444----2444-444444--144-----------------------------   01000
29 Eury line    ----------------11------1112-11111---11-----------------------------   01000
9  Tham frat    -------555555555555555555555555555255555551124451555 2--55-----------   010010
34 Lime rock    3333334434444433444444444444444444-4444444433443443333333-----------   010010
36 Lime bank    ----3344-4444444444444444444444444344-43-3333443---333333-----------   010010
5  Relh unif    ---1---2------------------------------------------------2-----------   010011
12 Pase galp    5555555---455554-5442-524334542545555555345555555554 5--55---1-------   010011
16 Rhus luci    1--------------------------------------------------11---------------   0101
38 Soil medi    ------4---4------------4-------------44444444-44444444444-----------   0101
6  Open area    5555555----55555-444-4--5----45-544-54-4455-45-353-444444-343------2   011
10 Chon micr    ----------------41444555433-55542255555252255545554354454554--------   10
11 Eric vern    ----------------------------4454545555455555555554555551255555 24--55   10
13 Eric inop    -----------------------------43------1-------------3154--223------5-   10
40 Soil leac    -----------------------------444444444444444444444444444444444444444   10
15 Phyl axil    ---------1-1-------3--4-------------3--1------------------54--------   110
42 Flat area    44444444444444444444444444444444444444444444444444444444444444444444   110
14 Otho frut    1------1--1-------1--11-------------------------------------------33   1110
1  Elyt rhin    ---1--1111---------------------------------1-------------2--2354--22   1111
8  Tham insi    ---------------------------------------------------------55555555555   1111
17 Merm cinc    --------------------------------------------------------2-22--------   1111
37 Soil deep    444444---------------------------------------4-----------44444444444   1111

                00000000000000000000000000000000000000000000000000000000011111111111
                00000000000000000000000000001111111111111111111111111111100011111111
                000000011111111111111111111110000000001111111111111111111   00000011
                000000100001111111111111111101111111100000000000000000011   001111
                000011     000001111111111111 00000111000000000000001111
                           01111000000000001 00111   0011111111111111
```

Appendix 5

TWINSPAN classification of the Euchaetis, Erica, Thatch, Passerina and Fire community quadrat data, excluding the Fire community quadrats' soil features.

```
                                 1 1                             1 1                                                         1 1   1 1
               3 3 3 4 3 4 4 4 3 1 1 3 2 2 2 2 2 2 2 3 3 3 3 4 4 1 1 2 4 2 1 4 4 4 5 5 5 5 5 5 5 5 6 6 6 6 6 6 6 5 6 6 6 7 5 1 1 1 1 2 1 1 1 1 1 1 1 2
               0 1 2 1 7 3 2 5 4 3 4 9 2 4 5 6 1 3 7 6 8 3 5 6 0 5 6 8 4 9 8 7 8 9 1 2 3 4 5 6 7 8 5 6 7 8 2 4 9 9 0 1 3 0 0 7 8 6 9 0 1 4 5 2 3 7 9 0

3  Rhus glau   1 - 1 - 2 1 - 1 - 1 - 1 2 - - 1 1 1 1 1 1 2 1 - 1 - 1 1 1 1 - - - - 1 - - - - - - - - - - - - - 1 - - - - - - - - - - - - - - - - - - -   000000
5  Relh unif   2 - - - - - - - - - - - - - - - - - 1 - - - - - - - - - - 2 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   000001
19 Tarc camp   1 - 1 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   000001
20 Eric spec   4 5 4 5 - 3 - - - - - - - - - - - - - 1 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   000001
21 Euch meri   2 2 5 5 - 5 5 5 5 - 3 2 - - - - - - - - - 3 - 1 5 4 5 - - - - - - - - - - - - - - - - - - - - - - 1 - - - - - - - - - - - - - - - - - -   000001
22 Leuc muri   3 3 4 4 5 4 5 - 4 5 4 4 - - - - - - - 4 3 4 5 5 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   000001
23 Leuc meri   3 4 - - 5 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   000001
