A forest map of southe Africa with the aid of LANDSAT imagery

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Cover: Pine plantation in the eastern Transvaal
(photograph L S Davies, Division of Production Technology, CSIR)

ABSTRACT

Even after 300 years of indigenous forest protection as well as 100 years of plantation forestry, no forestry map of South Africa was available. The development and availability of LANDSAT images in the early 1970s opened up possibilities to use satellite data. A project was initiated in 1981 to compile a forestry map of southern Africa (Republic of South-Africa, Swaziland, Lesotho, Ciskei, Venda, Transkei and Bophuthatswana).

A portfolio of 31 maps on a scale of 1:250 000 has now been produced. Three examples of these form part of this report. A combination of LANDSAT and field data was used to bring about this set of maps. A number of teething problems were experienced, e.g. mountain shadow; distinction between pine and wattle; no tree canopy before about 10 years of plantation growth.

In this report the procedure is discussed in detail. Problems are stated and solutions offered. Both sophisticated computer classification and qualitative approaches were used. The experience related in this report will be of considerable benefit to many other researchers and planners contemplating the inclusion of satellite data in their particular application fields.

SAMEVATTING

Hoewel inheemse bosse reeds vir 'n tydperk van 300 jaar beskerm word en plantasiebosbou gedurende die afgelope 100 jaar plaasvind, was daar nog geen bosboukaart van Suid-Afrika beskikbaar nie. Die ontwikkeling en beskikbaarheid van LANDSAT-beelde in die vroë sewentigerjare het die gebruik van satellietgegewens moontlik gemaak. In 1981 is daar met 'n projek begin om 'n bosboukaart van suidelike Afrika (Republiek van Suid-Afrika, Swaziland, Lesotho, Ciskei, Venda, Transkei en Bophuthatswana) saam te stel.

'n Portefeulje van 31 kaarte op 'n skaal van 1:250 000 is nou voltooi. Drie voorbeelde hiervan is by dié verslag ingesluit. 'n Kombinasie van LANDSAT- en veldgegewens is gebruik om dié stel kaarte te voltooi. Heelwat aanvangsprobleme (bv. effek van bergskaduwee; onderskeid tussen denne en wattel; geen kroondak van plantasies vóór 10 jaar nie) is ondervind en moes oorkom word.

Hierdie verslag bevat 'n volledige uiteensetting van die prosedure wat gevolg is asook van die probleme wat ondervind is, en hoe hulle oorkom is. Beide rekenaarklassifikasie en kwalitatiewe benaderings is gevolg. Die ondervinding wat opgedoen is, sal van groot waarde wees vir talle ander navorsers en beplanners wat die gebruik van satellietbeelde oorweeg in hul besondere studievelde.

KEYWORDS

Forest map, LANDSAT images, Satellite data, Computer classification.

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LIST OF ABBREVIATIONS

ATM Airborne Thematic Mapper

CCT Computer Compatible Tape

CSIR Council for Scientific and Industrial Research

CSP Co-operative Scientific Programmes

DEA Department of Environment Affairs

DIP Digital Image Processing

FRD Foundation for Research Development

GCP Ground control point(s)

GDP Gross Domestic Product

HDDT High Density Digital Tape

IAS Image Analysis Package/System

MSS Multispectral Scanner

NASA National Aeronautics and Space Administration

PCA Principal Components Analysis

SLAR Side-looking Airborne (or Aperture) Radar

SPOT Satellite Probatoire d'Observation de la Terre

SRD Surface Reference Data (or Ground Truth)

SRSC Satellite Remote Sensing Centre

TM Thematic Mapper

UTM Universal Transverse Mercator Grid System

WRS World Reference System

1. GOALS OF THE PROJECT

The principal goal of the project was to produce a forestry map of Southern Africa, south of the Limpopo River, showing indigenous forests and exotic plantations. Indigenous forests are those remaining natural forests which can be managed for timber production, nature conservation and recreation. Exotic plantations consist of exotic tree species grown for commercial timber production and other products such as bark for the production of tannin. They can be subdivided into wattle, gum and pine plantations. Wattle plantations consist of a single species, *viz. Acacia mearnsii*, grown for bark and timber. Gum plantations consist of several *Eucalyptus* species, grown for mining timber, poles and sawtimber. These two classes together are referred to as hardwoods. Pine plantations are grown for pulpwood, poles and sawtimber. This class is referred to as softwoods. During the planning stage it was decided that the scale of the map would be 1:250 000. Both LANDSAT false colour imagery and digital image analysis were used and converted to land-use classes.

Two secondary goals were recognized, *viz.* firstly, to demonstrate the use of satellite remote sensing techniques in forestry itself as well as in relation to other land uses and secondly, to provide a macro basis for a National or Regional Forest Inventory.

Originally the project was planned to run from 1 October 1981 to 31 March 1983. It was subsequently extended to 31 March 1985. Only those 1:250 000 sheets covering Transvaal, Swaziland, Natal and other states within these boundaries were to be completed. Another extension, to 31 March 1986, included completion of maps covering the Cape Province. LANDSAT Index maps are attached as Appendices 1 and 2, and the 1:250 000 map index is added as Appendix 3.

Two area limitations were envisaged i.e. that the area determination should not have an error of more than 10 per cent and that areas of 25 ha or less (for exotic tree plantations) and 50 ha or less (for indigenous forests) would not be mapped.

2. MAGNITUDE OF THE SOUTH AFRICAN FORESTRY INDUSTRY

Today, after the culmination of many years of growth and development, especially in the wake of World War II, South Africa has a highly developed forestry industry. It is capable of meeting the bulk of the timber needs of the local population and of the industry. The commercial forests represent a complex and valuable resource yielding many different products such as sawlogs, poles, pulpwood, mining timber, tan bark and veneer logs. Timber is grown in plantations of exotic species in areas with adequate rainfall and suitable soil. Certain

categories of wood and wood-based products such as high quality furniture timbers, art papers and certain blending pulps are still imported, but in net terms South Africa is also an exporter of wood products.

At the end of March 1986, the estimated total area of commercial plantation in the RSA and independent homelands was 1 207 678 hectares (Department of Environment Affairs, 1987) of which 1 133 224 hectares were located in the Republic. This represents 0,93 per cent of the total land area concerned covering 117,8 million hectares. Their distribution is shown in Figure 1(a).

Private ownership has gradually increased. The 1985/86 Forestry Census (Department of Environment Affairs, 1987) reveals that 70 per cent or 799 448 hectares was owned by individuals and companies. Of the total softwood plantations (613 747 hectares), 46 per cent is state-owned. Ninety per cent of the hardwoods is in private ownership. A further analysis of the statistics indicates that 11 per cent of the plantation area is owned by 1 309 individuals and partnerships, each owning an area of less than 500 hectares. On the other hand 524 companies own 53 per cent of the total commercial plantations (Fig. 1(c)).

In 1985, the estimated annual increment of utilizable timber was 16,7 million cubic metres from plantations in the Republic and the independent homelands (Scharfetter, 1987). This corresponds to an annual increment of 14,8 m³/ha/annum. This yield compares favourably with other countries. Increments of 15-20 m³/ha/annum for pines and 15-25 m³/ha/annum for Eucalypts are common in Australia, Brazil, New Zealand and South Africa. The estimate quoted for the USA is 3,0, for Scandinavia 2,5 and for Canada 1,0 m³/ha/annum (Davies 1984) (See Fig. 1(b)). The actual consumption by the local industry during 1985/86 was 14,6 million cubic metres (Department of Environment Affairs, 1987).

Investment in the Forestry Sector in terms of current market values (1984) is shown in Figure 1(d) (Source: Forest Owners Association).

It is estimated that about 90 000 workers were employed in timber plantations and 49 000 workers in the roundwood processing industry, whereas 1 040 300 workers are employed in agriculture. In 1986 the number of economically active persons in the Republic was 8,7 million.

In addition to its strategic importance, the Forestry Sector makes a substantial contribution to the national economy. Expressed in terms of its contribution to the gross domestic product (GDP) at factor incomes at current prices the following information was recorded for 1986 (Department of Statistics, 1988):
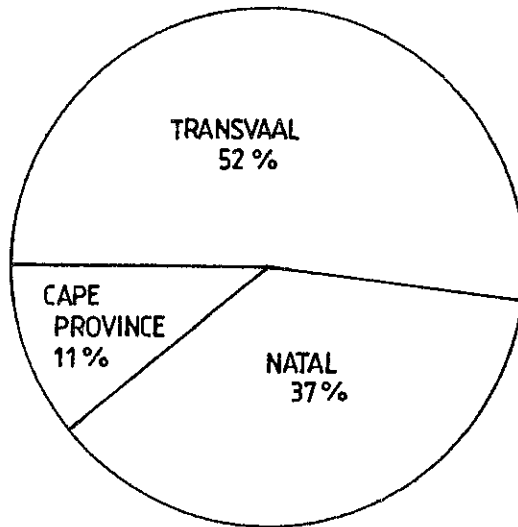
1(a) Location of exotic tree plantings

SOUTH AFRICA, BRAZIL, AUSTRALIA, NEW ZEALAND

U.S.A.
SCANDINAVIA
CANADA
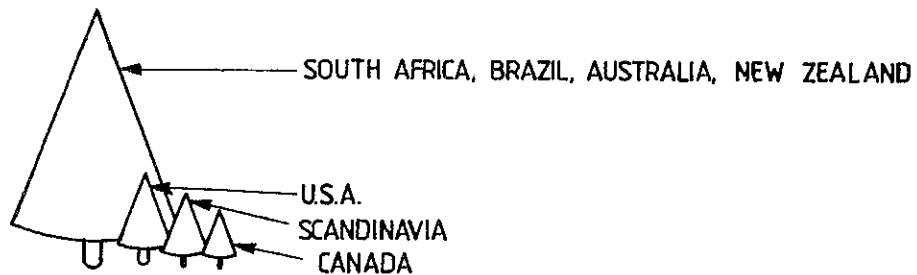
1(b) Relative average annual growth rate per hectare in various countries (adapted from Davies, 1984)

PINES
670 356 ha
56 %

OTHER
8678 ha
1 %

WATTLE
126 642 ha
10 %

GUMS
401 912 ha
33 %

PINES
R 2 400 million
66 %

OTHER
R10 million
0,5 %

WATTLE
R286 million
8 %

GUMS
R 924 million
25,5 %
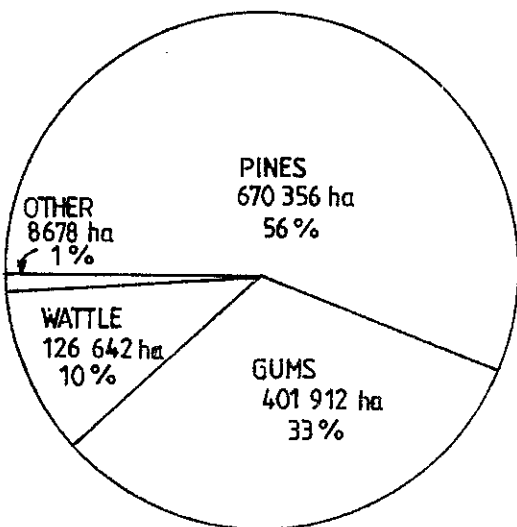
1(c)   1(d)
Area distribution per Genus class   Investment in terms of market values
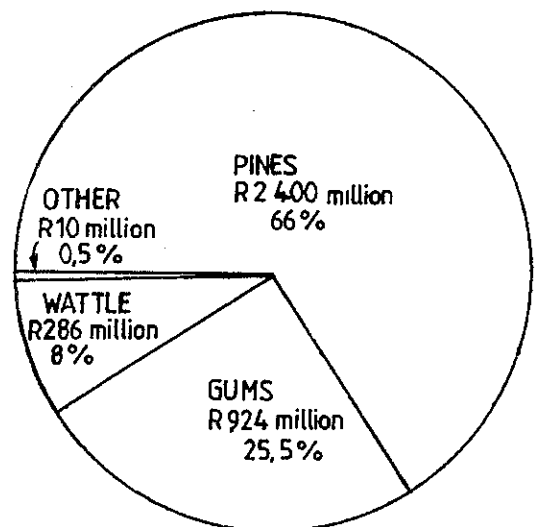
FIGURE 1:   DIAGRAMS TO ILLUSTRATE THE MAGNITUDE OF THE SOUTH AFRICAN FORESTRY INDUSTRY (MARCH 1986)

Total GDP – RSA   R127 112 000 000 (100%)
Total GDP – Agricultural sector   R   7 277 000 000 (5,7%)
Total GDP – Forestry   R   446 600 000 (0,4%)

The value of sales in the three 'Forestry' Sectors as related to the manufacturing section was in 1986 as follows:

Total manufacturing   R 86 921 218 000
Wood and wood products   R 1 402 530 000
Furniture   R   758 981 000
Paper and paper products   R 3 785 425 000

On index the latter industry sector showed the highest growth in the manufacturing section.

Through investment in forestry the RSA has become almost self-sufficient in terms of its forest products requirements. Paradoxically a map of the South African forestry enterprise has not previously been produced.

3. HISTORICAL BACKGROUND

3.1   AVAILABILITY OF MAP INFORMATION FOR FORESTRY

Many individual forests and plantations have been mapped at the medium scales of 1:10 000, 1:12 000 or 1:24 000, but private forestry estates often use the standard 1:50 000 maps. The Directorate of Surveys and Mapping produces 1:500 000, 1:250 000 and 1:50 000 map series for Southern Africa. At this stage a relatively new series, *viz.* 1:10 000 and 1:30 000 orthophoto maps are available only for certain areas in South Africa, mainly for metropolitan areas. The South African topocadastral maps produced at scales of 1:50 000 and 1:250 000, show a single class for any indigenous forest, exotic timber plantation, closed savanna forest, invader tree thicket, woodlot, shrub forest or wattle jungle. These maps are of limited use to the Forestry Sector, for district, regional and national planning purposes.

In 1953 the then Department of Forestry produced an administrative map which indicated the position of State plantations and the boundaries of forestry districts and regions. The larger private companies produced similar maps for their own estates. A silvicultural map indicating silvicultural growth zones in southern Africa was published by Poynton (1971). Since 1972 the Department (now Branch) of Forestry as an addendum to its annual "Report on Commercial Timber Resources", publishes a forest economic map at a scale of 1:7 000 000 showing economic forestry regions. The afforested areas are shown by means of a symbol, e.g. one tree for every 2 000 hectares of exotic timber plantations.

It is standard practice in Government Departments and to a large extent also in the larger private companies to produce plantation maps. They are sometimes based on aerial surveys. Colour or colour infrared aerial surveys are undertaken for specific areas of high interest.

3.2 THE ROLE OF REMOTE SENSING IN FORESTRY

Airborne photographic sensors have been used extensively to map forest cover types and photogrammetry has become the universally accepted tool for map making. The scale of the photographs varies widely between 1:1 000 and 1:120 000. Initially, medium-scale photographs, varying between 1:15 000 and 1:30 000 were used for mapping of forest cover types. More recently experiments were conducted to test ultra-high altitude, small-scale photography from aircraft flying at 20 000 m above the terrain. The results were satisfactory in terms of boundary placement and accuracy of forest type identification and compared favourably with medium-scale photography (Lauer and Benson, 1973).

Progress has been made with the use of aerial photographs in forest inventories. Tree height, crown diameter, crown cover and number of trees per hectare can be measured satisfactorily and accurately, provided the scale is 1:12 000 or larger. With increasing scale the accuracy of the measurement of these characteristics tends to increase (Aldred and Sayn-Wittgenstein, 1972). Tree counts can be accurate when using photographs of a scale of 1:1 200 (Aldred and Kippen, 1967). The accuracy of the estimation of crown closure increases with increasing scale (Rogers *et al.*, 1959), but the increase in the accuracy of the measurements of crown diameter is insignificant.

