THE MAPPING OF STANDS OF PARANA PINE (ARAUCARIA ANGUSTIFOLIA (BERT.) O. KTZE) IN THE FOREST OF SOUTH-WEST PARANA STATE (BRAZIL) USING COMPUTER-AIDED ANALYSIS OF LANDSAT MSS DATA

by

ATTILIO ANTONIO DISPERATI

Thesis submitted for the Degree of Doctor of
Philosophy in the University of London
Geography Department
Bedford College
1981

Abstract

This study examines the value of Landsat data for mapping stands of Parana Pine (Araucaria angustifolia (Bert.) O. Ktze) in the natural forests of southern Parana State, Brazil. This species is economically the most important forest tree in southern Brazil and estimation of its reserves and the rate of exploitation are important.

Two forest areas were selected for detailed studies. For one area (Quedas do Iguacu) Landsat data in both computer compatible tape (CCT) and transparency format was used. No aerial photographs were available but an existing forest map was used as ground truth. For the second area (Mangueirinha) Landsat CCTs and aerial photographs were available. From the latter a forest cover type map was produced and used as ground truth. Additionally some field checking was undertaken.

For the Quedas do Iguacu area visual qualitative temporal analyses were carried out on the products generated from transparencies of six different Landsat scenes. On these Parana Pine stands could be recognized in the MSS bands 6 and 7 and in colour composites generated from the MSS bands 4, 5 and 7. For a selected subarea a supervised computer classification using CCT data was tested successfully for mapping both mature Parana Pine stands and reforestation areas. A supervised classification using transparencies of MSS bands 5 and 7 that were scanned and digitized by microdensitometer successfully mapped Parana Pine stands but failed to discriminate reforestation areas.

For the Mangueirinha area CCTs of Landsat imagery acquired in spring and in winter were used for mapping Parana Pine stands. Both visual and computer classification methods were employed. For the latter, a small area of Parana Pine stands with two different crown

densities (as ascertained from study of aerial photographs) was selected. Different combinations of MSS bands were tested using supervised and unsupervised classifications. The results showed that using a supervised classification combinations of MSS bands 5 and 7 were most effective, but that only dense stands of Parana Pine could be mapped accurately. The spring imagery yielded better discrimination than that acquired in winter.

ACKNOWLEDGMENTS

I wish to express thanks to my supervisor, Professor Monica M. Cole, for the attention dedicated during the realization of this thesis and also for her useful comments about the manuscript.

I would like to thank The Federal University of Parana for the support during the time of my research and The British Council for the scholarship (ref: BRA/2305/715/TF2).

The field study was possible due to support from the Conselho Nacional de Pesquisas (CNPp) (Proc. 40.2232/79). Also I am grateful to the Fundacao de Pesquisas Florestais of The Federal University of Parana, in the name of Professor Joesio D. P. Siqueira, for the support for the execution of the field study. Acknowledgement is also extended to Mr. Rene Antonio Novaes at the Instituto de Pesquisas Espaciais (INPE), who provided me with access to the General Electric Image 100.

I offer my appreciation to Mr. Dave Waddell (former computer programming adviser at the Bedford College Computer Unit) for help with computing. Acknowledgement also is given to Dr. Roger F. Smith and to the postgraduates Helen Thomas and David Edminston for the review and correction of parts of this manuscript. I would like to extend thanks to all the other friends at the Geography Department who helped in various ways.

I would like to express my thanks and deep appreciation to Mr. Maurice A. Keech, at the National College of Agricultural Engineering at Silsoe, for his encouragement about the mapping of Parana Pine stands.

Finally, I give special thanks to my wife for the encouragement and patience during the time of my research and for help with the cartographic work.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This thesis examines the feasibility of using Landsat satellite remote sensing data for mapping Parana Pine stands in the natural forest of the south west of Parana State (Brazil).

Parana Pine (*Araucaria angustifolia*) is one of the most important trees of the Araucaria forest, which is a special association of the wet tropical forest. Araucaria forest occurs in several countries of South America, but the largest area is located in the states of Parana, Santa Catarina and Rio Grande do Sul in the southern region of Brazil.