24 Prot obtu   - - - - 1 - 2 - - - - - - - - - - - - - 5 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   000001
25 Eric brun   4 4 3 - - - - 2 - - 2 2 - - - - - - - 4 2 - 2 - - 5 3 3 3 2 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   000001
26 Aspa calc   - 1 - - 4 - - - 2 - - 2 - - - - - - - - 2 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   000001
30 Anth spat   - - - 4 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   000001
28 Eric scyt   - - - - - - - 2 4 4 4 4 - - - - - - - - - - 4 4 - - - - - - - - - - - - - - - - - - - - - 1 4 4 4 4 4 4 4 4 - - - - - - - - - - - - - -   00001
29 Eury line   - - - - 2 - - - 1 1 1 - - - - - - - - - - - 1 1 - - - - - - - - - - - - - - - - - - - - - - 1 1 - 1 1 1 1 1 - - - - - - - - - - - - - -   00001
9  Tham frat   5 5 5 5 5 5 5 5 5 5 5 5 - - - - - - - 5 5 5 5 5 5 5 5 5 5 5 5 5 5 1 2 1 2 4 4 5 2 1 5 5 5 5 5 5 5 5 5 5 5 5 5 - - - - - - - - - - - - -   0001
12 Pase galp   - - - 4 4 - 2 2 - 3 3 4 5 5 5 5 5 5 5 5 5 5 5 5 4 4 5 4 5 5 5 3 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 4 2 4 5 4 - - - - - 1 - - - - - - -   0001
7  Chry moni   - - - - - - - - - - - - - - - - - - - - - - - - - - - - 1 - - - - - 1 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   00100
16 Rhus luci   - - - - - - - - - - - - - - - - 1 - - - - - - - - - - - - - - - - - 1 - - - - - - - - - - - - - - - - - - - 1 - - - - - - - - - - - - -   00100
2  Nyla spin   - - - - - - - - - - - - 3 2 2 2 3 3 4 1 - - - - - - 1 - - - - - - - - 1 1 - - 1 - - - - - - - - - - - - - - 1 - - - - - - - - - - - - -   00101
4  Aspa sang   - - - - - - - - - - - - 3 3 - - 1 - 1 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   00101
27 Myri quer   - - - - - - - - - - - - - - - - - - - - - 2 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   00101
6  Open area   - - - - - 4 - - - - - 4 5 5 5 5 5 5 5 5 5 5 4 5 4 5 5 4 - 4 4 4 5 5 4 - 4 5 - 3 4 5 - 3 - 5 - - - 4 4 5 5 4 4 4 4 - 3 4 3 - 2 - - - - -   0011
10 Chon micr   - - - - - 5 4 5 4 3 3 4 - - - - - - - - - - 1 4 4 - - 5 5 4 2 5 2 2 5 5 5 5 4 5 5 5 5 5 4 5 4 5 5 5 5 5 2 2 3 4 4 5 5 4 - - - - - - - -   01
11 Eric vern   - - - - - - - - - - - - - - - - - - - - - - - - - - - 1 - 2 5 5 5 5 5 5 5 5 5 5 5 5 5 5 4 5 5 4 4 4 5 4 5 5 4 5 5 5 5 5 5 5 5 2 5 4 - -   01
13 Eric inop   - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 1 - - - - - - - - - - - - - - 1 4 3 - - 3 5 4 2 2 3 - 5 - - - - - -   10
1  Elyt rhin   1 1 1 - - - - - - - - - - - - - - 1 1 - - - - - - - - - - - - - - - - 1 - - - - - - - - - - - - - - - - - - - - - 2 - - 2 2 2 5 3 4 - -   110
8  Tham insi   - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 5 5 5 5 5 5 5 5 5 5 5   110
14 Otho frut   1 - - 1 - 1 - - - - - 1 - - - - 1 - - - - - - - - - - - 1 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 3 3 - - - - -   110
17 Merm cinc   - - - - - - - - - - - - - - - - - - - - - - - - - - - - - 2 - - - - - - - - - - - - - - - - - - - - - - - - - - - - 2 2 - - - - - - - -   110
15 Phyl axil   - - 1 - - - - - - - - - - - - - - - - - 1 - - - 3 - - - 4 - 1 - - - - - - - - - - - - - - 3 - - - - - - - - - - - - 5 4 - - - - - - - -   111

               0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1
               0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1
               0 0 0 0 0 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1       0 0 0 1 1 1 1 1
               0 0 0 0 1 0 1 1 1 1 1 1 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1             0 0 0 1 1
                           0 0 0 0 0 1 0 0 0 0 1 1 1 0 0 0 0 0 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1
                           0 0 1 1 1                 0 0 1 1 1 0 0 0 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1
```

Appendix 6

Included are the Principal Component Analysis (PCA) results as obtained for the different data sets. Component 1 obtained from each of the PCA's was used to obtain the representative imagery for the various years.