Initially aerial tree volume tables were used to estimate tree volume from tree height and crown width. Multiplied by the estimated trees per hectare it gives the stand volume. Because of the propagation of errors and the bias inherent in the estimation of crown diameter and stems per hectare, these tree volume tables were gradually replaced by aerial stand volume tables (Gingrich and Meyer, 1955; Stellingwerf, 1973). Crown cover and top height may be used as predictor-variables. Because of systematic errors of measurement, the magnitude of which depends largely on the skill of the interpreter, the direct estimation of volumes on aerial photographs has gradually been replaced by sampling designs, combining aerial photography with ground surveying. Three-stage sampling, combining LANDSAT imagery with medium-scale photography and ground surveying was used by Langley (1967) and Schade (1980). Double sampling for stratification was introduced by Bickford (1952) and has been used ever since (Maclean, 1973; Bickford, 1961). This sampling strategy may imply three species categories, three height strata and three stand density strata, giving 27 strata. The strata are subsequently sampled by ground surveying, with probability of selection proportional to the size of the strata.

The gradually improved quality of photographic equipment, aircraft and photographic film has ensured an improved quality of the final product, although a breakthrough in the direct application of aerial photographs to forest inventories has not yet been noted.

Many attempts were made to use aerial photographs for the identification of species and ecological forest types. This could be particularly useful for inaccessible tropical forests. Such attempts based on spectral reflectance curves for the different species have not always been successful, primarily because site, age, time of year and angle of incidence influence spectral reflectance (Howard, 1970).

The period between 1950 and 1955 witnessed attempts to use aerial photographs for mapping the spread of diseases (Harris, 1951), to control forest fires (Arnold, 1951) and infestation by forest insects (Wear and Bongberg, 1951). Heller (1955) suggested the use of aerial photography for the assessment of damage caused by budworm. More recently, colour infrared has been used to detect damage caused by SO_2-pollution, drought, snow and wind, and epidemics (Hildebrandt, 1979; Cagirici and Hildebrandt, 1978; Kenneweg, 1981).

In addition to the photographic process electro-optical systems were developed, especially since the 1960s. The radiation detectors are classified on the basis of the physical process for converting the radiation input to electrical output (American Society of Photogrammetry, 1975). Radiation sensors are classified as active or passive. An active sensor provides its own source of illumination, whereas a passive sensor does not. A radar or laser altimeter is an example of an active sensor, while the thematic mapper (the additional instrument on board LANDSAT 4 and 5) is a passive sensor. Microwave remote sensors have the advantage of being able to sense through cloud cover and light rain. Side-looking airborne radar is increasingly being used. More recently, there has been an increasing emphasis on non-photographic remote sensing products, e.g. LANDSAT imagery. Many studies revealed the usefulness of LANDSAT products to classify cover types. You-Ching Fang (1979) reported on their use in China (to map forests) and Poulton (1979) about resource analysis in Tanzania. Novaes (1979) used LANDSAT to map the progress of deforestation in the Amazon Region. Kalensky et al. (1981) reported on their use in forest resource analysis in Canada, and Heller (1975) about a similar study in the USA.

At Freiburg, Hildebrandt is currently involved in comparisons between LANDSAT imagery and space shuttle photographs to stratify cover types in Central Africa (personal communication, 1984). In remote sensing applications to map cover types and to assist management in decision-making, Canada is undoubtedly the most advanced country. There is strong evidence that cover type mapping can be undertaken with sufficient accuracy and with favourable cost-efficiency by using

LANDSAT. The coming years will hopefully bring considerable advances in satellite imagery, partly because sensors will have higher spatial resolution and cover a wider range of spectral bands, and also because the development of software and hardware will improve image processing.

3.3   STUDIES WHICH USED LANDSAT[1] IMAGERY IN SOUTH AFRICA

South Africa was for the first time involved with use of multispectral remote sensing imagery from satellites in the ERTS-A programme (ERTS later to be called LANDSAT) in 1972-73. The relevant project by Malan (1973) was named: *To assess the value of satellite imagery in resource evaluation on a national scale.* In the 1970s and early 1980s various studies using LANDSAT imagery were initiated in South Africa. Their purpose was to assess the extent of the application of satellite imagery to resource-related problems. These projects included the use of LANDSAT imagery for mapping land cover in both urban and non-urban areas in Natal, the identification of agricultural crops – notably *The Heilbron Crop Mapping Project* by Malan and Turner (1984) of the then National Physical Research Laboratory[2], CSIR, initiated in 1978, and studies using LANDSAT imagery to map the Fynbos Biome. A pilot study entitled *Remote Sensing Products for studying and mapping the Fynbos Biome* by Jarman *et al.* (1981) was followed up by a project to map the entire Fynbos Biome with the aid of LANDSAT imagery, at scales of 1:250 000 and 1:1 000 000 (Moll, 1984). Since 1980 the number of projects aimed at experimental applications of LANDSAT and other remotely sensed data for land cover mapping in agriculture, forestry and natural vegetation systems has increased substantially (CSIR, 1987).

In 1978 a feasibility study was carried out by Malan, Van der Zel and Brink called *Preparation of a forestry map of South Africa using LANDSAT data*, as published in February 1980. A second feasibility study to assess and demonstrate the usefulness of digital image processing techniques was conducted at the Satellite Remote Sensing Centre by Snyman and Caithness (1981). These results were presented in an internal report, identifying problem areas and possible solutions with regard to computer classification. The authors of both reports concluded that LANDSAT imagery could be used for the preparation of a forest map for South Africa.

These results encouraged the formulation of a project to prepare forest maps of southern Africa on a 1:250 000 scale with the aid of LANDSAT data. A proposal was submitted to the National Programme for Remote Sensing in October 1981 and funding of the project was subsequently approved.

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[1]A summary of the LANDSAT system appears as Appendix 4
[2]Now: Division of Earth, Marine and Atmospheric Science and Technology

4. ORGANIZATION OF THE PROJECT

During the course of the second forest mapping feasibility study, the then Co-operative Scientific Programmes of the CSIR invited a group of interested parties to review the results of the study and to -

(a)   determine the need for remote sensing research and for studies to assess the usefulness of satellite imagery in forestry;

(b)   formulate goals for such studies; and

(c)   propose an appropriate work plan and/or approach for achieving such goals.

Since then the resultant *ad hoc* Forest Mapping Panel has acted as a steering committee for the project, meeting on an *ad hoc* basis to monitor project progress and to formulate future work plans and procedures.   At the second meeting of the Panel, D.W. van der Zel was proposed as Project Leader, to be assisted by C.H. Snyman and by T.P. Boyle of the Satellite Remote Sensing Centre.   N.H. Mönnig (Forestry Branch) joined the project team at a later stage. The Panel reports to the National Committee for Remote Sensing through the Working Group on Remote Sensing in Land Cover. It held its last meeting on 6 March 1986.

Funding of the project is administered through the Foundation for Research Development (formerly the Co-operative Scientific Programmes) of the CSIR.   The Department of Environment Affairs, the Forestry Council and the Foundation for Research Development contribute to the budget.

The names of past and present members of the *ad hoc* Forest Mapping Panel are given in Appendix 5.

The work calendar is discussed in Chapter 7.

5. CHOICE OF SENSOR AND RELATED ASPECTS

5.1   USE OF LANDSAT IMAGERY

In the late 1960s the objectives of the proposed Earth Resources Technology Satellite (ERTS) mission were defined by NASA in the USA. The primary objective was to demonstrate the feasibility of multispectral remote sensing from space for the purpose of earth resources management applications (Short, 1982). ERTS 1 was launched in 1972, followed by LANDSAT 2 in 1975, LANDSAT 3 in 1978, LANDSAT 4 in 1983 and LANDSAT 5 in 1984. Particulars of the LANDSAT system are shown

in Appendix 4. One of the most significant advantages of the system is the repetitive cycle of 18 days for LANDSAT 1, 2 and 3; and 16 days for LANDSAT 4 and 5. By synchronizing two satellites, e.g. LANDSAT 4 and 5, repetitive cover every 8 days is maintained. In 1970 NASA invited countries and researchers all over the world to participate in an evaluation of the ERTS-1 satellite. In the original South African project proposals, land use and vegetation studies featured prominently (Malan, 1974). Forestry was subsequently encouraged to participate.

Information needs of forest resource managers are manifold:

(a)   Areal extent of forest cover.
(b)   Forest class identification (indigenous, softwoods, hardwoods)
(c)   Volume estimates.
(d)   Stress detection.
(e)   Fire perimeter mapping, fire detection, fire protection planning.
(f)   Monitoring of changes.

Information of the kind listed above is expensive and time consuming to obtain by field surveys and aerial photography. At the time when the LANDSAT system was introduced to South Africa no forestry map of southern Africa existed due to the high cost of airphoto surveys. The use of LANDSAT imagery to map forest areas seemed a practical alternative in that it offered a high degree of accuracy at a low cost (Carneiro, 1978). Carneiro (1978) calculated that the basic cost of satellite imagery is 200 times cheaper than black and white airphotography at a scale of 1:24 000 and 50 times cheaper than colour infrared airphotography at a scale of 1:120 000.

In the beginning it was reported that a picture element recorded on the LANDSAT Computer Compatible Tape (CCT) represented a ground area of 57 m by 79 m, i.e. a ground dimension of about 0,45 ha. However, several researchers subsequently found that the smallest area that could be correctly identified from LANDSAT imagery is from 5 to 10 ha.

The four spectral bands available in LANDSAT MSS data had also been found by several research workers to be of particular use in American and European forestry applications. It was stressed by several overseas investigators (e.g. Carneiro, 1978) that bands 5 and 7 identified vegetation best. Band 4 was found to be useful in discrimination of iron content in rocks and soils, band 5 was sensitive to chlorophyll and bands 6 and 7 sensitive to vegetation density or biomass. Forests and plantations showed up best in spring, autumn and winter in temperate zones (like South Africa's afforestable land areas) on band 5.

A World Reference System grid was compiled for the LANDSAT scenes, as shown in Appendices 1 and 2. A catalogue of images, available from the Satellite Remote Sensing Centre, makes it possible to determine what

imagery, as well as the quality and per cent cloud cover thereof, is available for each scene. A variety of LANDSAT products are also available, e.g. standard black and white prints of one or a combination of the bands, standard colour infrared prints (on film positive, film negative or on paper), computer compatible tapes, enhanced imagery in the form of colour composites or any other form, as well as precision geometrically corrected imagery.

The fact that the LANDSAT products initially had to be obtained from the USA, was a deterrent to the initiation and initial progress of the forestry project. However, the assistance of staff of the National Physical Research Laboratory, and at a later stage, of staff of the Foundation for Research Development (and its predecessor, the Co-operative Scientific Programmes) all of the CSIR, were motivations for continued investigation of all LANDSAT's possibilities in forestry. The Special Users Project at the SRSC finally contributed to the conviction that this present forestry project would be undertaken and would result in acceptable results, as long as it was realized that LANDSAT was but one of a number of tools or input into a final forestry map. LANDSAT imagery must therefore be viewed, as in this project, as one of several mapping aids used. In this project it is used in conjunction with other information such as ground and aerial surveys and conventional maps on many scales. It became the policy of the project leaders to integrate as far as possible several information sources to obtain a final map result.

5.2   SCALE OF MAP PRODUCTS

The possible scale of a forest map for South Africa ranges between 1:7 000 000 (i.e. one wall map for the area as a whole) to one of 1:5 000 (i.e. one map per plantation unit). The 80 m resolution of the available LANDSAT images, however, indicates that a 1:1 000 000 scale is convenient although a 1:250 000 scale is also possible. A comparison between Appendices 2 and 3 reveals that 32 topocadastral map sheets for southern Africa are involved to cover the forests and commercial plantations, if a scale of 1:250 000 is used.

An area of 1 mm by 1 mm on a 1:250 000 scale map represents about 6,25 hectares. A 1:50 000 scale map would be less accurate and the work volume would increase considerably since about 300 topocadastral sheets then have to be classified.

The 1:250 000 scale is a standard scale for map products of the Chief Directorate of Surveys and Mapping of the Department of Public Works and Land Affairs.

5.3 ACCURACY

The objective set was to try and achieve an error of less than 10 per cent. The basis to which this accuracy was to be measured, is the accuracy with which present 1:250 000 maps depict afforested areas. If the present maps depict indigenous forests with an accuracy of 65 per cent and the project's map improved on this by providing an accuracy of more than 90 per cent, then this goal will have been achieved.

5.4 FOREST CLASSES

The indigenous forests in southern Africa can broadly be divided into -

(a)   high evergreen forests;
(b)   deciduous savanna forests; and
(c)   fynbos and other scrub forests.

The high evergreen forests are the indigenous protection forests. Apart from being managed as protection forests, they also produce timber which can be used for furniture and for other purposes. There is a need for accurate mapping in order to manage, plan and protect more efficiently. These forests are therefore being identified for the purposes of this project as one indigenous forest class.

The exotic tree species grown in plantations can be divided in two classes: softwoods and hardwoods. Of the softwoods pines occupy about 99 per cent of all commercial plantations. They represent a homogeneous forest class. The most important hardwoods are *Eucalyptus* species (mainly *Eucalyptus grandis*), *Acacia mearnsii* and *Populus deltoides*. *Eucalyptus* species and *Acacia mearnsii* make up 98,5 per cent of the hardwoods and represent two distinct classes.

This classification of exotic plantations in three classes is considered adequate for the Forestry Sector as well as agriculture and other land-use planners, including conservation planners.

The final classification was therefore as follows -

(a)   indigenous forests;
(b)   pine plantations including *Cedrus, Widdringtonia* and *Cupressus* spp.;
(c)   gum plantations but including poplar and oak plantations; and
(d)   wattle plantations including all commercially grown *Acacia* species.

Based on the pilot study, it was decided not to distinguish between individual species' age classes but to introduce this refinement at a later stage as soon as resolution of LANDSAT products and expertise of project participants had improved substantially.

5.5   MINIMUM MAPPING UNIT

There were two reasons for selecting a minimum mapping unit of 25 hectares:

(a)   An area of 25 hectares, representing 2 x 2 mm on a 1:250 000 sheet, is a practical constraint for mapping.

(b)   This size of the mapping unit would hopefully distinguish woodlots, wattle jungle and other non-commercial exotic tree lots from commercial plantations.

For indigenous forests the minimum mapping unit was extended to 50 hectares. In this way the elongated riverine forest patches which cannot be utilized economically, were, hopefully, excluded.

5.6   USE OF DIGITAL IMAGE PROCESSING TECHNIQUES

An image is a recorded representation of an object produced by optical, electro-optical, optical mechanical or electronic means (Short, 1982). It is a most efficient way to convey a large amount of information to a user. Although the extraction of specific information from a photographic image is normally carried out by visual interpretation, digital imagery, as received from LANDSAT MSS, also lends itself to computer-aided, information-extraction procedures. Both techniques were used in the project. Digital Image Processing (DIP) is any numerical or mathematical operation carried out on digital image data. It may include any or all of the following:

*   Radiometric correction to adjust the digital data for atmospheric and sensor anomalies.

*   Geometric correction and re-sampling to correct for earth and satellite movements as well as several sensor and scene effects, and to transform the data to map projection format.

*   Image enhancement for improved viewing and information extraction.

*   Classification or thematic mapping of the data into land cover classes.

*   Generation of black and white or false colour film products.

There are two generally accepted methods for classification into land cover classes. In the unsupervised method (Ball and Hall, 1965), the computer algorithms cluster the data points into numerical or spectral classes. In the supervised method (Odenyo and Pettry, 1977), the analyst manually selects data samples which are typical of the desired

land cover classes. These data are then used by the computer algorithms to allocate every individual picture element into the most probable class.

Some of the major advantages of DIP are:

* The digital data are synoptic, frequently obtained and computer compatible.