In the mature and old age natural forest the Parana Pine is the most common and dominant species. It usually forms the main part of the stands. The Parana Pine trees have a comparatively well-developed crown. Other important species in the highest canopies of the forest include, as for example, *Apuleia biocarpa (Vog.) Macbr.* ("grapia"), *Patagonula americana L.* ("guajuvira"), *Parapiptadenia rigida (Benth) Brenan.* ("angico"), *Peltophorum dubium (Spr.) Taub.* ("canafistula") and *Myrocarpus frondosus Fr. Allem.* ("cabreuva"). "Grapia" and "angico" have some tendency to constitute stands. None of these species, however, have such crown canopy characteristics and is as easily distinguished as Parana Pine.

The development of forest industries in the last few decades in the south of Brazil has depended mainly on the large quantity of Parana Pine in the natural forest. The exploitation of this species has resulted in the installation of sawmills and other wood-using industries in the region (Siqueira, 1977). Parana Pine is economically important because the timber is of good quality and a large proportion of the trunk may be used. The wood is used for furniture, house construction and paper making.

Widespread timber cutting and the indiscriminate use of forest fire for the development of new agricultural areas has resulted in serious devastation of the Araucaria forest. The original area of Araucaria forest in Parana State of 73,780 km^2 was reduced to 3,166 km^2 by 1977, most of the area being second growth Araucaria forest (Machado and Siqueira, 1979).

Periodic surveys are essential for the orderly development of the remaining Araucaria forest resources. The results of such surveys provide a basis for the development of policies and for decision making. As one example of this, the results of the 1966 forest inventory of Parana Pine in the south-west of Parana State, were the bench-mark for the development of policies to activate the (re)forestation and for legislation regarding the exploitation of Araucaria forest.

The use of remote sensing techniques may assist in providing the information required for development of forest policies and for decision making. Avery (1967) has pointed out that forest cover type maps are no longer essential to all foresters, but at times their cost may be justified. In addition, many topics in silviculture, forest management and even in forest inventory there is no need of forest cover type maps at all. Perhaps, a map showing principal roads, streams and forest cover types may be desired for management and illustrative purposes. The management map is primarily a means of orientation and of planning, executing and recording forest operations. Also up-to-date forest maps may be desired as a result of cutting operations, damage, regeneration and growth of the forest.

The elaboration of forest maps is usually accomplished by selecting an appropriate classification scheme, interpreting the imagery through the defined scheme, and field work in order to eliminate the possible misinterpretation and/or to acquire more detailed information that was not possible from the imagery. The remote sensing imagery is used to complement, improve or reduce field work rather than take its place. Thus, a desirable classification procedure is one which maximizes the use of imagery and minimizes the amount of field work in a manner that meets survey objectives (Thorley, 1975).

A great variety of remote sensing imagery may be applied to forestry and especially to forest cover type mapping. At least three symposia sponsored by the International Union of Forest Research Organization (IUFRO) have dealt exclusively with remote sensing in forestry (see Hildebrandt, 1971, 1973, 1976).

According to the elevation of the platform (remote sensor) during the time of acquiring information, the output may be broadly classified as aerial or space imagery. Within the aerial imagery section, aerial photographs have been most frequently used to produce forest cover type maps. Since early this century, foresters have routinely acquired aerial photographs and practised photogrammetry and photo-interpretation (Lauer, 1971). Aerial photographs have been used for classifying and stratifying forests throughout the world, except in parts of Europe where the availability of very accurate forest maps, based on field survey and accurate forest cadastral sheets, makes the advantages of aerial photographs less obvious (Loetsch and Haller, 1964).

The mapping of Parana Pine stands in the natural forest in Brazil has been carried out using different types of aerial photographs at a variety of scales. Forest maps have been produced for forest surveys from the interpretation of the following types of aerial photographs: panchromatic black and white, infra-red black and white and colour infra-red. The range of the scales of the photographs has been from 1:10,000 to 1:70,000. No example has yet been reported using true colour aerial photographs, but high success in the photo-interpretation of Parana Pine can be expected with this image (Disperati et al, 1979). Using small scale aerial photographs photographic tone and texture are the main diagnostic features for the photo-identification of Parana Pine stands. Perhaps, with medium and large scale photographs the main diagnostic features are the crown shape and photographic tone for the identification of individual Parana Pine in the forest context.