Results of Principal Component Analysis done on all the bands 1 of the various years.

VAR/COVAR	1990Band1	1991Band1	1993Band1	1994Band1	1995Band1	1996Band1	1997Band1
1990Band1	179.75	215.98	183.66	161.42	165.17	127.34	137.27
1991Band1	215.98	306.11	245.87	212.96	223.88	159.31	175.73
1993Band1	183.66	245.87	391.53	217.39	215.03	168.18	239.4
1994Band1	161.42	212.96	217.39	214.95	174.17	134.58	147.73
1995Band1	165.17	223.88	215.03	174.17	199.49	137.15	152.34
1996Band1	127.34	159.31	168.18	134.58	137.15	134.65	136.55
1997Band1	137.27	175.73	239.4	147.73	152.34	136.55	221.23

COR MATRX	1990Band1	1991Band1	1993Band1	1994Band1	1995Band1	1996Band1	1997Band1
1990Band1	1.000000	0.920748	0.692305	0.821224	0.872262	0.818545	0.688357
1991Band1	0.920748	1.000000	0.710198	0.830188	0.905970	0.784678	0.675288
1993Band1	0.692305	0.710198	1.000000	0.749342	0.769409	0.732453	0.813415
1994Band1	0.821224	0.830188	0.749342	1.000000	0.841088	0.791026	0.677438
1995Band1	0.872262	0.905970	0.769409	0.841088	1.000000	0.836796	0.725172
1996Band1	0.818545	0.784678	0.732453	0.791026	0.836796	1.000000	0.791145
1997Band1	0.688357	0.675288	0.813415	0.677438	0.725172	0.791145	1.000000

COMPONENT	C 1	C 2	C 3	C 4	C 5	C 6	C 7
% var.	81.12	8.78	3.7	2.63	1.59	1.33	0.85
eigenval.	1336.58	144.72	60.92	43.37	26.15	21.98	14
eigvec.1	0.333293	-0.331648	0.094649	-0.137651	0.005526	-0.629276	0.595819
eigvec.2	0.441109	-0.463603	-0.052689	-0.460084	-0.287943	0.058527	-0.538242
eigvec.3	0.482919	0.649231	-0.513945	-0.211976	0.13438	-0.133498	-0.018331
eigvec.4	0.36103	-0.174087	-0.301421	0.801562	-0.322629	0.026977	-0.034308
eigvec.5	0.362323	-0.204372	0.001614	-0.071434	0.351861	0.719954	0.423921
eigvec.6	0.282426	-0.030577	0.368346	0.27574	0.698626	-0.223144	-0.411969
eigvec.7	0.346039	0.424938	0.705401	0.028351	-0.427816	0.117941	0.065988

LOADING	C 1	C 2	C 3	C 4	C 5	C 6	C 7
1990Band1	0.908851	-0.297583	0.0551	-0.067616	0.002108	-0.220075	0.166261
1991Band1	0.921727	-0.318761	-0.023504	-0.173181	-0.084155	0.015685	-0.115092
1993Band1	0.892254	0.394709	-0.202724	-0.070552	0.034727	-0.031634	-0.003466
1994Band1	0.900263	-0.142842	-0.160463	0.360057	-0.112524	0.008627	-0.008754
1995Band1	0.937845	-0.174069	0.000892	-0.033308	0.127387	0.239004	0.112287
1996Band1	0.88981	-0.031699	0.247755	0.156495	0.307861	-0.090166	-0.132821
1997Band1	0.850553	0.343689	0.370158	0.012553	-0.147079	0.03718	0.016598

Results of Principal Component Analysis done on all the bands 2 of the various years.