* The individual pixels can be objectively analyzed.

* Large data volumes can be swiftly accessed, handled and stored.

* The data are conveniently manipulated by mathematical and statistical analysis.

* Rapid hard copy can be provided.

Fifteen of the thirty-two 1:250 000 forest map sheets (as shown in Appendix 3) contain sufficiently large tracts of forests or plantations to warrant computer classification of the LANDSAT digital data as an aid to the final mapping. The balance of the sheets, with small forest areas, will be mapped by visual interpretation with the aid of LANDSAT film products.

A shortcoming, brought to light by previous experience in forest mapping, is the inability of computer processing to adequately classify indigenous forests. This is due to the wide range of spectral reflectances shown by this cover type, and its typical location along streams and narrow valleys, often in shadow, on the LANDSAT images. Consequently it was decided that indigenous forests would mainly be mapped from sources independent of LANDSAT imagery, namely the Wildlife Society (Cooper, 1985) and the Forest Biome research group (CSIR) findings.

The DIP facilities used for the forest mapping input are those of the then SRSC, National Institute for Telecommunications Research[1] CSIR. These facilities are the most powerful and flexible in the RSA and are made available under the Special User Service Projects Scheme of the National Programme for Remote Sensing. The DIP techniques were those available at the SRSC in 1984.

The DIP hardware comprises the following:

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[1]Now: Satellite Applications Centre, Division of Microelectronics and Communications Technology

*   High Density Digital Tape (HDDT) Drives for archival and retrieval of LANDSAT data.

*   Perkin-Elmer 8/32 mini-computer.

*   300 megabyte disc storage.

*   Comtal 8 000 colour display.

*   Tape drives for tape (CCT) data input and storage.

*   Line printer output.

*   Polaroid colour graphic camera for instant hardcopy from the Comtal display.

*   Optronics Colorwrite C-4300 drum recorder, for high resolution colour or black and white film output.

*   Optronics Photoscan P-1000, scanning microdensitometer for digitization of colour or black and white transparencies.

The software consists of an Image Analysis Package (IAS) developed by Macdonald, Dettwiler and Associates of Canada. The SRSC has made considerable adaptations and additions to this package. Years of experience in the use of the IAS have built up a high level of analyst expertise.

5.7   USE OF THE 1:250 000 TOPOCADASTRAL MAP SERIES

In paragraph 5.2 it was indicated that the decision to use a scale of 1:250 000 in the proposed production of a forestry map was influenced by the existence of a standard 1:250 000 topocadastral map series, covering southern Africa. These maps are regularly updated and have all been metricated. One example of a recent update and improvement was the replacement of the Dundee (2830) and St Lucia (27 1/2 32) maps with one Richards Bay (2830) map. On the maps information such as roads, railway lines, urban areas, farm boundaries and contours every 50 metres are indicated. "Plantations and forests" are, besides "Pans, marshes and vleis", the only land cover indicated on these maps. The maps are generally available at a nominal price and are extensively used. Slotting in with such an established standard product, has the support of the office of the Chief Director of Surveys and Mapping.

It was arranged that the first three experimental maps be prepared as special products. If successful, all other 1:250 000 map sheets, where applicable, will be updated with the new four-class classification as stocks of the relevant sheet is exhausted and a new print must be

prepared. The high cost of production of the final forest maps to the project itself has thus considerably reduced by using the existing 1:250 000 map series.

The topocadastral map is preferred to the topographical map as it contains the names and numbers of farm properties.

The first three experimental maps are:
* Pilgrim's Rest 2430.
* Barberton 2530.
* Oudtshoorn 3322.

6. PROCEDURES AND METHODOLOGY

6.1 DIGITAL IMAGE PROCESSING

6.1.1 Selection of LANDSAT data

Experience has shown (Snyman and Caithness, 1983) that DIP of single-date LANDSAT data does not give sufficiently accurate class discrimination for identification of forest types and genera. The best two dates of LANDSAT imagery are therefore chosen from the SRSC catalogue. The imagery is usually six months apart in summer and winter, but the choice of dates will be influenced by the weather pattern prevailing at that time and the availability of clear data.

The digital data tapes of likely imagery are generated from the HDDT and loaded onto disc. The data are then digitally enhanced and inspected on the Comtal display screen for quality of data and cloud cover and visually for land cover class separability.

6.1.2 Geometric correction of LANDSAT data

Before any classification of the data can take place, the two images must be registered to each other and transformed to map projection format (at the SRSC this projection is the Universal Transverse Mercator Grid System, (UTM). Black and white film negatives of the individual bands of the selected LANDSAT images, at 1:1 000 000 scale, are produced to aid in the selection of Ground Control Points (GCPs).

GCPs are points of detail, such as bridges, road junctions and runway crossings, which are identified both on the LANDSAT film images (and thus on the digital data) and on 1:50 000 topocadastral sheets. The scaled co-ordinates of up to thirty-five of these points in latitude, longitude and height above mean sea level are used as input for computer programmes which geometrically correct the digital data. The output is two-date LANDSAT data registered pixel for pixel with each other, producing an eight-band data set on the UTM projection.

6.1.3 Principal components analysis

To comply with the input requirements of certain computer routines in the IAS and to speed up the overall computer processing, the eight band data may be condensed into four bands. Principal Components Analysis (PCA) is used to transform each four-band spectral data image into four bands of principal component data. Each principal component value is a linear combination of the four original reflectance values (Davis, 1973). The first two principal components of each transformed image, which may contain 90 per cent of the image information in terms of variance, are then combined to form a new four band, two-date, data set.

6.1.4 Training areas

Training areas are recognizable areas on an image with distinct special properties useful for identifying other similar areas (Short, 1982). They are used to "train" the image and the user to recognize similar areas with similar properties within the set boundaries.

6.1.5 Surface reference data (= ground truth)

This is supporting data collected on the ground or surface of the earth, and derived information, as an aid to the interpretation of remotely recorded surveys (Short, 1982). The data are generally collected as near as possible in time to the remotely recorded surveys.

6.1.6 Training and classification of LANDSAT data

In this phase of DIP, the computer is used to identify individual pixels as belonging to a selected ground cover class, e.g. pines. The training is a hybrid approach using both supervised and unsupervised methods. See Figure 2 for a detailed flow chart of the hybrid classification method. Where compartments of homogeneous cover type can be located in the digital data, the supervised method is used. The compartment or training area is identified as a ground cover class using the known surface reference data (SRD) as described in the next paragraph. A typical, statistical signature (mean and variance/covariance matrix) of the reflectances for this cover type on this site, is then calculated by the computer. Because of the natural variations in the surface cover due to age, stress, topography and forestry activities, several signatures are normally required to adequately represent one cover type. This process is repeated for all cover types of classes to build up a representative signature file of the data in the training areas covered by SRD The set of signatures is tested by classification against other known areas and edited by deletion, addition or merging of signatures.

HYBRID SUPERVISED/UNSUPERVISED APPROACH

```
┌─────────────────────────────┐
│ Choose Training Areas based │
│ on Surface Reference Data   │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│ Choose Signature Sites for  │
│ Ground Cover Classes        │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│ Develop Supervised Signatures│
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│ Numerically Evaluate Signatures │
│ (Divergence and Variance)   │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│ Edit Signatures (Merge, Delete, Split) │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│ Classify Training Areas     │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐        ┌─────────────────────────┐
│ Visually Evaluate Classification │ - - ▶│ Mask Incorrect/Poorly   │
└─────────────────────────────┘        │ Classified Areas        │
              │                         └─────────────────────────┘
              │                                      │
              │                                      ▼
              │                         ┌─────────────────────────┐
              │                         │ Generate Unsupervised   │
              │                         │ Signatures for Masks    │
              │                         └─────────────────────────┘
              │                                      │
              │                                      ▼
              │                         ┌─────────────────────────┐
              │                         │ Numerically Evaluate    │
              │                         │ & Edit Signatures       │
              │                         └─────────────────────────┘
              │                                      │
              ▼                                      ▼
┌─────────────────────────────┐        ┌─────────────────────────┐
│ Classify next Training Area │        │ Classify Masked Areas   │
└─────────────────────────────┘        └─────────────────────────┘
              │                                      │
              ▼                                      ▼
┌─────────────────────────────┐        ┌─────────────────────────┐
│ Classify Full Image         │        │ Identify Signatures as  │
└─────────────────────────────┘        │ Ground Cover Classes    │
              │                         └─────────────────────────┘
              ▼                                      │
┌─────────────────────────────┐        ┌─────────────────────────┐
│ Produce Hard Copy Classified│        │ Add to Existing Supervised│
│ Product (1/250 000 colour print) │   │ Signatures              │
└─────────────────────────────┘        └─────────────────────────┘
```

FIG. 2:   FLOWCHART OF THE HYBRID CLASSIFICATION METHOD

Where the SRD shows confused or incorrect classification or where homogeneous training sites cannot be identified in the data, the unsupervised training method is used. The computer classes are then identified as surface cover classes and edited into the signature set. When the best compromise has been reached in the classification of all available training SRD, the final set of signatures is used to classify the full scene into the chosen land cover classes. The output product is a 1:250 000, precision corrected, colour coded, LANDSAT classified image.

Factors affecting the accuracy of such a computer classification are discussed in paragraph 6.5. Where classification accuracy is not acceptable, as indicated by the known SRD, the only solution is to try a better combination of two-date LANDSAT data, or to make the best classification possible and then conduct comprehensive field checks. The LANDSAT classified image is used by the forester/analyst as an input, together with all other possible relevant data, for compilation of the final forest map sheet.

6.2   COLLECTION AND USE OF SURFACE REFERENCE DATA (SRD)

Once a sheet has been selected for classification it is then necessary to collect all the SRD available for the area. The quality of the final computer classification is to a large degree dependent on the quality of the surface reference data which can be in the form of maps, aerial photographs, compartment records or notes from field trips. There is usually little or no problem in collecting data from State agencies, companies and, in some instances, co-operatives. Where data are inadequate it can be supplemented by oblique or vertical small format (35 mm) aerial photography,

A major problem is to obtain data which correspond to the date of the image acquisition. The data which are to be used as training areas for the classifier should be evenly distributed throughout the afforested area represented on the image. Remaining data can be used to check the accuracy of the classification although it is more advantageous to use all the data for training sets.

SRD information which is used for training areas must be comprehensive, include information on the following and be representative of the whole map:

(a)   General

The classification covers pines, wattles, eucalypts and indigenous forests and as much information as possible must be collected in respect of each class.

(b)   Age class distribution and planting espacement

The age class distribution corresponding to the date of imagery must be known because of the relationship between age and/or espacement and spectral reflectance.   The specific values for various genera of the same or similar age or espacement of small samples can be identical and then results in misclassification. It is essential that as many data as possible are collected to obtain a large and representative set of signatures.

(c)   Aspect

Contour maps, either large scale (orthophoto) or the standard 1:50 000 map sheets are useful for determining where shadows occur, especially where winter images are used, as shadows can cover a large area in mountainous terrain.

(d)   Compartment composition

Where mixed compartments occur, i.e. *Pinus patula* and *P. elliottii*, these should be noted. Their spectral signature will be different from that of pure stands and if not identified, valuable time is lost in removing anomalies.

(e)   Other crops

Other crops, i.e. tea and citrus orchards, might be confused with forests and therefore should be identified on the colour transparency of the LANDSAT image.

So far late summer and early autumn images have been used when there are only small areas of agricultural dryland crops present which in turn reduce the classification problems.

(f)   Indigenous forests

Because of similarity of spectral signature, problems may occur when exotic plantations and indigenous forests adjoin each other. The exact position of each or one of these classes should be determined from other sources and mapped from this information.

6.3   MAPPING OF SHEETS WHERE DIGITAL IMAGE PROCESSING IS USED

With the aid of the SRD the individual classes are identified and training areas obtained. The computer then uses the training areas to classify the image. If the classification is not satisfactory further training areas are selected to improve the classification. A hardcopy of the final classification is produced in the form of a 1:250 000 scale

photograph.   Relevant information is then transferred to the map sheet.
Classification   data   are   traced   on   clear   plastic   film   and   then
transferred onto the map sheet. A grid with units equal to the minimum
mapping unit (25 ha for exotic plantations and 50 ha for indigenous
forests) is used to delineate the individual classes. Areas below the
minimum mapping unit are incorporated in the dominant adjoining class.

SRD are continually used to monitor the classification and where
necessary to supply additional information such as on newly planted
areas or recent clearfellings. Use is made of local extension officers,
foresters and other sources of information to improve the information on
the draft map.   Planning foresters and staff of large companies can
normally supply accurate information about their own plantations and
afforested areas within a region.   This is one of the most efficient
methods of correcting the draft map.   The existing 1:250 000 and
1:50 000 topocadastral series show (amongst others) afforested areas in
a single colour.   The boundaries are accurate and except for new
expansion this serves as a useful guide in compiling the draft map.
Extensive travelling by vehicle and/or aircraft is also undertaken to
verify the draft map.

6.4   MAPPING OF SHEETS WHERE DIGITAL IMAGE PROCESSING IS NOT USED

Manual classification applies to the following sheets:

Messina 2230, Alldays 2228, Pietersburg 2838, Tzaneen 2330, Nylstroom
2428, Pretoria 2528, East Rand 2628, Frankfort 2728, Mkuze 2632,
Harrismith   2828, Drakensberg 2928, Kokstad 3028, Kei Mouth 3228,
Queenstown 3126, Port Elizabeth 3324, Ladismith 3320, Riversdale 3420,
Worcester 3319 and Clanwilliam 3218.

6.4.1 Methodology

The plantation statistics for the region of interest submitted annually
by all plantation owners in the area are obtained from the computer data
bank of the Department of Environment Affairs. For each plantation
owner, the name and number of his farm(s) and magisterial district is
given.   The farm boundaries are marked in pencil on the map sheet. The
marked areas are subsequently compared with the LANDSAT film images to
identify omissions, commissions and other problems on the map sheet.
The names and numbers of "problem" farms are listed on a separate sheet
of paper.   Confidentiality is, however, maintained and individual farms
or properties are not identified on the final map.

All easily available information (State plantations and their
boundaries, large private plantations, etc.) is transferred to the map
sheet using three different colours to identify pine, eucalypt and
wattle.   The statistics are also used to identify estates with only

eucalypt species. Should the area of the present green shade on the map sheet correspond to the planted area given in the plantation statistics, the area will be marked to represent the relevant species. A more comprehensive search for information in the form of maps, aerial photos and compartment lists is hereafter conducted.

At this stage all information available in the Department of Environment Affairs (DEA) will have been used. Visits and/or field inspections are necessary to obtain further information. The owners of larger plantations are visited to obtain plantation maps and other useful information regarding other plantations in the vicinity.

After mapping this information, the map sheet is considered to be ± 80 per cent complete. The remaining ± 20 per cent consists of small private plantations, problem areas and areas shown on one or two of the map sheet/plantation statistics/LANDSAT image which are not shown on the third plantation statistics/LANDSAT image/map sheet. During all the above-mentioned stages, LANDSAT film images (mostly the false colour composite, but also negatives of bands 5 and 7) are used continuously to confirm information, e.g. to reveal missed forest areas. This additional information is conveyed to the map sheet.

Contact by telephone or a second visit to the region covered by the map sheet is necessary to resolve the remaining uncertainties.

Information on indigenous forests is added to the map sheet in a fourth colour from sources mentioned in paragraph 5.5.

The steps subsequent to 'include information on indigenous forests and State forest boundaries on map' on the flow chart (See Appendix 7) are then followed. These include the correction of maps, planimetering of areas and comparison with other statistical reports and distribution of copies of annotated maps for assessment by evaluators. Once the mapped information is deemed satisfactory, a composite master transparency of the relevant 1:250 000 map is ordered from the Chief Directorate of Surveys and Mapping and a transparency is prepared per forestry class. All transparencies are finally returned to the Chief Directorate of Surveys and Mapping for printing of the 1:250 000 sheet in question.