The manned spacecraft as used in the Mercury, Gemini and Apollo missions and Skylab demonstrated the potential value and advantages of acquiring orbital and space images. It appears that with the advent of automated imaging systems, such as meteorological satellites and Landsat, manned spacecraft are no longer essential for acquiring orbital images (Sabins,1978). According to Heller (1975), the greatest benefits to forest investigations from the low detection space imagery is for: planning, detecting changes and stratifying forest land from other types of land use. Since the first ERTS (now Landsat) was launched on 23 July 1972 many research projects have been carried out to investigate and to evaluate its real potential for forestry purposes and research continues into more efficient methods for analysis and interpretation of the imagery.

An important potential of Landsat imagery, mainly for very large and developing countries, is a primary source of information for reconnaissance forest maps (1:250,000 to 1:1,000,000 scales). For such maps Landsat imagery can provide information more quickly and at lower cost than traditional methods. Landsat imagery has thus been used successfully in Thailand (Klankansorn, 1976), in the Phillipines (Dietrich and Lachwski, 1977) and in Brazil (Nosseir et al, 1975; Superintendencia do Desenvolvimento da Região Sul, 1978). Landsat imagery has also been used in more detailed mapping of coniferous and deciduous forest, as for example, in U.S.A. (Aggers and Kelley, 1976; Tueller, 1975; Hoffer and staff, 1976), in France and Italy (Commission of the European Communities, 1978).

The Brazilian Institute of Forest Development (IBDF) is responsible for the Brazilian forest policy planning and development. Landsat images have been widely used in new projects carried out by IBDF, as for example, for the detection, analysis and control of all changes occurring in the Brazilian Amazon forest cover. Also, it has been used for the multidisciplinary surveys of all Brazilian national parks (Carneiro, 1980).

In spite of the broad synoptic coverage of each scene and repetitive coverage, the main limitation of Landsat imagery for forest mapping is its small spatial resolution, i.e. the 56 x 79 m pixels dimension.

Many methods may be used to interpret Landsat images, but the most accurate are the digital ones. The principal advantages of digital processing methods are their versatility, repeatability and the preservation of the original data precision.

The basic aim of this thesis is to evaluate the mapping of Parana Pine stands in the forest in south-west of Parana State, using computer-aided analysis of Landsat images. Concurrently, with the computer-aided analysis, visual interpretation was carried out in the output of MSS Landsat bands from computer compatible tapes (CCTs) and from transparencies. Field checking was also carried out as an integral part of the mapping scheme.

Hoffer (1976, p. 104) wrote:

> Basically, there are two conditions, which must be met by each class involved in an analysis of multispectral scanners data using computer-aided analysis techniques:
>
> a) the class must be spectrally separable from all the other classes,
>
> b) the class must be of interest to the user or have informational value.
>
> In working with multispectral scanner data, one often finds that the class of interest to the user cannot be spectrally separated at certain times of the year. Quite often, different species of green vegetation have very similar spectral characteristics, even though their morphologic characteristics may be quite different.

The second Hoffer condition may be gauged from the following quotation:

> Of all trees in the forest, Parana Pine is the most important because it is the basis of the timber economy of Parana State, and is the most common timber tree in all the forest of the south and south-west of the state ... In 1970 the exploitation of forest products was in second place in terms of contribution to the GNP of the state. (Centro de Pesquisas Florestais, 1974, p. 67, translated from Portuguese.)

The silhouette of the Parana Pine is the official symbol of Parana State and in any advertisement about the State it will be present. Although, due to the high rate of devastation of the forest, Parana State can no longer be considered an active timber exporting state. Perhaps the exploitation of the forest continues to contribute to the economy of the state.

Examination of the first of Hoffer's conditions is the main purpose of the thesis. Some preliminary work carried out by the author in the Forest School in Curitiba, Brazil, and the use of Landsat images in the forest inventory of Parana Pine in south of Brazil (Instituto Brasileiro do Desenvolvimento Florestal, 1978; Keech et al, 1978; Gantzel, 1979) gave a strong indication that Landsat imagery would be useful for the mapping of the Parana Pine stands, but no classificatory programs were attempted.

Complementary to the basic aim of the thesis are investigations of:

a) the best combinations of bands of Landsat imagery for the mapping of Parana Pine stands,

b) the degree of accuracy obtainable using classificatory programs (supervised and unsupervised).