VAR/COVAR	1990Band2	1991Band2	1993Band2	1994Band2	1995Band2	1996Band2	1997Band2
1990Band2	71.43	68.72	61.2	59.76	61.37	50.49	50.71
1991Band2	68.72	81.61	67.98	68.3	68.72	52.15	53.97
1993Band2	61.2	67.98	110.92	73.23	70.23	57.81	75.8
1994Band2	59.76	68.3	73.23	85.64	66.8	50.61	53.97
1995Band2	61.37	68.72	70.23	66.8	72.68	52.77	55.18
1996Band2	50.49	52.15	57.81	50.61	52.77	53.38	52.31
1997Band2	50.71	53.97	75.8	53.97	55.18	52.31	79.47

COR MATRX	1990Band2	1991Band2	1993Band2	1994Band2	1995Band2	1996Band2	1997Band2
1990Band2	1.000000	0.900094	0.687594	0.764055	0.851794	0.817768	0.673054
1991Band2	0.900094	1.000000	0.714560	0.816956	0.892380	0.790215	0.670153
1993Band2	0.687594	0.714560	1.000000	0.751334	0.782243	0.751267	0.807312
1994Band2	0.764055	0.816956	0.751334	1.000000	0.846758	0.748479	0.654212
1995Band2	0.851794	0.892380	0.782243	0.846758	1.000000	0.847177	0.726027
1996Band2	0.817768	0.790215	0.751267	0.748479	0.847177	1.000000	0.803200
1997Band2	0.673054	0.670153	0.807312	0.654212	0.726027	0.803200	1.000000

COMPONENT	C 1	C 2	C 3	C 4	C 5	C 6	C 7
% var.	80.51	7.97	4.44	2.79	1.77	1.53	0.99
eigenval.	446.93	44.22	24.67	15.47	9.84	8.51	5.47
eigvec.1	0.358365	-0.361944	-0.336321	-0.3073	-0.108778	-0.580592	0.429077
eigvec.2	0.391704	-0.406754	-0.099675	-0.274649	-0.385468	0.349227	-0.570269
eigvec.3	0.443209	0.571222	0.412213	-0.525351	0.113623	-0.116342	-0.070086
eigvec.4	0.39048	-0.227273	0.612632	0.57889	-0.166374	-0.240133	0.00984
eigvec.5	0.380185	-0.194308	0.02566	0.010074	0.405011	0.631899	0.503601
eigvec.6	0.311653	0.022556	-0.347866	0.270708	0.665175	-0.229228	-0.461592
eigvec.7	0.357163	0.536037	-0.458309	0.381632	-0.438748	0.133839	0.137825

LOADING	C 1	C 2	C 3	C 4	C 5	C 6	C 7
1990Band2	0.896428	-0.28479	-0.19764	-0.143027	-0.040383	-0.200408	0.118789
1991Band2	0.916666	-0.299418	-0.054799	-0.11959	-0.133877	0.112776	-0.147701
1993Band2	0.889678	0.36068	0.194391	-0.196218	0.03385	-0.032227	-0.015571
1994Band2	0.892038	-0.163314	0.328788	0.246062	-0.056407	-0.075699	0.002488
1995Band2	0.942794	-0.151567	0.014949	0.004648	0.149057	0.216234	0.138216
1996Band2	0.901801	0.020531	-0.236474	0.145749	0.285653	-0.09153	-0.147825
1997Band2	0.846977	0.399846	-0.255325	0.168389	-0.154413	0.043797	0.036173

Results of Principal Component Analysis done on all the bands 3 of the various years.