6.5   FACTORS AND FEATURES INFLUENCING COMPUTER CLASSIFICATION AND MAPPING ACCURACY

6.5.1 Computer classification accuracy

The actual classification technique or algorithm does not affect the classification accuracy of MSS data. The classifier itself is not as important as the development of representative and distinct class signatures (Scholz *et al.*, 1979). This was confirmed by Hoffer (1978)

who states that the selection of training areas and obtaining their signatures are the two most important steps in the image processing and classification sequence. Signatures and training areas which represent cover types depend exclusively on accurate and adequate SRD. The omission of a class or subset of a cover class from a signature set will seriously affect classification accuracy. The training areas and signatures should include all relevant vegetation categories.

Indistinct or overlapping forestry signatures result from five probable general causes: data processing; inherent spectral response; topography; stress and forestry activities.

6.5.1.1 Data processing

Misregistration of the two LANDSAT data sets will cause misclassification. Misregistration occurs when difficulty is experienced in locating an adequate number of GCPs, or when the distribution or quality of the GCPs are poor. The two sets of data will not be registered pixel to pixel and non-distinct signatures will result.

6.5.1.2 Inherent spectral response

(a)   Indigenous forests

These forests have an extremely diverse composition with a large variety of genera and species which vary from region to region, resulting in a large range of spectral reflectances. It has not been possible to adequately resolve classification of these forests with computer processing.

In the Transvaal and Natal a large percentage of these forests is to be found bordering streams in deep valleys where they have been protected from fire. Many of these forests are in shadow at the time of the satellite overpass which further complicates classification.

Along the Eastern Transvaal escarpment indigenous forests are found along the upper region of the escarpment while bushveld is found at the bottom. The transition zone between the two is often gradual and difficult to identify and results in misclassification.

The wide range of spectral reflectances results in confusion with exotic plantations where the two adjoin each other.

Indigenous forests which are not in close proximity to exotic plantations or in shadow areas can be identified and the total extent of the forest determined. No attempt is being made to classify the genera. Only boundaries of the indigenous forests are determined.

(b)   Mixed stands

These stands also present signatures with considerable variability. They usually result from the conversion of a stand from one genus to another (*Acacia* to *Pinus*). The subsequent regrowth of trees from the original genus will result in a spectral signature which is a combination of signatures from the original and new genus. Careful study of the class signature means on each image may help to distinguish a mixed or a stand contaminated by weeds, but the nature of the mix or the land use will have to be established by field survey or local enquiries.

6.5.1.3 *Topography*

The LANDSAT image is obtained at approximately 09h30 which results in a low sun angle in winter. A considerable portion of the exotic plantations in Southern Africa are in mountainous terrain and shadow is a major problem (Snyman and Caithness, 1983). Where the shadow effect is not so dense as to obliterate reflectance, confusion may still exist. still exist. For instance, a ten year old *Eucalyptus* stand on a shady western slope has a similar spectral signature as a *Pinus* stand in the sun. The careful selection of multitemporal imagery may help. The imagery should be chosen to minimise the shadow area. At present an autumn image is selected to minimise the effect of other annual crops such as maize and a summer image to obtain high sun angles and greater spectral discrimination between genera.

The use of additional data sets such as a digital terrain model yielding altitude, aspect and slope for each pixel would almost certainly solve this problem, but such data are not readily available at present.

6.5.1.4 *Stress*

The spectral signature of a plantation can be influenced by drought, frost, hail, disease and insect damage. The influence can be so great as to alter the signature to such a degree that it resembles that of a different class. Comprehensive surface reference data in the form of annual growth calendars and rainfall data can assist in the choice of optimum dates of imagery, but computer classification can still be influenced by stress (e.g. drought) of long duration.

6.5.1.5 *Forestry activities*

The distinction between land cover and land use can sometimes cause computer classification problems. When a compartment has been felled, the ground cover can vary from green freshly delimbed branches to dry, brown material.

If the residue is burnt then the cover can be ash or bare soil. After a while there will be a regrowth of grass or weeds on these areas. Newly planted or young naturally regenerated stands cannot be identified until the canopy has closed sufficiently to form a dominant feature. Even then it can be confused with bright, green crops such as tea or sugar cane with a closed canopy. A further problem with naturally regenerated stands such as *Acacia* species is that the large number of seedlings result in rapid crown closure. The subsequent removal of excess seedlings can alter the signature during the growing cycle. At this stage there are no indications that thinnings influence computer classification, but a heavy thinning may affect the spectral signature. Planting espacement affects the age at which crown canopy closes and can be distinguished from other land cover categories. Crown closure will also be influenced by crown characteristics of the species. The narrow crown of *P. radiata*, for example, differs from that of other Pines.

The use of multi-temporal and surface reference data showing the locations of non-forest vegetation or crops which can be confused with forests may improve classification. The future use of more sophisticated sensors measuring reflectance in the mid-infrared and thermal infrared sections of the spectrum will certainly assist in discriminating between thinned or regenerated forest and clearfelled areas. The Satellite Remote Sensing Centre, however, is not yet equipped with facilities to receive or process data from the new generation of satellites and sensors.

6.5.2 Mapping accuracy

6.5.2.1 *Misregistration*

To transfer the final computer classification data to the 1:250 000 map sheet, the computer classification is printed at a scale of 1:250 000. Where insufficient surface control points (or poor distribution of points) are collected the final registration of the classification to the map sheet can be poor and this results in difficulties in the transfer of data.

6.5.2.2 *Minimum mapping unit (see paragraph 5.5)*

The final mapping accuracy can be influenced by the minimum mapping unit. The decision as to whether a class will be included or not is taken by passing a grid the size of the minimum mapping unit over the computer classification. Areas which are smaller than the minimum mapping unit are excluded from the final map, but where an area consists of a mixture of classes, each the size of or smaller than the minimum mapping unit, errors occur in the final decision.

6.6   TESTING THE ACCURACY OF A LANDSAT PRODUCT

The decision to allocate the single picture element to a specific land cover category is a decision made under some uncertainty. In supervised classification, the training sites serve to obtain estimates for the mean and variance of reflectance values in four bands of the electromagnetic spectrum. If they extend over two seasons, each of the signatures provides a set of eight means and eight variances. Normally, the assumption is that reflectance values follow the Gaussian distribution. In consequence when eight variables are involved, the resultant distribution is a multivariate instead of a univariate normal distribution, which would occur when a single variable were involved. The maximum likelihood rule of classification is a decision rule which allocates the single picture element to the i-th category if the likelihood of the occurrence of the sample for this category is greater than for the other categories. The uncertainty arises from variability in reflectance values for the land cover types. due to site, illumination, slope, age, and species. It increases when few training samples are used to assess the variance/co-variance matrix of reflectance values. The problem in accuracy testing is analogous to that arising in discriminant analysis, namely to assess the probability of a misclassification, resulting in omission and commission. When a pixel, selected to test the accuracy of a LANDSAT product against surface data is not classified as belonging to category I, to which it should have been allocated, but incorrectly to category J to which it should not have been allocated, it is omitted in category I and committed to category J. The result can be presented in a confusion matrix. In case of four categories being distinguished, a symmetric confusion matrix is a 3 x 3 matrix e.g. such as that shown in the table on page 26

The "samples" in column 2 of this table represent picture elements actually present in the test area. Hence, the true number of picture elements (assuming homogeneity within the pixel) in the category conifers was 9 634 of which 94,6 per cent were indeed classified as such. The probability of misclassification for conifers is greater than that for the deciduous cover type. Of the 9 278 coniferous picture elements, 9 110 pixels were correctly classified, whereas 113 pixels were committed to the deciduous cover type, 49 to grassland and 6 to water.

Cover type	No. of Samples	No. of samples classified as:						Correct %
		Coniferous	Deciduous	Grassland	Barren	Water	Shadow	
Coniferous	9 634	9 110	22	53	21	96	332	94,6
Deciduous	1 475	113	1 286	76	0	0	0	87,2
Grassland	3 677	49	129	2 988	510	0	1	81,2
Barren	35	0	0	1	34	0	0	97,1
Water	1 349	6	0	0	0	1 334	9	98,9
Total	16 170	9 278	1 437	3 118	565	1 430	342	

Overall performance = (9 110 + 1 286 + 2 988 + 1 334)/16 170 = 91,2 %
Source: Hoffer (1978)

In consequence, the off-diagonal row entries are omissions, the off-diagonal column entries represent commissions.

Piper (1983) recommends Jaccard's coefficient to quantify the accuracy of classification:

$$J = \frac{N_1}{N_1 + N_2 + N_3}; \quad 0 \quad J \quad 1$$

where N_1 = number of positive matches
      N_2 = number of omissions
      N_3 = number of commissions

This index is identical to the "overall performance" criterium of Hoffer (1978). It has the property of not being affected by the size of the pixel. Applied to a 4 x 4 confusion matrix it is found as the sum of the diagonal elements divided by the total sum of the elements of this matrix.

In order to avoid bias, Hoffer *et al.*, (1979) recommended the selection of test areas prior to sampling by statistical sampling designs.

The occurrence of a number of omissions and commissions does not imply that area estimates are of necessity inaccurate. The following 2 x 2 matrix serves as illustration:

No. of samples	No. of samples, computer-classified as			
		A	B	Sum
No. of samples	A : B :	700 300	300 1 700	1 000 2 000
	Sum :	1 000	2 000	3 000

In this matrix, 300 A-pixels were committed to B and 300 B-pixels were committed to A. Jaccard's coefficient is equal to 0,80 but the area estimate was error free. This would occur when the row totals of the confusion matrix are equal to its column totals. In practice this will never happen. It may therefore be necessary to supplement the confusion matrix with area estimates, e.g. obtained from existing maps. The following information was extracted from Kalensky et al. (1981):

Source	Softwood		Hardwood	
	ha	%	ha	%
Inventory map (240 000 ha)	82 440	100	864	100
Supervised single-date	77 428	94	–	0
Supervised two-date	75 720	92	–	0
Supervised three-date	65 453	79	–	0
Unsupervised single-date	152 333	185	?	?

This table is of great value and indicates e.g. that the two-date supervised classification produced an eight per cent error for softwoods whereas hardwoods were not detected at all. Obviously the table for area accuracies and the confusion matrix, to some extent, are related. In the hardwood category all pixels were committed to other categories. If they had been committed to the softwood category the latter would have been overestimated. The 94 per cent accuracy, however, indicates that the pixels omitted in the hardwood category were committed to categories other than softwoods. The reliability of the area comparison depends upon the reliability of the area-information from maps, working plans or from other information such as small-scale aerial photography, used to represent "true" values. A disparity between estimates from

LANDSAT imagery and from maps is normally attributed to LANDSAT-bias, but could be partially associated with erroneous map areas, partly with LANDSAT-misclassification.

6.7 QUALITATIVE ASSESSMENT OF MAP PRODUCTS

At three stages the maps were evaluated qualitatively, namely by the project team, by the *ad hoc* Forest Mapping Panel and by regional or field evaluators. For the first experimental sheet (2530 Barberton) this was done on the four-colour sheet; in future it will be done on overlays of existing 1:250 000 map sheets or on copies of existing 1:250 000 map sheets.

The project team evaluates the map qualitatively by comparing it with all available information for the four forestry classes. It ensures that no obvious errors are made and discrepancies due to fires, clearfellings, conversion to agriculture, etc. can be explained. The proposals are also submitted to the Forestry Branch, Department of Environment Affairs, to large companies and to the Planning Committee of Forestry Council.

The *ad hoc* Forest Mapping Panel is supplied with the proposed map, which also shows State Forest boundaries. Individual members will compare map information with surface reference data from their own respective organization and with other information at their disposal. Relevant changes are then transferred to a master copy of the map.

The Panel is responsible for the release of the experimental sheet or the proposed map. Copies of the amended master copy are sent to evaluators, who are leaders in the forestry industry in specific regions, well-informed about the forest area and species composition of their own and of neighbouring estates. They are appointed by the Forestry Council and evaluate the usefulness of the map for the region, indicate discrepancies and the location of sawmills, pulpmills, preservation plants, mining timber depots and other important timber processing installations as well as fire lookout towers and forestry administration centres. They also evaluate other features of the proposed maps, such as the accuracy of boundaries, acceptability of colours and adequacy of other information on the maps.

The qualitative assessment of the indigenous forests between Mariepskop Lebowa Forest and New Agatha State Forest on the present 1:250 000 map sheets of Pilgrim's Rest (2430) serves as illustration. Based on aerial reconnaissance by the co-leader and the representative of the Wildlife Society of Southern Africa, the actual indigenous forests on the present 1:250 000 maps in these otherwise inaccessible areas were redrawn. The resultant reduction in estimated area was approximately 50 per cent.

The evaluators and Panel together determine whether it is justified to produce the final map. The project team compiles the final proposal after having received the comments of the evaluators for formal approval by the Panel.

6.8 MAP PRODUCTION

When the draft map has been approved, a composite transparency of the 1:250 000 series is obtained from the Chief Directorate of Surveys and Mapping (Department of Public Works and Land Affairs), Mowbray. It includes cadastral boundaries, roads and rivers, i.e. all the existing information except the green overlay. The information from the draft map is transferred to the transparency which in turn is overlaid on the draft map. On the transparency each individual class is indicated with 'letratone'. For the first maps (Barberton and Pilgrim's Rest) separate overlays were required. In future one overlay of all four classes and of the State Forest boundaries will be supplied. Sepia copies of this map are then printed for distribution to the evaluators.

Areas for each class are planimetered after which the totals are compared with the plantation statistics. Anomalies are investigated and their source determined and if necessary corrections made to the map. Areas per class, per magisterial district and/or per river catchment can also be derived.

Once the draft map has been approved drafting film is used to print an overlay of the transparency. It is sent to the Chief Directorate of Surveys and Mapping for the printing of the final map. On the final map each class is represented by a different colour. It was decided to use palest green for Pines and a darker shade of green for Eucalypts. A still darker yellow-green will be used for Wattles, while the darkest brown-green is used to indicate Indigenous Forests.

6.9 INVENTORY OF SURFACE REFERENCE AND LANDSAT DATA

The SRD were collected regionally from all possible sources and organizations where up to date information was made available. The information was available in the form of maps and compartment registers. In many cases maps and compartment information are used simultaneously as maps, in most instances, only show compartment numbers and size. Age and genus are obtained from compartment registers.

Aerial photographs corresponding to the date of imagery were sometimes borrowed but returned to the owner on completion of the map sheet.

The LANDSAT data were used in the form of black and white and also colour transparencies as well as some colour composites. After final classification a 1:250 000 hardcopy of the classification was made. An inventory of these data appears as Appendix 8.

All the above data will ultimately be stored in the offices of the Forestry Branch, Department of Environment Affairs, Pretoria.

7. WORK CALENDAR AND FLOW CHART

7.1 WORK CALENDAR

The work calendar is enclosed as Appendix 6. It lists the 1:250 000 map sheets in order of priority and leaves space to indicate progress during the project period. In the first place it indicates the corresponding LANDSAT WRS reference numbers for LANDSAT 4-5. It also indicates whether evaluators were selected and then leaves space to insert dates when ground control points, surface reference data, training areas and classification are expected to be completed. It also leaves space to indicate when the draft map is expected to be available, when verification is expected to be completed, when the Panel is expected to give clearance and, finally, when the final map is ready for printing. It should also be dated because it gives both progress and planning dates. The main function of the work calendar is to serve as a guideline. Progress may differ from these guidelines.

7.2 FLOW CHART

The flow chart is attached as Appendix 7. It can be divided into four major sections, each describing an individual main task. These main tasks are the collection of surface reference data, computer classification, classification where no computer input is required and the preparation of the final draft map.