In order to carry out the research, two areas in the south-west of Parana State, both supporting wet tropical and Araucaria forests, were selected. For convenience, they were designated Quedas do Iguaçú and Mangueirinha. The first area was selected because it contains a large area of unexploited forest. The Mangueirinha area was selected because black and white aerial photographs at a scale of 1:10,000 for 1972 and a forest inventory carried out in the area in 1973 was available.

For the Quedas do Iguaçú area, visual analysis was carried out in individual MSS Landsat bands and in colour composites for six Landsat scenes. The main purpose was to determine the best season for the mapping of Parana Pine stands. Later, a test site of 221 x 191 pixels was selected for supervised computer-classification in order to map Parana Pine stands and reforestation areas. For the same test site digital data from microdensitometer scanning of two Landsat scenes in transparency format was computer classified.

For the Mangueirinha area, which covers an area of 302 x 400 pixels on the Landsat imagery, two Landsat scenes in CCT format were available for the mapping of Parana Pine stands. A visual interpretation was carried out on the images of MSS bands 5 and 7 and on the colour composites in order to evaluate the usefulness of the images for mapping the stands. Later, a test site of 71 x 100 pixels was selected in order to map two different crown densities of Parana Pine stands. The results from supervised and unsupervised programs were compared using data from just one scene.

SECTION A : LANDSAT IMAGERY

CHAPTER 2

BASIC CONSIDERATIONS ABOUT THE LANDSAT PROGRAM

2.1 Introduction

National Aeronautics and Space Administration (NASA) has launched three unmanned satellites. The first was originally named ERTS 1, but was subsequently renamed Landsat 1 and the following two named Landsat 2 and 3. The fourth satellite of the Landsat series is planned to be launched in 1981.

The basic aim of the Landsat program is to acquire continuous multispectral imagery in order to evaluate the natural resources of the Earth.

Landsat 1 was launched on July 23, 1972 and officially retired on January 6, 1978. Less than 72 hours after it had been launched, images of the earth's surface were acquired (Colwell, 1975).

Landsat 1 was placed in near-polar orbit, with an inclination to the Equator of $99{,}008^{o}$, circling the Earth from north to south every 103 minutes (i.e. 14 times per day) and in orbital altitude of approximately 910 km. The sun synchronous orbit pattern was chosen to acquire midmorning imagery at intermediate sun angles. Each complete frame of imagery covers more than 33,000 km^2 (Palestino, 1976).

Landsat 2, identical to Landsat 1, was launched on January 21, 1975 and is still in operation.

The third satellite was launched on March 5, 1978 and was equipped with an additional sensor: a thermal infrared scanner (sensing in the range of 10.4 - 12.6 micrometers) with the capability of sensing temperatures from $-13^{o}C$ to $67^{o}C$, with a temperature resolution of 1.5°C and ground resolution cell of 238 m.

2.2 System of Data Collection

The Landsat satellites carry two types of sensor: MSS (multispectral scanning system)and three vidicon cameras (RBV - Return Beam Vidicon). As well as these main sensors it has: Wide Band Tape Record and Data Collection System. Brief considerations about each of them will be given. An extensive and comprehensive explanation about the sensors carried on board Landsat was given by NASA (1976).

2.2.1 Multispectral Scanning System (MSS)

The Landsat 1 and 2 MSS is a line scanning device that uses an oscillating mirror to continously scan perpendicular to the spacecraft direction. It acquires four different images for each terrain scene, each of them in a different spectral band (Table 1).

Table 1. Landsat MSS Band relationship

Band	Wavelength (μm)
4 (blue)	0.5 - 0.6
5 (green)	0.6 - 0.7
6 (near infrared)	0.7 - 0.8
7 (infrared)	0.8 - 1.1

The radiance reflected from the terrain and scanned by the mirror, is directly through an optical-mechanical device to 24 detectors (6 for each band), which transform the energy sensed into an electrical video signal. These signals are sampled, encoded and formatted into a continuous data stream, which is transmitted to a ground receiving station.

On Landsat 3, the MSS was modified to include a fifth spectral band operating in the thermal infrared region. But, on July 11, 1978, due to a failure on one of the two channels of the thermal band, it was turned off.