VAR/COVAR	1990Band3	1991Band3	1993Band3	1994Band3	1995Band3	1996Band3	1997Band3
1990Band3	262.41	256.65	229.96	213.2	228.35	180.45	175.75
1991Band3	256.65	304.8	256.04	244.94	258.77	188.21	187.62
1993Band3	229.96	256.04	466.26	269.27	267.55	218.25	292.41
1994Band3	213.2	244.94	269.27	288.32	240.74	175.75	181.82
1995Band3	228.35	258.77	267.55	240.74	273.8	190.83	194.34
1996Band3	180.45	188.21	218.25	175.75	190.83	189.52	182.48
1997Band3	175.75	187.62	292.41	181.82	194.34	182.48	286.29

COR MATRX	1990Band3	1991Band3	1993Band3	1994Band3	1995Band3	1996Band3	1997Band3
1990Band3	1.000000	0.907484	0.657427	0.775090	0.851912	0.809175	0.641231
1991Band3	0.907484	1.000000	0.679187	0.826278	0.895764	0.783106	0.635161
1993Band3	0.657427	0.679187	1.000000	0.734399	0.748806	0.734199	0.800353
1994Band3	0.775090	0.826278	0.734399	1.000000	0.856831	0.751848	0.632867
1995Band3	0.851912	0.895764	0.748806	0.856831	1.000000	0.837714	0.694129
1996Band3	0.809175	0.783106	0.734199	0.751848	0.837714	1.000000	0.783431
1997Band3	0.641231	0.635161	0.800353	0.632867	0.694129	0.783431	1.000000

COMPONENT	C 1	C 2	C 3	C 4	C 5	C 6	C 7
% var.	79.36	9.48	4.31	2.65	1.72	1.53	0.95
eigenval.	1643.76	196.44	89.35	54.86	35.64	31.64	19.71
eigvec.1	0.355662	-0.368484	0.262483	-0.444099	-0.072102	-0.495771	0.469696
eigvec.2	0.39242	-0.411791	0.040895	-0.270644	-0.314685	0.280793	-0.650878
eigvec.3	0.469814	0.619374	-0.438321	-0.431935	0.128135	-0.007804	-0.021857
eigvec.4	0.373502	-0.208742	-0.520363	0.6027	-0.138977	-0.403126	-0.032772
eigvec.5	0.382895	-0.210195	-0.05197	0.178947	0.166711	0.699506	0.507332
eigvec.6	0.303508	-0.012825	0.369454	0.188173	0.785149	-0.153229	-0.309636
eigvec.7	0.347212	0.472338	0.572128	0.335084	-0.464532	-0.00276	0.030517

LOADING	C 1	C 2	C 3	C 4	C 5	C 6	C 7
1990Band3	0.890158	-0.318817	0.153165	-0.203062	-0.026571	-0.172141	0.128717
1991Band3	0.911309	-0.330587	0.022142	-0.114824	-0.107603	0.090464	-0.165502
1993Band3	0.882124	0.402023	-0.191878	-0.148164	0.035425	-0.002033	-0.004493
1994Band3	0.891817	-0.172301	-0.28968	0.262908	-0.048861	-0.133535	-0.008568
1995Band3	0.938169	-0.17804	-0.029688	0.080102	0.060145	0.237774	0.136107
1996Band3	0.893855	-0.013057	0.253681	0.101245	0.340474	-0.062605	-0.099847
1997Band3	0.831979	0.391259	0.319626	0.146687	-0.163896	-0.000918	0.008007

Results of Principal Component Analysis done on all the bands 4 of the various years.

VAR/COVAR	1990Band4	1991Band4	1993Band4	1994Band4	1995Band4	1996Band4	1997Band4
1990Band4	195.37	153.96	158.51	133.94	145.74	125.97	121.48
1991Band4	153.96	200.26	158.01	145.87	158.23	112.74	125.43
1993Band4	158.51	158.01	294.16	176.15	177.99	145.55	199.9
1994Band4	133.94	145.87	176.15	212.88	156.86	119.54	117.19
1995Band4	145.74	158.23	177.99	156.86	202.76	134.97	133.08
1996Band4	125.97	112.74	145.55	119.54	134.97	141.18	125.21
1997Band4	121.48	125.43	199.9	117.19	133.08	125.21	235.62

COR MATRX	1990Band4	1991Band4	1993Band4	1994Band4	1995Band4	1996Band4	1997Band4
1990Band4	1.000000	0.778359	0.661191	0.656783	0.732224	0.758496	0.566211
1991Band4	0.778359	1.000000	0.651026	0.706505	0.785237	0.670504	0.577439
1993Band4	0.661191	0.651026	1.000000	0.703937	0.728792	0.714213	0.759296
1994Band4	0.656783	0.706505	0.703937	1.000000	0.755029	0.689543	0.523267
1995Band4	0.732224	0.785237	0.728792	0.755029	1.000000	0.797727	0.608839
1996Band4	0.758496	0.670504	0.714213	0.689543	0.797727	1.000000	0.686528
1997Band4	0.566211	0.577439	0.759296	0.523267	0.608839	0.686528	1.000000

COMPONENT	C 1	C 2	C 3	C 4	C 5	C 6	C 7
% var.	73.46	9.32	5.55	3.6	3.56	3.03	1.49
eigenval.	1088.85	138.14	82.3	53.29	52.72	44.85	22.08