The first task, that of collecting surface reference data is common to the next two. Based on the results of this first section, the decision is made, whether to apply digital image processing or manual processing. The work tasks for each section is presented in the flow chart. The result of the middle two sections come together again in the final draft map preparation progress.

The flow chart assists in orderly handling each map sheet according to a fixed, complete, process.

8. FUTURE REMOTE SENSING POSSIBILITIES FOR FORESTRY

There exists a considerable potential for remote sensing research and application in forestry and forestry research in Southern Africa. Several project proposals have been submitted and are being evaluated.

8.1 PRESENT LANDSAT MSS DATA

8.1.1 During 1984 a project proposal was submitted for investigations into stress detection with conventional black and white and colour photography to detect stresses in the plantations of the southern Cape. These conventional products will be supplemented with LANDSAT MSS products.

8.1.2 It is foreseen that digital elevation data be incorporated in future research based on LANDSAT MSS data to improve the usefulness of LANDSAT products in mountainous areas. Richards *et al.* (1982) showed an increase in accuracy from 68 to 81 per cent. The products derived from LANDSAT 5 are of an improved quality. This will be beneficial to LANDSAT uses by government and private forestry companies e.g. for determining the extent of a burnt area.

8.2 LANDSAT THEMATIC MAPPER (TM)

At the time of writing TM data have been collected for at least 125 scenes over South Africa and are available from NOAA in the USA. A catalogue is being kept by the Hartebeesthoek SRSC. Only a few scenes cover afforested regions.

Hoffer *et al.* (1982) evaluated TM data for forest cover. With the standard per-point Gaussian Maximum Likelihood classifier (as also used at SRSC) 30 m TM data had a lower average classification performance than 80 m MSS data. Using an alternative classifier (called SECHO), however, higher classification performances were obtained. It appears that classifiers with a higher degree of sophistication are needed for efficient use of the 30 m, 7 channel, TM data. Should TM data be available at SRSC by direct reception, the software will most probably be upgraded to process such data.

8.3 SPOT DATA

The first French high-resolution spacecraft (SPOT-1) designed for the remote sensing of the earth's land masses was launched in 1985. The Hartebeesthoek SRSC is involved in the support of this program. The SPOT satellite has some useful capabilities, i.e. to achieve high surface resolutions of 10 and 20 m without reducing radiometric quality; the possibility of selecting either the panchromatic mode (at 10 m resolutions) or the multispectral mode (at 20 m resolutions) and the possibility of selecting instrument viewing angles anywhere within the range 27° W to 27° E to the orbital plane (PEPS, 1984). The latter capability makes repeat coverage for a number of dates of a specific area as well as stereoscopic viewing possible.

Studies by Guyon *et al.* (1983) and Torres (1983) on simulated SPOT imagery indicate that even more useful satellite imagery may be obtained from this source. Guyon *et al.* (1983) stated: 'the resolution of SPOT images would even appear sufficient for the detection and location of important phenomena occurring within forestry compartments: mortality, thinning cuts, selective cuts ... variable regeneration ...', while Torres (1983) concluded that 'SPOT is destined to become an effective tool for the systematic monitoring of forest health'.

Due to lack of staff, funds and time no forestry project has been proposed in the first round of invitations to submit projects to the SPOT organizers and sponsors. It is advisable, however, to consider a SPOT-orientated project at a next opportunity.

8.4   SIDE-LOOKING AIRBORNE RADAR (SLAR)

Side-looking airborne radar was first developed for military purposes in the early 1950's. It has since developed in non-military applications in terrain reconnaissance surveys, especially in areas which are notorious for their persistent cloud cover. Such areas are usually afforested, so that it has been applied in forest vegetation mapping, differentiation between dry and wet land with delineation in the dry land of physiographic features such as drainage and topography (Smit, 1978).

SLAR data for southern Africa was acquired during the second mission of the Space Shuttle in November 1981. A 50 km wide swath passed from Maputo in a southwesterly direction over the Orange Free State, as far as Calvinia in Cape Province (Lamb, 1983). Copies were obtained by the CSIR from NASA and a portion was allocated for forestry interpretation (i.e. the Swaziland/southern Transvaal area). A paper was recently published (Lamb, Mönnig and Van der Zel, 1986). Radar satellites launched in future may be increasingly useful for forestry. A second Shuttle flight was undertaken more recently.

8.5   DAEDALUS AIRBORNE THEMATIC MAPPER

A private company, Hunting Geology and Geophysics Ltd, has purchased an 11 channel digital multispectral scanner. The spectral bands are those used by the LANDSAT 4 TM, the LANDSAT 3 MSS and the SPOT system as shown in the next table. Overseas the Airborne Thematic Mapper (ATM) has already found many applications in agriculture, crop monitoring, terrain analysis, environmental studies and forestry. During October 1984 the company introduced the system into South Africa for possible applications in many disciplines. No application in forestry has been undertaken during this trial period yet, although an Eastern Transvaal test is being considered.

Comparison of Daedalus with Satellites' spectral bands

Daedalus spectral bands	Wavelength	Landsat 4 TM bands	Landsat MSS bands	SPOT bands
1	0,42 – 0,45			
2	0,45 – 0,52	1		
3	0,52 – 0,60	2	4	1
4	0,605 – 0,625			
5	0,63 – 0,69	3	5	2
6	0,695 – 0,75		6	
7	0,76 – 0,90	4		3
8	0,91 – 1,05		7	
9	1,55 – 1,75	5		
10	2,08 – 2,35	7		
11	8,50 – 13,00	6		

In a comparison with LANDSAT data (Hunting, 1983) the improved results obtained from their ATM system was clearly demonstrated. Participation by the larger forestry firms, linked to mining firms, is obviously advantageous for further developments of this type of information in the forestry sector.

9. CONCLUSIONS

A 1:250 000 forest map with four vegetation classes has been produced for southern Africa in a collection of 31 standard maps. On the three experimental sheets (Barberton, Pilgrim's Rest and Richards Bay, the latter now replaced by the Oudtshoorn 3322 sheet) the one–class-forestry-green 1:250 000 topocadastral maps have been replaced by the three or four classes-forests classification, as shown on the enclosed maps. For all these sheets the primary goal of the project has been achieved.

It remains uncertain whether or not the specified accuracy of an error not exceeding 10 per cent has been met. The total area occupied by plantations below 25 ha is unknown. Furthermore, it can be assumed that between 10 and 25 per cent of the farm area has not been afforested and is occupied by roads, river beds, rock outcrops, farmyards, etc. There are also uncertainties with regard to the exact area under indigenous forests. In consequence, the land area covered by trees can not be assessed error-free. A discrepancy between the area estimated from the LANDSAT-based forest map and the existing maps will inevitably represent two error sources, which at this stage can not be separated.

The first and second secondary goals, namely to demonstrate that satellite imagery is a useful tool for the inventory of forest resources and to produce a macro basis for a National Forest Inventory, were achieved.

10. PUBLICATIONS

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BOYLE, T.P., MöNNIG, N.H. and VAN DER ZEL, D.W. 1988. (in press) A Forest Map of Southern Africa with the aid of LANDSAT Imagery. Submitted to *S. Afr. J. of Photogrammetry, Remote Sensing and Cartography*, Mowbray (based on paper read at EDIS '87).

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MöNNIG, N.H. 1984. Forest economic map of Southern Africa. Appendix to Commercial timber resources and roundwood processing in South Africa 1985/86 Report, Departement of Environment Affairs, Pretoria.

VAN DER ZEL, D.W. 1985. Present and future applications of satellite remote sensing in the forestry sector, *S. Afr. For. J.* 132: 46-49, March 1985.

11. RECOMMENDATIONS

11.1 To the Forestry Branch, Department of Environment Affairs

(a) Make the availability of the map set actively known in southern Africa by using it in extension, information, planning, training, management and research work.

(b) Include the portfolio of maps in the revised Forestry Guide Plan for Southern Africa.

(c) Accept the permanent involvement of research staff in order to maintain and extend the remote sensing expertise, improve on the first set of maps, monitor changes to the present set of maps and follow it up in 5 years' time with a second set, and extend the expertise to other applications in forestry as shown below. Such a speciality section should be provided with computer-based

support through an image processing system, graphics possibilities and possibility of linkage with other systems. Needed research projects are –

(i) digital terrain model of the forest areas;

(ii) a fire monitoring system based on satellite data;

(iii) a vegetation monitoring system using remote sensing data;

(iv) a forestry crop profile for the calendar year, for the four classes of the map;

(v) a greenness/brightness transfer for forestry;

(vi) an investigation into the applications of Side Looking Aperture Radar (SLAR) in forestry;

(vii) Research into forestry inventory problems involving remote sensing.

(d) Encourage the Chief Directorate of Surveys and Mapping, Department of Public Works and Land Affairs, to –

(i) use the four-class-forestry-green maps to be regularly provided to them by the Forestry Branch, on all future 1:250 000 topocadastral maps; and

(ii) regularly update their map sets by the information collected and supplied by the Forestry Branch.

11.2 TO THE FOUNDATION FOR RESEARCH DEVELOPMENT OF THE CSIR

Continue to support forestry-related remote sensing research and development projects.

11.3 TO THE PERMANENT PLANNING AND THE RESEARCH COMMITTEES OF THE FORESTRY COUNCIL

(a) Provide financial support for the future updating of this first set of maps on a regular basis.

(b) Provide financial support for research and development based on remote sensing, involving aircraft, satellite or other platforms (including infrared, thermal and radar scanning methods or products).

11.4 TO THE DEAN, FACULTY OF FORESTRY, UNIVERSITY OF STELLENBOSCH

(a) Continue to maintain remote sensing as part of the forest mensuration course and extend or update it regularly.

(b) Consider the inclusion of a regular short course in remote sensing e.g. such as at the University of Cape Town for postgraduate course training and, in this way, evolve a remote sensing course with forestry applications.

(c) Participate in remote sensing research in Southern Africa.

12. ACKNOWLEDGEMENTS

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Appendices
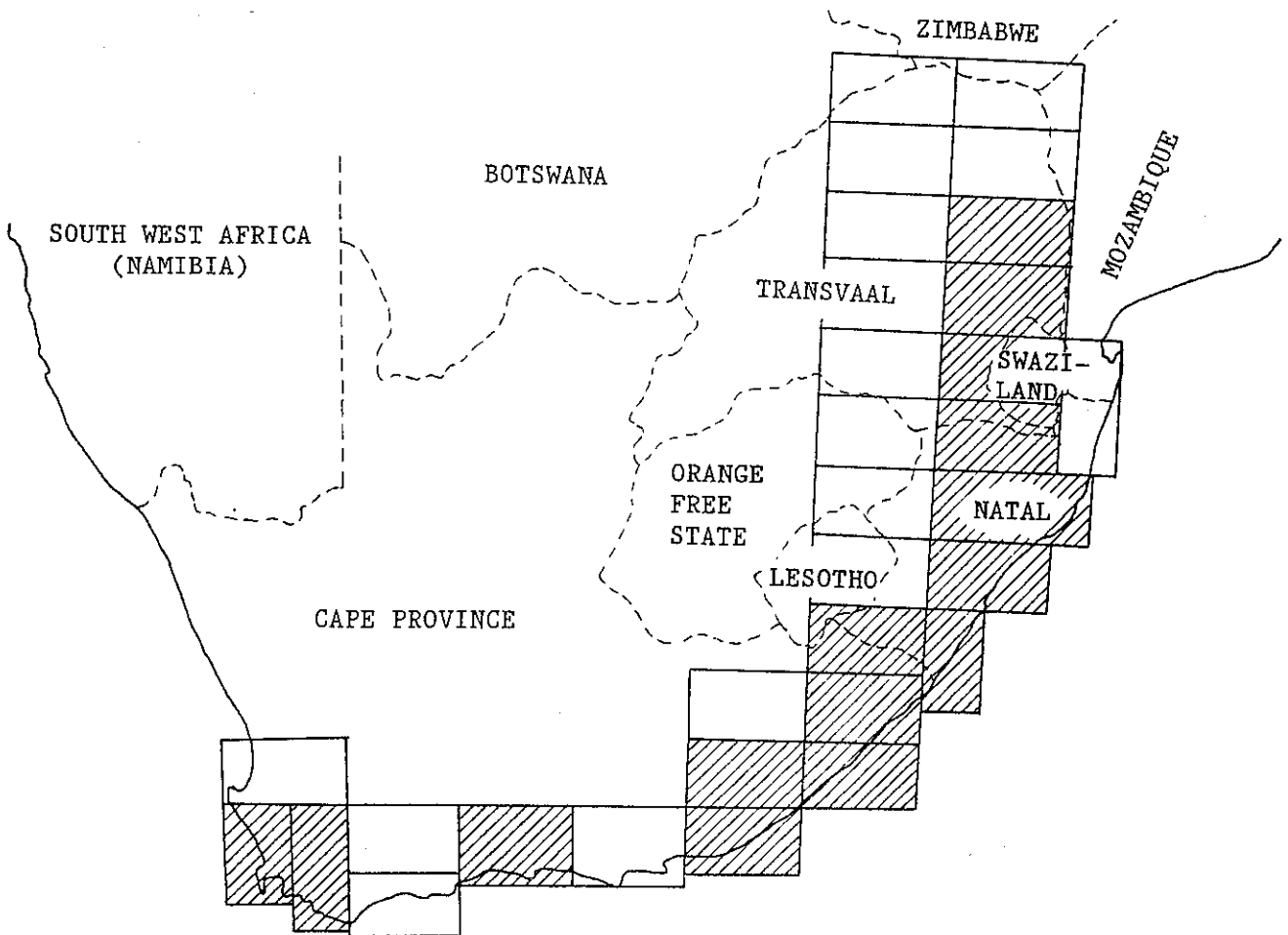
APPENDIX 3: MAP SHOWING THE COVERAGE OF THE 1 : 250 000 FORESTRY MAP SHEETS.

THE SHADED RECTANGLES INDICATE MAP SHEETS WHICH REQUIRED COMPUTER CLASSIFICATION.

APPENDIX 4

A summary of the LANDSAT system in general, and of LANDSAT 1, 2 and 3 in particular, is provided in the table below (taken from Short, 1982) while the data following this table (on LANDSAT 4 and 5) was taken from pages 158, 160 and 164 of NOAA (1984).

THE LANDSAT SYSTEM

. Coverage of nearly the entire land surface and selected ocean areas of the Earth
. Spacecraft altitude: 917 km (570 nautical miles)
. 14 revolutions/day; repetitive 18-day cycle; multiseasonal
. Sun-synchronous near polar orbit; fixed time (c. 9:30 a.m. local Sun time at Equator) of pass over imaged scene
. 185 km x 185 km (115 statute mile x 115 statute mile) ground scene in each image; orthographic; standard image scale in 9-in format: 1:1 000 000
. Stereo sidelap viewing: 85 per cent near polar to 14 per cent equatorial
. Effective ground resolution of image: 79 m (260 ft); 0,45 hectare or 1,1 acre
. Sensor systems:

*Multispectral Scanner (MSS)   *Return Beam Vidicon (RBV)
 Band 4: 0,5-0,6 microns (green)   Band 1: 0,48-0,57 microns (green)
  5: 0,6-0,7 microns (red)   2: 0,58-0,68 microns (red)
  6: 0,7-0,8 microns (near IR)   3: 0,69-0,83 microns (IR)
  7: 0,8-1,1 microns (near IR)

. Onboard digitization of data
. Principal data products:
 *Black-and-white and colour prints and transparencies
 *Computer-compatible tapes (CCT's); 7 and 9 track; 800 and 1 600 bits per inch (bpi)
 *Computer-processed data bases:
 - Statistical evaluation of radiometric parameters
 - Density-sliced images or printouts
 - Contrast-stretched images
 - Edge-enhanced (band pass filtered) images
 - Band ratio images or printouts
 - Classification (thematic) printouts or images ("maps")

LANDSAT-1 launched on July 23, 1972 and ceased operation on January 6, 1978;

LANDSAT-2 launched on January 22, 1975, stopped on January 22, 1980 but resumed operation on May 27, 1980;

LANDSAT-3 launched on March 5, 1978, MSS turned off on December 17, 1980, reactivated April 13, 1981

LANDSAT-4 ORBIT

LANDSAT provides near global coverage from its position in near polar orbit. LANDSAT, like the other polar satellites, is sun-synchronous, but in addition has its orbit adjusted periodically to maintain fixed orbital paths. There are 233 fixed orbital paths spaced equally around the Earth. Each path is covered once in 16 days.

ORBIT CHARACTERISTICS

Orbit Type: Near polar, sun-synchronous
Orbit Period: 98,9 minutes
Altitude (circular): 706 km (438 mi.)
Orbit Time (Equator Crossing): 9:45 a.m. local
Longitudinal Separation of Adjacent Orbits: 811 km (503 mi.) 24,7° longitude
Sensor Cross Track Scans at the Equator: 185 km (115 mi.)

LANDSAT INSTRUMENTS

The Multispectral Scanner (MSS) is the operational sensor on land satellites. It has been the primary Earth-observing instrument on these spacecraft for 11 years.

The Thematic Mapper (TM) is a new R & D sensor on LANDSAT-4 and 5. It is operational, but so far only a limited number of images are available over southern Africa.

TM INSTRUMENT

The TM scans the Earth across the satellite path providing 185 km images. There are 100 detectors (16 for each of six reflective bands and four for one emissive band). The reflective bands measure light in the visible or near infrared. Each picture element (pixel) is 30 metres by 30 metres. The emissive band measures temperature in the thermal infrared where each pixel is 120 metres by 120 metres. Both reflective and emissive bands are quantized to 256 levels.

APPENDIX 5

AD HOC FOREST MAPPING PANEL

MEMBERSHIP LIST

AT PRESENT

Mr T.P. Boyle, Satellite Applications Centre, Division of
    Microelectronics and Communications Technology, CSIR
Mr K. Cooper, Wildlife Society of Southern Africa
Mr D.B. Mackenzie, Forestry Council (Forest Owners' Association)
Mr N.H. Mönnig, Forestry Branch, Department of Environment Affairs
Mr D.L. Owen, Forestry Branch, Department of Environment Affairs
Mr C.H. Snyman, Aerial Agricultural Services
Dr D.W. van der Zel, Forestry Branch, Department of Environment Affairs
Prof. A. van Laar, Faculty of Forestry, University of Stellenbosch
Mr N.O. Wessels, Forestry Branch, Department of Environment Affairs
Mr P.M. Stratten, Forestry Council (Research co-ordinator)
Dr C.W. Louw, Foundation for Research Development, CSIR

PAST MEMBERS

Dr H.C. Laurens, Forestry Council (HL & H Timber Products)
Mr P.J. van der Westhuizen, South African Scientific Liaison Office –
    Paris, CSIR

APPENDIX 6: FAC 3 Work calendar for the Forest Mapping Project

A. WORK CALENDAR FOR COMPUTER CLASSIFIED MAPS

Sheet name and number	WRS 4,5	Ground control points	Surface reference data	Training areas	Classification	Draft map/ statistics	Verification	Selection of evaluators	Clearance
Pilgrim's Rest 2430	169-77	8.8.80 8.9.80	31.8.80 31.10.80	1.12.80 1.2.81	1.2.81 1.6.84	1.8.81 1.7.85 1.2.82	1.3.82 1.1.84	1.9.82 1.2.86	1.11.85 7.3.86
Barberton 2530	169-77 169-78 168-78	1.9.81 1.11.81	1.12.81 1.3.82	1.4.82 1.1.83	1.8.82 1.6.83	1.12.82 1.12.83	1.4.83 1.4.84	1.6.83 1.12.84	1.12.83 10.5.85
Richards Bay 2830	167-80 168-80	1.6.83 1.8.84	1.12.83 1.1.84	1.3.84 1.3.84	31.6.84 13.9.85 27.7.84	31.10.84 13.9.85 13.1.86	18.9.85 27.1.86	6.9.85 1.3.86	1.1.86 ---
Mbabane 2630	169-78 169-79 168-79	1.10.83 1.10.83	1.1.84 1.1.84	1.4.84 1.6.84	1.8.84 1.9.84	31.12.84	1.8.85	1.10.85	1.1.86
Vryheid 2730	168-79	1.12.83 1.12.83	1.3.84 1.2.84	1.6.84 1.8.84	1.10.85	1.12.85	1.1.86	1.2.86	1.3.86
Durban 2930	168-80 168-81	1.1.85 1.3.85	4.10.85	16.10.85	22.10.85	22.11.85	29.11.85	22.10.85	1.2.86
Port Shepstone 3030	168-81 168-82	1.2.85 1.4.85	4.10.85	16.10.85	22.10.85	22.11.85	29.11.85	22.10.85	1.2.86
Cape Town 3318	175-83 175-84 175-83	1.4.85 1.5.85	31.1.86 1.12.85	15.5.86 5.12.85	22.5.86 11.12.85	31.5.86 27.1.86	6.6.86	22.5.86	1.8.86

B. WORK CALENDAR FOR MANUALLY CLASSIFIED MAPS

Sheet name and number	WRS 4,5	1st round information gathering	2nd round information gathering	3rd round information gathering	Draft map and statistics	Verification	Clearance
Messina 2230	169-76	1.1.83	1.4.83	1.1.84	31.10.84	1.2.85	1.8.85
		11.1.83	1.6.83	1.3.84	31.11.84	1.2.85	----
Alldays 2228	170-76	1.1.83	1.4.83	1.1.84	31.10.84	1.2.85	11.8.85
		12.1.83	15.6.83	1.3.84	31.11.84	1.2.85	----
Pietersburg 2328	169-76 169-77 170-76 170-77	1.6.83	1.12.83	31.03.84	31.10.84	1.2.85	21.8.85
		1.9.83	1.6.84	1.7.84	31.12.84	1.2.85	----
Tzaneen 2330	169-77 169-76	1.4.83	1.8.83	1.12.83	31.10.84	1.2.85	28.8.85
		1.8.83	1.11.83	1.6.84	31.11.84	1.2.85	----
Nylstroom 2428	169-77 170-77	1.5.83	1.7.83	1.10.83	31.10.84	1.2.85	3.9.85
		1.5.83	1.7.83	1.1.84	31.12.84	1.2.85	----
Pretoria 2528	170-77 169-77 170-78 169-78	1.7.83	1.9.83	1.12.83	30.11.84	1.4.85	1.8.85
		1.7.83	1.10.83	11.2.84	1.3.85	1.6.85	----
East Rand 2628	170-78 169-78 170-79 169-79	1.8.83	1.11.83	1.4.84	30.11.84	1.3.85	15.9.85
		1.10.83	1.1.84	1.6.84	1.1.85	1.3.85	----
Frankfort 2728	170-79 169-69	1.9.83	1.12.83	1.8.84	30.11.84	1.3.85	15.9.85
		1.11.83	1.3.84	1.10.84	1.1.85	1.4.85	----
Mkuze 2632	167-79	1.10.83	1.11.84	1.4.84	15.12.84	1.4.85	15.9.85
		1.12.83	1.5.84	1.8.84	15.2.85	1.6.85	----
Harrismith 2828	169-80	1.11.83	1.3.84	1.6.84	30.11.84	1.4.85	15.9.85
		1.1.84	1.3.84	1.8.84	1.1.85	1.7.85	----
Drakensberg 2928	169-80 169-81	1.12.83	1.4.84	1.7.84	30.11.84	1.3.85	15.9.85
		1.2.84	1.3.84	1.9.84	1.1.85	1.5.85	----

B. WORK CALENDAR FOR MANUALLY CLASSIFIED MAPS (Continued)

Sheet name and number	WRS 4,5	1st round information gathering	2nd round information gathering	3rd round information gathering	Draft map and statistics	Verification	Clearance
Kokstad 3028	168-81 169-81	14.2.85	18.5.85	22.10.85	15.12.85	31.12.85	1.3.86
	169-82	14.2.85	18.5.85				
Umtata 3128	169-82 169-83 168-82	5.8.85	23.8.85	13.9.85	4.10.85	9.10.85	1.6.86
Kei Mouth 3228	169-82 169-83	5.8.85	23.8.85	13.9.85	4.10.85	9.10.85	1.6.86
Queenstown 3126 King Williams's Town 3226 Grahamstown 3326	169-83 170-82 170-83	11.11.85	25.11.85	10.1.86	24.1.86	31.1.86	1.6.86
Port Elizabeth 3324	170-83 171-83	7.7.84	12.7.84	30.9.84	30.11.85	31.12.85	
	171-84 172-83	7.7.84	12.7.84	30.9.84	1.11.85	7.11.85	
Ladismith 3320	173-84 174-84	9.12.84	7.2.86	25.5.86	25.6.86	6.8.86	1.10.86
Riversdale 3420	175-84 175-85	9.12.84	2.10.85	23.1.86	27.1.86	27.2.86	
Oudtshoorn 3322	172-83 173-83	30.6.84	31.7.84	31.3.85	31.8.85	31.12.85	1.4.86
	172-84 173-84	30.6.84	31.7.84	31.3.85	31.7.85	23.8.85	
Worcester 3319	175-83 175-84	9.12.84	7.2.86	22.5.86	25.6.86	6.6.86	22.7.86
		9.12.84	2.10.85	23.1.86	27.1.86	27.2.86	
Clan William 3218	175-82 175-83	9.12.84	7.2.86	22.5.86	25.6.86	6.6.86	1.7.86
		9.12.84	2.10.85	23.1.86	27.1.86	27.2.86	

APPENDIX 7

FOREST MAPPING PANEL: FLOW CHART FOR EACH INDIVIDUAL MAP SHEET
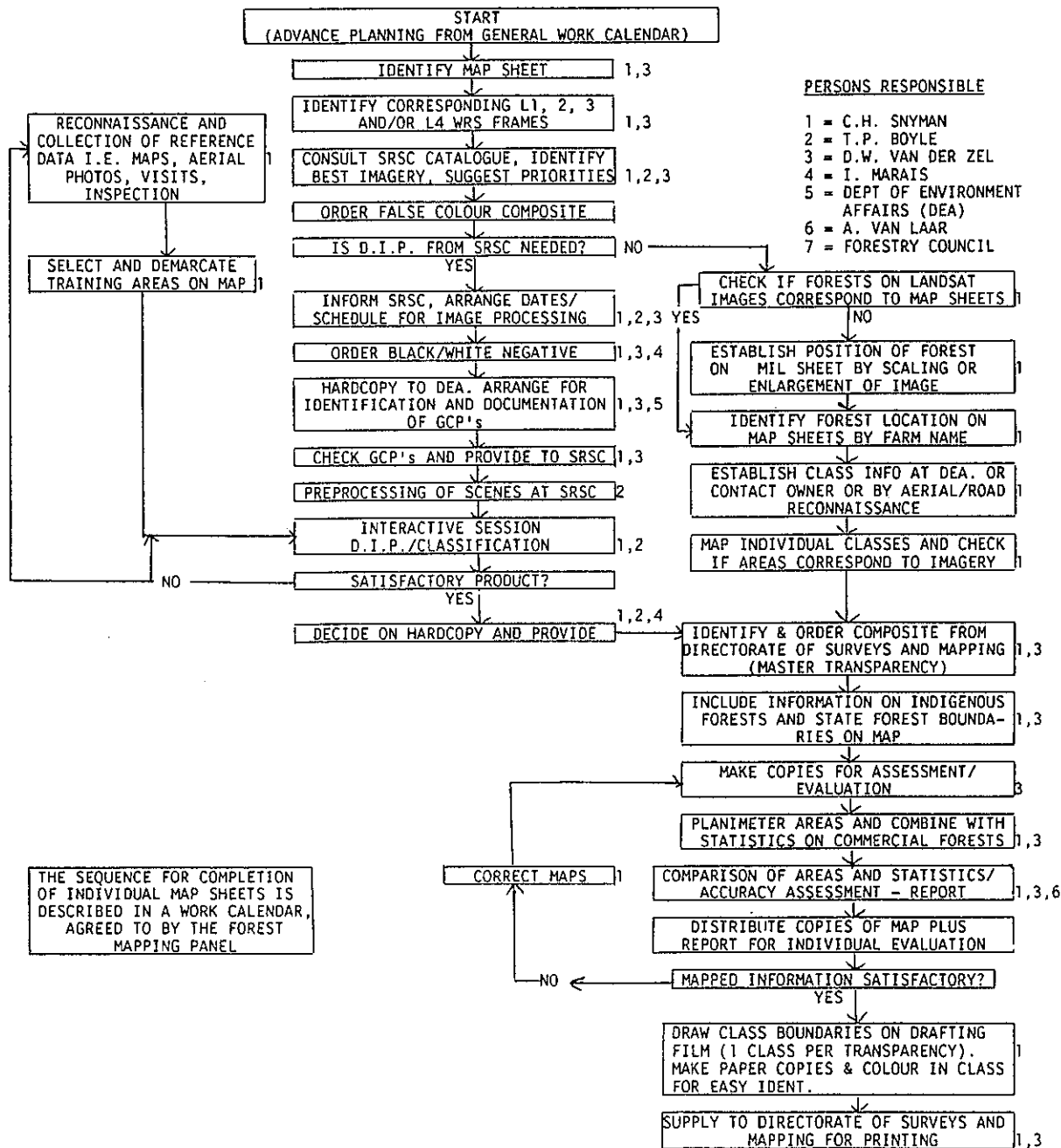
```
                        ┌─────────────────────────────────────────┐
                        │              START                      │
                        │ (ADVANCE PLANNING FROM GENERAL WORK CALENDAR) │
                        └─────────────────────────────────────────┘
                                       ↓
                        ┌──────────────────────────────┐
                        │      IDENTIFY MAP SHEET       │ 1,3
                        └──────────────────────────────┘
                                       ↓
┌──────────────────────────┐   ┌──────────────────────────────┐      PERSONS RESPONSIBLE
│ RECONNAISSANCE AND       │   │ IDENTIFY CORRESPONDING L1, 2, 3│ 1,3
│ COLLECTION OF REFERENCE  │   │    AND/OR L4 WRS FRAMES        │      1 = C.H. SNYMAN
│ DATA I.E. MAPS, AERIAL   │ 1 └──────────────────────────────┘      2 = T.P. BOYLE
│ PHOTOS, VISITS,          │   ┌──────────────────────────────┐      3 = D.W. VAN DER ZEL
│ INSPECTION               │   │ CONSULT SRSC CATALOGUE, IDENTIFY│      4 = I. MARAIS
└──────────────────────────┘   │ BEST IMAGERY, SUGGEST PRIORITIES│ 1,2,3  5 = DEPT OF ENVIRONMENT
                               └──────────────────────────────┘           AFFAIRS (DEA)
                               ┌──────────────────────────────┐      6 = A. VAN LAAR
                               │ ORDER FALSE COLOUR COMPOSITE  │      7 = FORESTRY COUNCIL
                               └──────────────────────────────┘
┌──────────────────────────┐   ┌──────────────────────────────┐
│ SELECT AND DEMARCATE     │   │ IS D.I.P. FROM SRSC NEEDED?   │ NO ─────────┐
│ TRAINING AREAS ON MAP    │1  └──────────────────────────────┘             │
└──────────────────────────┘          YES                        ┌──────────────────────────────┐
                               ┌──────────────────────────────┐   │ CHECK IF FORESTS ON LANDSAT  │
                               │ INFORM SRSC, ARRANGE DATES/   │   │ IMAGES CORRESPOND TO MAP SHEETS│ 1
                               │ SCHEDULE FOR IMAGE PROCESSING │ 1,2,3 YES      NO
                               └──────────────────────────────┘   ┌──────────────────────────────┐
                               ┌──────────────────────────────┐   │ ESTABLISH POSITION OF FOREST │
                               │ ORDER BLACK/WHITE NEGATIVE    │ 1,3,4 │ ON  MIL SHEET BY SCALING OR │ 1
                               └──────────────────────────────┘   │ ENLARGEMENT OF IMAGE         │
                               ┌──────────────────────────────┐   └──────────────────────────────┘
                               │ HARDCOPY TO DEA. ARRANGE FOR  │   ┌──────────────────────────────┐
                               │ IDENTIFICATION AND DOCUMENTATION│ 1,3,5 │ IDENTIFY FOREST LOCATION ON │ 1
                               │ OF GCP's                      │   │ MAP SHEETS BY FARM NAME      │
                               └──────────────────────────────┘   └──────────────────────────────┘
                               ┌──────────────────────────────┐   ┌──────────────────────────────┐
                               │ CHECK GCP's AND PROVIDE TO SRSC│ 1,3 │ ESTABLISH CLASS INFO AT DEA. OR│
                               └──────────────────────────────┘   │ CONTACT OWNER OR BY AERIAL/ROAD│ 1
                               ┌──────────────────────────────┐   │ RECONNAISSANCE               │
                               │ PREPROCESSING OF SCENES AT SRSC│ 2 └──────────────────────────────┘
                               └──────────────────────────────┘   ┌──────────────────────────────┐
                               ┌──────────────────────────────┐   │ MAP INDIVIDUAL CLASSES AND CHECK│
                               │ INTERACTIVE SESSION           │   │ IF AREAS CORRESPOND TO IMAGERY│ 1
                               │ D.I.P./CLASSIFICATION         │ 1,2 └──────────────────────────────┘
                               └──────────────────────────────┘
                NO ──────      ┌──────────────────────────────┐
                               │ SATISFACTORY PRODUCT?         │
                               └──────────────────────────────┘
                                      YES
                                           1,2,4
┌──────────────────────────────────────┐   ┌──────────────────────────────┐
│ DECIDE ON HARDCOPY AND PROVIDE       │   │ IDENTIFY & ORDER COMPOSITE FROM│
└──────────────────────────────────────┘   │ DIRECTORATE OF SURVEYS AND MAPPING│ 1,3
                                            │ (MASTER TRANSPARENCY)        │
                                            └──────────────────────────────┘
                                            ┌──────────────────────────────┐
                                            │ INCLUDE INFORMATION ON INDIGENOUS│
                                            │ FORESTS AND STATE FOREST BOUNDA-│ 1,3
                                            │ RIES ON MAP                  │
                                            └──────────────────────────────┘
                                            ┌──────────────────────────────┐
                                            │ MAKE COPIES FOR ASSESSMENT/  │
                                            │ EVALUATION                   │ 3
                                            └──────────────────────────────┘
                                            ┌──────────────────────────────┐
                                            │ PLANIMETER AREAS AND COMBINE WITH│
                                            │ STATISTICS ON COMMERCIAL FORESTS│ 1,3
┌──────────────────────────────┐           └──────────────────────────────┘
│ THE SEQUENCE FOR COMPLETION  │  ┌─────────────┐ ┌──────────────────────────────┐
│ OF INDIVIDUAL MAP SHEETS IS  │  │ CORRECT MAPS│1│ COMPARISON OF AREAS AND STATISTICS/│
│ DESCRIBED IN A WORK CALENDAR,│  └─────────────┘ │ ACCURACY ASSESSMENT - REPORT  │ 1,3,6
│ AGREED TO BY THE FOREST      │           └──────────────────────────────┘
│ MAPPING PANEL                │           ┌──────────────────────────────┐
└──────────────────────────────┘           │ DISTRIBUTE COPIES OF MAP PLUS │
                                            │ REPORT FOR INDIVIDUAL EVALUATION│
                                            └──────────────────────────────┘
                                ─NO ←       ┌──────────────────────────────┐
                                            │ MAPPED INFORMATION SATISFACTORY?│
                                            └──────────────────────────────┘
                                                  YES
                                            ┌──────────────────────────────┐
                                            │ DRAW CLASS BOUNDARIES ON DRAFTING│
                                            │ FILM (1 CLASS PER TRANSPARENCY).│ 1
                                            │ MAKE PAPER COPIES & COLOUR IN CLASS│
                                            │ FOR EASY IDENT.              │
                                            └──────────────────────────────┘
                                            ┌──────────────────────────────┐
                                            │ SUPPLY TO DIRECTORATE OF SURVEYS AND│
                                            │ MAPPING FOR PRINTING          │ 1,3
                                            └──────────────────────────────┘
```