eigvec.1	0.358488	-0.301643	-0.49372	0.542347	-0.01653	0.352019	0.344104
eigvec.2	0.366282	-0.354237	-0.279763	-0.378469	-0.595012	-0.142011	-0.380316
eigvec.3	0.463792	0.410605	0.387827	0.518567	-0.328694	-0.272536	-0.121094
eigvec.4	0.370653	-0.302322	0.642534	-0.22237	0.075148	0.546797	0.06546
eigvec.5	0.386535	-0.22954	0.051087	-0.214749	0.334219	-0.639461	0.478083
eigvec.6	0.313208	-0.019007	-0.153203	0.096332	0.646734	-0.01216	-0.6711
eigvec.7	0.370578	0.685917	-0.297713	-0.434584	0.045093	0.271285	0.197647

LOADING	C 1	C 2	C 3	C 4	C 5	C 6	C 7
1990Band4	0.846313	-0.253641	-0.32045	0.283243	-0.008586	0.168667	0.115686
1991Band4	0.854091	-0.294206	-0.17935	-0.19523	-0.305285	-0.067208	-0.12629
1993Band4	0.892308	0.281375	0.205141	0.22071	-0.139147	-0.10642	-0.033178
1994Band4	0.838268	-0.243531	0.399517	-0.111255	0.037396	0.250987	0.021083
1995Band4	0.895734	-0.18946	0.032548	-0.11009	0.170417	-0.300755	0.157771
1996Band4	0.869832	-0.018801	-0.116975	0.059183	0.395202	-0.006854	-0.265414
1997Band4	0.796635	0.525196	-0.175955	-0.206671	0.021329	0.118363	0.060507

Results of Principal Component Analysis done on all the bands 5 of the various years.

VAR/COVAR	1990Band5	1991Band5	1993Band5	1994Band5	1995Band5	1996Band5	1997Band5
1990Band5	1064.27	1274.34	835.39	916.04	1093.97	786.35	684.26
1991Band5	1274.34	1762.1	1084.32	1204.97	1458.98	944.95	855.88
1993Band5	835.39	1084.32	1352.07	950.98	1041.39	768.93	893.11
1994Band5	916.04	1204.97	950.98	1059.8	1101.34	759.72	682.04
1995Band5	1093.97	1458.98	1041.39	1101.34	1365.09	880.78	805.76
1996Band5	786.35	944.95	768.93	759.72	880.78	801.73	686.51
1997Band5	684.26	855.88	893.11	682.04	805.76	686.51	969.33

COR MATRX	1990Band5	1991Band5	1993Band5	1994Band5	1995Band5	1996Band5	1997Band5
1990Band5	1.0000000	0.9305570	0.6964100	0.8625360	0.9076090	0.8512840	0.6736910
1991Band5	0.9305570	1.0000000	0.7024930	0.8817600	0.9407080	0.7950210	0.6548820
1993Band5	0.6964100	0.7024930	1.0000000	0.7944390	0.7665380	0.7385330	0.7801340
1994Band5	0.8625360	0.8817600	0.7944390	1.0000000	0.9156490	0.8241870	0.6729140
1995Band5	0.9076090	0.9407080	0.7665380	0.9156490	1.0000000	0.8419190	0.7004720
1996Band5	0.8512840	0.7950210	0.7385330	0.8241870	0.8419190	1.0000000	0.7787480
1997Band5	0.6736910	0.6548820	0.7801340	0.6729140	0.7004720	0.7787480	1.0000000

COMPONENT	C 1	C 2	C 3	C 4	C 5	C 6	C 7
% var.	83.38	7.79	3.56	1.82	1.48	1.01	0.95
eigenval.	6982.92	652.56	298.04	152.55	123.54	84.84	79.94
eigvec.1	0.367633	-0.321536	0.087452	-0.103062	-0.254797	0.795425	-0.213469
eigvec.2	0.478151	-0.398257	0.084789	-0.279125	-0.315549	-0.59912	-0.262959
eigvec.3	0.371115	0.636594	-0.502347	0.093603	-0.44162	0.003813	-0.029399
eigvec.4	0.367504	-0.017192	-0.370623	0.06975	0.747396	0.003776	-0.404728
eigvec.5	0.428632	-0.190374	-0.145844	-0.075884	0.179223	0.016368	0.84889
eigvec.6	0.300995	-0.007143	0.399528	0.861267	-0.029999	-0.083945	0
eigvec.7	0.298511	0.544211	0.643859	-0.387687	0.221038	0.031805	0

LOADING	C 1	C 2	C 3	C 4	C 5	C 6	C 7
1990Band5	0.941688	-0.251776	0.046279	-0.039019	-0.086811	0.224577	-0.058505
1991Band5	0.951851	-0.242359	0.034871	-0.082127	-0.083552	-0.131459	-0.056009
1993Band5	0.843387	0.442255	-0.235855	0.031441	-0.133492	0.000955	-0.007148
1994Band5	0.94334	-0.01349	-0.196545	0.026463	0.255179	0.001068	-0.111156
1995Band5	0.969443	-0.131624	-0.068147	-0.025367	0.053916	0.00408	0.205424
1996Band5	0.888308	-0.006445	0.243598	0.375686	-0.011776	-0.027307	0
1997Band5	0.801205	0.446521	0.357023	-0.153797	0.078911	0.009409	0

Results of Principal Component Analysis done on all the bands 6 of the various years.