APPENDIX 8

INVENTORY OF SURFACE REFERENCE DATA

A.   AVAILABLE AND STORED WITH DEPARTMENT OF ENVIRONMENT AFFAIRS

E.T.T.C. - BARBERTON SHEET
MONDI - (VICTORIA'S POORT) - BARBERTON EN MBABANE
SAPPI (MOOIPLAATS) - RICHARDS BAY
SAPPI (HODGSONS ESTATE) - DURBAN
SAPPI (SHAFTON) - DURBAN
SAPPI (MOSSBANK) - DRAKENSBERG
SAPPI (CLAIRMONT) - DRAKENSBERG
SAPPI (GOWAN BRAY) - DURBAN
SALIQUE (LEBOWA) - PILGRIM'S REST
MARIEPSKOP (LEBOWA) - PILGRIM'S REST
HEBRON (LEBOWA) - PILGRIM'S REST
ONVERWACHT (LEBOWA) - PILGRIM'S REST
PEAK TIMBER - MBABANE
KWAZULU GOVT - MANZENGWENYA - MKUZE
KWAZULU GOVT - MTUNZINI - RICHARDS BAY
KWAZULU GOVT - SOKULU - RICHARDS BAY
KANGWANE GOVT - BLAIRMORE - MBABANE
KANGWANE GOVT - REDHILL - MBABANE
ALL STATE FORESTS (DEA) MAPS

B. **MAPS USED BY AERIAL AGRICULTURAL SERVICES, BARBERTON AND WHERE APPLICABLE NOW ALSO STORED AT DEPARTMENT OF ENVIRONMENT AFFAIRS, PRETORIA**

BARBERTON MAP SHEET

SAPPI - ELANDSHOOGTE - MAPS (RETURNED)
HL+H - DEKAAP PLANTATION - MAP AND ORTHOPHOTO
SHANNON SAWMILLS - MAPS - (RETURNED)
MONDI - MAPS - (RETURNED)
PEAK TIMBERS - MAPS - (RETURNED)

PILGRIM'S REST MAP SHEET

MONDI - (BORROWED MAPS AND RETURNED)

TZANEEN MAP SHEET

WESTFALIA - MAPS - (RETURNED)
LOTZABA - MAPS - (RETURNED) AND AERIAL PHOTOS (RETURNED)

MBABANE MAP SHEET

LOTZABA - MAPS AND PHOTOS - (RETURNED)
HL+H - MAPS - (RETURNED)
SAPPI - MAPS - (RETURNED)
SAWGU AERIAL PHOTOS - (RETURNED)

VRYHEID MAP SHEET

HL+H - MAPS AND AERIAL PHOTOS (RETURNED)
TRANSVAAL WATTLE GROWERS - MAPS (RETURNED)
SWAGU AERIAL PHOTOS - (RETURNED)

RICHARDS BAY MAP SHEET

SALIGNA FORESTRY - MAPS - (RETURNED)

Explanatory memoranda on experimental map sheets

PART 1:   THE 2530 BARBERTON SHEET

1.   BACKGROUND

The 2530 Barberton sheet, an area of 22 550 km², is probably the area with the oldest and largest afforested area. The plantation statistics (Department of Environment Affairs, 1984) show an area, estimated from adding parts of magisterial districts, of 260 714 hectares, which is 11,56 per cent of the total area. The area stretches from Graskop in the north to Jessievale in the south, and from Belfast in the west to Komatipoort in the east. It includes parts of Moçambique, Swaziland, KaNgwane and the Kruger National Park but is mainly known as the Eastern Transvaal. A total of 16 forest stations, 48 lookout towers and 45 timber processing plants are shown on the map.

A large number of land owners, a balanced mix of small and big forestry companies as well as a number of State Forests are present. A large pulpmill and a large number of other timber processing installations and sawmills are situated in this area. The Krokodil River Catchment takes up about 70 per cent of the 2530 Barberton sheet. The railway line from Pretoria to Maputo harbour bisects the sheet from west to east.

2.   PARTICULAR PROBLEMS EXPERIENCED

2.1   Registration

As the Forestry Mapping Project was the first user of LANDSAT 1, 2 and 3 images 180-78, 180-77, and 181-77, it was also our task to register the LANDSAT information with the map information by means of the procedure stated in paragraph 6.1.2 of the base report. Our team members, therefore, had to find the Ground Control Points, describe them in terms of height above sea level, longitude and latitude and help in the registration process e.g. supply 1:50 000 maps with GCPs marked etc. Per map sheet this process took initially from a week to a fortnight. It was improved to a minimum of three days at Hartebeesthoek for subsequent sheets. Correct registration is very important as it is used to establish permanent computer information on the relevant image.

2.2   Shadow

In both the feasibility and in the pilot study the shadow problem was pointed out. It must be acknowledged here that not enough attention has been given by our forestry project team to solve or even partially solve this problem. Especially in this first map, with the preponderance of mountainous areas and escarpments, these areas were simply allocated as a separate class, without efforts to consider an elevation map together

with a LANDSAT map or to map elevation, with regard to LANDSAT's sun angle, or to consider the influence of slope angle, orientation and terrain shadowing on spectral signature at all. These must be the main factors influencing the accuracy of LANDSAT maps in forestry's mountainous terrain, again especially in this first attempt here. In a next attempt much more attention should be given to this problem. On this sheet the problem was partly overcome by means of a large number of field visits and airplane flights.

2.3   Class differentiation

Problems are encountered where so-called 'dark' pine, 'medium' pine and 'bright' pine is intermingled with wattle, gums in shadow and even other non-forestry crops when comparing spectral bands. Age, slope angle, orientation, spacing, growth stress and many other factors, as yet undetermined for this map sheet, are the causes for different spectral signatures.   In the first effort it caused less reliance on LANDSAT and more reliance on map information of plantation owners in the region. This was not the original intention of the project. It points towards the need for better quantification of data, better co-ordination of dates of signatures (map sheet, photos, LANDSAT) and a measure of spectral signature, e.g. a forestry calendar for the year, in order to surmount or understand the differences.

2.4   Uni- and multitemporal comparison

In the pilot study (Caithness and Snyman, 1983) it was highlighted that unitemporal classification of forestry classes in mountainous areas was inadequate and gave a poor classification. On this particular scene a multitemporal classification (superimposing two or more LANDSAT dates into one classification e.g. winter and summer scenes) was tried for test areas on the sheet, where it proved to be successful. However, numerous problems were encountered in extending the classifications for test areas to complete LANDSAT scenes. The result, after more than 6 months of trying, was that the unitemporal classification of the pilot study was accepted as the superior classification. Further improvement based on field work was based on this unitemporal classification. On subsequent map sheets multitemporal classifications were successfully used.

2.5   Three-class map

It must be pointed out that in this first sheet the class wattle plantation does not occur because no commercial wattle plantation of more than 25 hectares exists.

Some wattle thickets or jungle wattle areas do exist, but have been disregarded for purposes of this study.

3. ACCURACY ASSESSMENT

Several exercises have been carried out to put into perspective the afforested or forested areas on the experimental sheet.

3.1 Computer comparison of LANDSAT imagery

Messrs Boyle and Snyman carried out a comparison of two single Estates (De Kaap of Lotzaba Forest, and Nelshoogte of the Department of Environment Affairs) on the computer at the SRSC by zooming in on multitemporal classifications and comparing these, gridwise, to existing plantation maps.

The results were:

Area	Computer classification of LANDSAT imagery	Areas from present maps
DE KAAP Total area	4 522 ha	4 521 ha
Eucalypts	3 778 ha	3 273 ha
NELSHOOGTE Total area	14 209 ha	14 178 ha
Eucalypts	716 ha	686 ha
Pines	6 984 ha	7 391 ha
Open areas	5 772 ha	5 953 ha

3.2 Comparison of cadastral and afforested areas

It is well known that, although the complete farm area may be shown as being afforested, this is an impossible feat, due to the fact that roads, open fire belts, living areas, houses, grazing camps, unplanted strips along streams and rocky areas take up a considerable area, usually up to 25 per cent of a particular farm.

Some comparisons of the cadastral and actual afforested areas were assembled by Messrs Snyman and Van der Zel (as on 1.4.1983):

(a)   Some private estates

	A Cadastral	B Afforested	% $\frac{B}{A}$
Klipkraal (Mondi)	1 678,9	1 253	74,6
London (Mondi)	2 962,2	1 721	58,1
Waterhoutboom (Mondi)	2 405,0	1 825	75,9
Elandshoogte (SAPPI)	21 163,7	15 119	71,4

(b)   Southern Transvaal Government Plantations

	A Cadastral	B Afforested	% B/A
Swartfontein	5 282,9	3 235,4	61,2
Witklip	5 265,9	3 042,3	57,8
Berlin	14 325,6	8 764,6	61,2
Belfast	4 452,9	2 127,8	47,8
Lisabon	2 322,3	1 437,7	61,9
Uitsoek	9 728,3	4 688,1	48,2
Nelshoogte	14 145,7	8 557,1	60,5

(d)   Eastern Transvaal Government Plantations

	A Cadastral	B Afforested	% B/A
Brooklands	6 010,3	5 327,8	88,6
Ceylon	9 261,7	3 784,7	40,9
Long Tom	4 161,7	1 989,6	47,8
Rosehaugh	6 857,7	4 519,2	65,9
Rietfontein	2 911,3	1 684,3	57,9
Spitzkop	4 676,7	3 620,0	77,4
Tweefontein	6 088,9	4 012,4	65,9
Witwater	3 024,0	2 171,8	65,7

Any map of a scale of above 1:50 000 can therefore not be used to planimeter exact afforested areas from previous and present maps, as the previous or existing ones, are and were never designed for this purpose.

3.3   Statistical comparison

Statistical comparison between the standard one-green class on the topocadastral map and the experimental map was carried out by Prof. A. van Laar, Faculty of Forestry, Stellenbosch, using transect sampling. The results are:

        Sample 1
                map: 17,3%
        satellite map: 18,9%
           discrepancy: 1,2% = 6,9% of map area

        Sample 2
                map: 17,2%
        satellite map: 19,6%
           discrepancy: 2,4% = 14,0% of map area
                  mean: (6,9 + 14,0)/2 = 10,4%

This discrepancy is partly due to recent new afforestation.

A complete planimetering exercise by Mr N.H. Mönnig at the Department of Environment Affairs resulted in the following comparison:

```
present map:    288 375 ha
satellite map:  pine plantations    253 888 ha
                gum plantations      93 575 ha
                indigenous forests    4 313 ha
                                     _____
                                     351 776 ha
```

When the actual afforested area mentioned in paragraph 1 (background) is taken as a percentage, this results in 75,0 per cent. This agrees with the average figure accepted as afforestable on the average farm in the Afforestation Permit System.

4. LIST OF EVALUATORS

Forestry Branch: The Regional Director
Department of Environment Affairs   Private Bag X503
                                              1260 SABIE

                                              The Regional Director
                                              Private Bag 11201
                                              1200 NELSPRUIT

Uitkyk Plantations (Pty) Limited   Mr J. Rae
                                             Brook House
                                             17 Fricker Road
                                             2196 ILLOVO

Sappi Forests (Pty) Ltd   Mr R.W. Scott
                                             P.O. Box 1011
                                             1200 NELSPRUIT

Mondi Timber   Mr D.J. Lundie
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Lotzaba Forests Limited   Mr G.P.L. du Plessis
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                                             1300 BARBERTON

Twello Forestry (Pty) Ltd   Mr H. de Villiers
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                                             1300 BARBERTON

H.L. & H. Forest Products (Pty) Ltd	Mr N. Erasmus P.O. Box 5906 2000 JOHANNESBURG
Shannon Sawmills	Mr D. Scholtz 1302 P.O. LOUW'S CREEK
H.L. Hall & Sons (Pty) Ltd	Mr H. Mooney 1205 P.O. MARAFFIN
Atherstone & Brooks (Pty) Ltd	Mr N.A. Haw P.O. Box 83 1240 WHITE RIVER
SATGA Extension Officer	Mr A.E. Barnard P.O. Box 962 1200 NELSPRUIT
Sappi Mining Timber	Mr N. Mostert P.O. Box 2702 1200 NELSPRUIT
Taylor & Mitchell Timber Supply Company (Pty) Ltd	Mr A.E.R. Dixon P.O. Box 3731 1451 ALRODE
SATGA Regional Chairman	Mr T.F. Prinsloo P.O. Box 20 1110 DULLSTROOM

PART 2: THE 2430 PILGRIM'S REST SHEET

1.   BACKGROUND

The 2430 Pilgrim's Rest sheet, an area of 22 550 km², lies directly north of the previously discussed Barberton sheet. On the area of these two sheets together 28 per cent of the totally afforested area of South Africa and 65 per cent of the indigenous forests of Transvaal is situated.   On this particular sheet about 44 673 ha of exotic plantations and 15 919 ha of indigenous forests are known to exist, so that 2,7 per cent of this sheet is covered by forests. The area stretches from Houtbosdorp in the Northern Transvaal to the Olifants Rest Camp in the east and Skukuza Rest Camp in the Kruger National Park in the south to Steelpoort in the southwestern corner of the sheet. About 25 per cent of the sheet is taken up by a National Park and several private nature reserves, another 25 per cent is land controlled by Lebowa and Gazankulu National States and the rest is, mostly dry, very mountainous, grazing land.

A total of 13 forest stations, 12 lookout towers and 11 timber processing plants are shown.

2.   PROBLEMS PARTICULAR TO THIS SHEET

2.1   Registration

The remarks made under this heading for the previous, Barberton 2530, map sheet are also applicable here. Much time was spent registering the sheet to the LANDSAT scene, and it still took one week per 1:50 000 map sheet.

2.2   Shadow effects

With forestry occurring above, on and suddenly far below steep escarpments of the Drakensberg the shadow effect on LANDSAT scenes poses a serious detrimental retarding effect in the forestry project, making comparisons unsure and even unreliable.   At this first stage of the forestry project not much attention to solving the particular problem was given.   The shadow areas were put in a separate class and these areas were divided into forestry classes, where applicable, based on existing maps or photographs.

2.3   Class differentiation

Again, three classes were present on this map, as in the previous (Barberton) one.   There was less confusion with other crops like tea

estates, but more confusion between indigenous forests and pine plantations, as well as the difficulty of determining where savanna forest takes over from indigenous forests as the change is mostly gradual. Deep ravines also made delimitation of the indigenous forests extremely difficult. However. a special flight was undertaken by the co-project leader and the member of the *ad hoc* Forestry Panel, Mr Keith Cooper, to specifically address this problem. A large number of photographs were taken to assure credibility of the substantial reduction in indigenous forest in comparison to the present 1:250 000 map. Three large forestry land owners (Lebowa Government, Mondi Timber and Eastern Transvaal Forest Region of the Department of Environment Affairs) between them own at least 39 000 ha (or 88%) of the afforested area and had adequate plantation maps available for correct surface reference data.

2.4   Uni- and multitemporal comparison

The remarks made about uni- and multitemporal classification of forestry classes, made in Part 1: Barberton sheet, are also fully applicable here. The two sheets were more or less attempted together. In the final instance a unitemporal classification was also used for this map sheet, although for the future, it was foreseen that multitemporal classification and interpretation would improve the final product and would, in fact, increase the use and contribution of LANDSAT towards the final forestry classes.

2.5   Four-class map

As with Part 1:   Barberton, this map is basically also a three-class map, although a single 90 ha wattle plantation has also been mapped.

3.   ACCURACY ASSESSMENT

3.1   Comparison between cadastral and afforested areas. Some comparisons between cadastral and afforested areas are as follows:

Name	Planted area (ha)	Cadastral area (ha)	% planted	Averages
Government plantations				
Blyde	4353,7	8522,7	51,1	
Mac Mac	2760,3	5081,1	54,3	
Morgenzon	1796,1	9824,2	18,2	
Wilgeboom	3912,8	4912,5	79,6	
Mariti	3465,2	6160,2	56,2	47,2
Mondi timber plantations				
London	1709,0	2962,0	58,1	
Driekop	3680,0	5327,0	69,1	
Grootfontein	3190,0	4486,0	71,1	
Ramanas	1760,0	2079,0	84,7	
Waterhoutboom	1835,0	2405,0	75,9	
Doornlaagte	1868,0	2239,0	83,0	72,2
				56,2

One of the reasons for the differences between government and privately
planted areas may be that Mondi Timber includes roads in their planted
areas. Another reason is that government land has more than one
obligation, i.e. also protection of scenic areas and mountain
catchments. It also did not originally acquire most of the farms for
purposes of afforestation.

It is, therefore, not advisable to use either the previous or the
present experimental 1:250 000 map sheet to calculate precise afforested
areas.

The annual forestry statistics indicate that the area under softwoods
and hardwoods is in the region of 44 678 ha. Keith Cooper's survey of
indigenous forests resulted in an estimate for indigenous forests on
this map sheet of 15 919 ha. When we planimetered the experimental map
sheet we obtained areas as follows:

Pine plantations: 50 625 ha
Gum plantations: 20 250 ha
Indigenous forests: 20 813 ha
                      _____
                      91 683 ha

The annual statistics represent 48,7 per cent of the planimetered area,
which is comparable to the 56,2 per cent average calculated above.

3.2 Statistical comparisons

Dr A. van Laar of the Faculty of Forestry at the University of Stellenbosch used transect sampling to determine the area under forest. His results are –

> map: 22,7%
> satellite map: 23,05%
> discrepancy: 0,35% = 1,5% of the map area.

When Mr N.H. Mönnig of the Department of Environment Affairs compared the forested area on the present map with the three classes of the experimental map he obtained figures of, respectively, 92 563 ha and 91 683 ha, a "discrepancy" of 1 per cent.

4. LIST OF EVALUATORS

The list of evaluators, agreed upon at a Forest Panel meeting in 1983, is as follows:

Regional Director of Forestry   Private Bag X503
                                             1260 SABIE

Mondi Timber   Mr D.J. Lundie
                                             P.O. Box 69
                                             1260 SABIE

Lebowa Government   Secretary for Agriculture
                                               and Forestry
                                             0745 P.O. CHUNIESPOORT

SAPPI Timber Products   Mr N. Mostert
                                             Box 822
                                             1240 WHITE RIVER

SATGA Extension Officer   Mr A.E. Barnard
                                             Box 962
                                             1200 NELSPRUIT

The *ad hoc* Forestry Panel accepted a recommendation to replace SAPPI Timber Products with SAPPI Forest Products (Mr W.S. Olivier, P.O. Box 1011, Nelspruit 1200) and to add at least H.L. & H Forest Products (Pty) Ltd (Mr N. Erasmus, P.O. Box 5906, Johannesburg 2000).

PART 3: THE 2830 RICHARDS BAY SHEET

1.   BACKGROUND

The present 2830 Richards Bay sheet combines the previous 2830 Dundee
and 2882 St Lucia sheets, making it the largest of all the 1:250 000
topocadastral sheets.

The rectangular area covered by the map stretches from Dannhauser
(NW-corner) to Weenen (SW-corner) and Hluhluwe (NE-corner) to Mtunzini
(SE-corner).

Of interest to forestry, are the mountainous Melmoth area, the
undulating Kranskop and Eshowe areas and the Zululand coastal plain.

Due to the distinct geographic separation of these forestry areas, the
differences in site parameters, the size of the Richards Bay sheet and
the ownership pattern, it was decided to evaluate this sheet in two
stages, using the 30°31' longitude as the division line. Only the sheet
to the east of this line is evaluated for this report.

The Zululand coastal plain has been planted mostly to pine and eucalypt,
with some *Casuarina* planted along the coastline. Most of the pine
plantations are found on State Land while the eucalypts are mostly in
private ownership. Along the coastline indigenous forest is frequently
found in a narrow strip. Indigenous forests also occur along the edge
of Lake St Lucia in the Nyalazi and Dukuduku State plantations.

The Umfolozi River divides the coastal forestry area into two parts.
The northern part is mostly State owned whilst the southern part is
mostly in private ownership.

Apart from forestry, sugar is the only major land use in this area.

2.   PARTICULAR PROBLEMS EXPERIENCED

Apart from State plantation maps, only LANDSAT scenes WRS 179/80 dated
29 October 1981 and WRS 167/80 dated 6 July 1985 were used. The former
of these scenes was precision-corrected and enlarged to a scale of
1:250 000. Much information could be traced from the LANDSAT scene and
copied into the 1:250 000 topocadastral sheet.

Because of the level terrain, no shadow problems were experienced using
LANDSAT.

The indigenous forest information was obtained from Mr K. Cooper of the
Wildlife Society of South Africa. (Cooper, 1985).

The use of all these inputs resulted in the rapid completion of the Zululand Coastal forestry area in the Pretoria office save for a few small areas. These were mapped during a field visit.

Some of the small private plantation owners also farm with sugarcane. This presented problems with mapping the resulting small scattered plantation areas. On LANDSAT a mixture of sugar and forestry causes some confusion.

3. ACCURACY ASSESSMENT

The three classes of the new forestry map were planimetered per magisterial district. The following areas were measured:

	Softwood	Hardwood	Indigenous	Total
Hlabisa	22 312	8 250	5 120	35 682
Lower Umfolozi	6 438	25 250	2 187	33 875
Mtunzini	375	3 125	4 625	8 125 *
TOTAL	29 125	36 625	11 932	77 682 ha

This can be compared to the following timber plantation statistics:

	Softwood	Hardwood	Total
Hlabisa	20 050	7 547	27 597
Lower Umfolozi	6 712	29 755	36 467
Mtunzini	783	3 897	4 680
TOTAL	27 545	41 199	68 744 ha

The indigenous forest areas as determined by Cooper (1985) are:

Hlabisa	4 024 ha
Lower Umfolozi	2 640 ha
Mtunzini	4 344 ha

The present one-class Richards Bay sheet has a total area of 97 078 ha for forests and wooded areas.

---

*These areas do not include the whole of Mtunzini magisterial district.

4.   LIST OF EVALUATORS

Mondi Timber Ltd
P.O. Box 35
3915 KWAMBONAMBI

Waterton Timber Co. Pty Ltd
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3915 KWAMBONAMBI

SAPPI Forests Pty Ltd
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The Secretary for Agriculture and Forestry
KwaZulu Government
Private Bag X05
3838 ULUNDI

The Regional Director
Zululand Forestry Region
Private Bag X506
3815 ESHOWE

PART 4: THE 3322 OUDTSHOORN SHEET

1. BACKGROUND

The Oudtshoorn sheet covers the bulk of the Southern Cape Forestry area along the scenic Garden Route. Both commercial forestry and indigenous forests are confined to the southern slopes of the Outeniqua and Tsitsikamma mountain ranges. Included in the area are the well known Knysna and Tsitsikamma indigenous forests. Hardly any forestry exists on the Riversdale and Ladismith sheets which lie to the west of the Oudtshoorn sheet. To the east, however, (on the Port Elizabeth sheet) the coastal stretch of forestry continues up to the Gamtoos River Mouth.

An estimated 75 per cent of the forestry covered by this map, is owned by the Department of Environment Affairs. This includes most of the indigenous forests.

Commercial forestry is mostly pine, with small scattered areas of gum and even smaller areas of *Acacia melanoxylon*.

2. PARTICULAR PROBLEMS EXPERIENCED

2.1 Obtaining ground truth

Having access to the State Plantation maps, a large portion of the Oudtshoorn sheet was mapped without problems. The Department of Environment Affairs has also accurately mapped all the indigenous forests on its property as well as a couple of large tracts of indigenous forest in private ownership.

Aerial photography with job number 837/80 obtained from the Surveyor General, Pretoria, was used to map the remaining areas. The black and white infrared aerial photography on a scale of 1:30 000 was most useful as differences between forestry classes became very clear.

The forestry information was confirmed by consulting the plantation statistical returns as well as using maps provided with applications for afforestation permits. LANDSAT scenes WRS 172-NS dated 19 December 1983 and WRS 173-NS dated 31 March 1984 were also used as confirmation. Strangely enough, hardly any shadow problems were encountered.

2.2 Other problems

The commercial plantations and indigenous forests are reasonably intermingled which led to problems in deciding where the boundaries of indigenous forests should be. With the naked eye no distinction can be made between plantations and indigenous forests on the LANDSAT scenes.

3.   ACCURACY ASSESSMENT

As most of the forestry on the Oudtshoorn sheet was mapped from accurate
plantation and indigenous forest maps, accuracy assessment consists of a
comparison between the forestry information of the one-class green on
the original 3322 Oudtshoorn sheet and the new four-class forestry map.

The original one-class green totalled 131 935 ha while the planimetered
four forestry classes are:

Indigenous forests	51 000 ha
Pine plantations	73 563 ha
Gum plantations	3 375 ha
Acacia plantations	500 ha
	128 438 ha

Figures on a magisterial district basis, obtained from the 1983/84
edition of "Commercial Timber Resources and Roundwood Processing in
South Africa", are as follows:

Magisterial district	Softwoods (pine)	Hardwoods (gum and *Acacia*)
Mossel Bay	2 564	61
George	18 255	987
Knysna*	31 402	3 309
Humansdorp (60%)**	10 597	1 025
TOTAL	62 405	5 381

* Areas of the Uniondale and Joubertina magisterial districts are
included under Knysna.

** Approximately 60 per cent of the forestry area in the Humansdorp
magisterial district is located on the Oudtshoorn sheet.

Planimetered areas are as follows:

Magisterial district	pines	gums	*Acacia*	Indigenous
Mossel Bay	3 016	–	–	510
George	22 804	658	55	3 060
Knysna*	34 575	2 045	385	35 700
Humansdorp	13 168	672	60	11 730
TOTAL	73 563	3 375	500	51 000

* Areas of the Uniondale and Joubertina magisterial districts are
included under Knysna.

4.   LIST OF EVALUATORS

The four-class forestry map has been sent to the following persons for evaluation:

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Southern Cape Forest Region
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KNYSNA

The Regional Director
Tsitsikamma Forest Region
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KNYSNA

Searles Limited
P.O. Box 1
GREAT BRAK RIVER

Urbans Industries (Pty) Ltd
P.O. Box 18
GEORGE

Geo. Parkes & Sons (Pty) Ltd
P.O. Box 12
KNYSNA

George Municipality
P.O. Box 19
GEORGE

Saasveld Forest Research Station
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GEORGE

Van Rheenen P.J. (Pty) Ltd
P.O. RHEENENDAL

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112 *The SANCOR Marine Pollution Research Programme 1986-1990. October 1985. 16 pp.

113 Alien and translocated aquatic animals in southern Africa: a general introduction, checklist and bibliography. M N Bruton and S V Merron. October 1985. 59 pp.

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117 South African Red Data Book: Plants - fynbos and karoo biomes. A V Hall and H A Veldhuis. 1985. 144 pp.

118 Invasive alien plants in the terrestrial ecosystems of Natal, South Africa. I A W Macdonald and M L Jarman (editors). 1985. 88 pp.

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