VAR/COVAR	1990Band6	1991Band6	1993Band6	1994Band6	1995Band6	1996Band6	1997Band6
1990Band6	224.34	235.07	155.01	191.3	211.44	166.14	140.21
1991Band6	235.07	286.64	179.14	223.45	249	179.32	151.85
1993Band6	155.01	179.14	236.49	187.95	190.17	146.63	157
1994Band6	191.3	223.45	187.95	227.65	220.73	162.04	139.19
1995Band6	211.44	249	190.17	220.73	254.34	178.42	154.09
1996Band6	166.14	179.32	146.63	162.04	178.42	176.62	151.97
1997Band6	140.21	151.85	157	139.19	154.09	151.97	217.13

COR MATRX	1990Band6	1991Band6	1993Band6	1994Band6	1995Band6	1996Band6	1997Band6
1990Band6	1.000000	0.926985	0.672955	0.846508	0.885175	0.834609	0.635287
1991Band6	0.926985	1.000000	0.688048	0.874730	0.922213	0.796943	0.608660
1993Band6	0.672955	0.688048	1.000000	0.810018	0.775418	0.717441	0.692847
1994Band6	0.846508	0.874730	0.810018	1.000000	0.917332	0.808108	0.626056
1995Band6	0.885175	0.922213	0.775418	0.917332	1.000000	0.841828	0.655710
1996Band6	0.834609	0.796943	0.717441	0.808108	0.841828	1.000000	0.776018
1997Band6	0.635287	0.608660	0.692847	0.626056	0.655710	0.776018	1.000000

COMPONENT	C 1	C 2	C 3	C 4	C 5	C 6	C 7
% var.	81.57	7.95	5.04	1.89	1.58	1.14	0.82
eigenval.	1324.12	129.05	81.88	30.71	25.65	18.54	13.28
eigvec.1	0.381847	-0.280866	-0.2841	-0.227822	-0.540979	-0.428358	0.408095
eigvec.2	0.435442	-0.408906	-0.154896	-0.398102	0.080912	0.288171	-0.609196
eigvec.3	0.356607	0.407504	0.702078	-0.216831	-0.380118	0.144738	-0.037466
eigvec.4	0.390973	-0.138526	0.325128	0.348693	0.394844	-0.639768	-0.188284
eigvec.5	0.421555	-0.191722	0.08583	0.09711	0.409472	0.466052	0.619568
eigvec.6	0.330995	0.16025	-0.293474	0.735367	-0.361624	0.256036	-0.203824
eigvec.7	0.311911	0.711494	-0.450754	-0.26611	0.319319	-0.143022	0.008643

LOADING	C 1	C 2	C 3	C 4	C 5	C 6	C 7
1990Band6	0.927674	-0.213017	-0.17163	-0.084284	-0.182938	-0.123139	0.099293
1991Band6	0.935884	-0.274362	-0.082784	-0.130296	0.024206	0.073287	-0.13113
1993Band6	0.843814	0.301022	0.413102	-0.078131	-0.125197	0.040525	-0.008879
1994Band6	0.942929	-0.104297	0.194985	0.128062	0.132549	-0.182573	-0.045477
1995Band6	0.96186	-0.136565	0.048698	0.033742	0.130047	0.125827	0.141579
1996Band6	0.906279	0.136977	-0.199814	0.306614	-0.137821	0.082951	-0.055892
1997Band6	0.770246	0.548503	-0.276792	-0.10007	0.109759	-0.041791	0.002138