2.2.2 Return Beam Vidicon (RBV)

On Landsat 1 and 2, the two inch (50.8 mm) Return Beam Vidicon (RBV) multispectral subsystem operates by shuttering three independent cameras simultaneously, each sensing a different spectral band in the range of 0.48 to 0.83 micrometers.

These three cameras are identical electronically. The ground scene viewed is 185 x 185 km in area (Miller et al, 1972).

Only a few images were acquired from Landsat 1 because of the failure of an external on-off switch (Sabins, 1978).

On Landsat 3, the RBV camera system is considerably different. Two panchromatic cameras are used (each with the same broad-band spectral response of 505 to 705 nanometers) to produce two side-by-side images rather than three overlapping images of the same scene. Each of the side-by-side images report a terrain scene of approximately 98 x 98 km in area and four RBV coincide approximately with one MSS frame.

2.2.3 Wide Band Video Tape Records

The RBV and MSS can operate over the same terrain during daylight hours.

When Landsat is within radio range of one of the Earth ground receiving stations, the image data are transmitted at real time to the station. When this is not happening, the image data may be recorded for posterior transmission, on two wide band video tape recorders, each with a recording capacity of 30 minutes.

One of the two tape recorders on Landsat 1 failed early in the mission and the other operated for 500 hours. Landsat 2 no longer has functional video tape recorders and is therefore being used in real time (NASA, 1980b).

The following countries have active ground receiving stations: Argentina, Australia, Brazil, Canada, Italy, Japan, Sweden and the United States. Additional stations are proposed in China, Chile and Thailand (NASA, 1980c).

2.2.4 Data Collection Systems

Data Collection Systems can obtain data from platforms and these data to ground receiving stations only when the Landsat spacecraft can mutually view any platform, and one of the ground stations. These platforms, equipped by specific investigators, automatically collect data about local environmental conditions.

2.3 Output Data Products

The original MSS and RBV data output are available in two different forms: photographic and digital. The photographic products are produced in black and white (positive and negative transparencies and in paper print) and in colour (positive transparencies and paper print). The digital data are available only in the form of 9 track computer compatible tape (CCT).

Although used less frequently than MSS and RBV, the Data Collection Systems output products are available in any of three forms: digital, punched cards and computer listings.

2.4 Advantages and Disadvantages of MSS images

The main advantages and disadvantages of MSS images can be summarized as follows:

a) Advantages:

- broad synoptic coverage of each scene,
- repetitive coverage, i.e. theoretically every nine days, Landsat acquires images of the same place, nearly at the same time,
- images are available for most places of the world with no political or security restrictions,
- images at four different bands of the spectrum,
- image distortion is negligible,
- images are available in digital format suitable for computer processing,
- low price of acquisition.

b) Disadvantages:

- small ground resolution of each picture element (pixel), that is 79 x 79 m in area,
- the photointerpreter does not interpret images, but differences in levels of gray, in black and white images, or differences in colour and hues in colour composites,
- limited stereo coverage is available.

CHAPTER 3

ANALYSIS AND INTERPRETATION OF THE MSS LANDSAT IMAGES

MSS Landsat images can be purchased from one of the specific active ground receiving stations (see p. 31), either in photographic or in digital form. Basically, photographic* products are analysed through visual interpretation while digital products through computer-aided techniques.

3.1 Interpretation of photographic products

Manual and visual interpretation of MSS Landsat photographic products can be carried out, individually for each one of the four bands or for colour composites, using several bands. This may be achieved at two different levels: rapid recognition and skilled interpretation. Rapid recognition or self-explanatory information can be done by anyone who has an appreciation of scale, maps and regional geography. The skilled interpretation is discipline-orientated and is often carried out by a specialist or team of specialists (Gregory, 1973).

Band 4, the green band, emphasizes movement of sediment-laden water and delineates shallow water. Band 5, the red band, emphasizes cultural features (as metropolitan areas, roads, etc.) and delineates

---

* Data from photographic products can also be analysed through computer-aided techniques, since its image has been digitized, usually with microdensitometer.

the boundaries of forest and vegetation. Band 6, the near infra-red, emphasizes vegetation, rivers and the boundary between land and water. Band 7, the infra red band, provides the best penetration of atmospheric haze and also emphasizes vegetation, the boundary between land and water, and landforms (Watkins, 1978).

Regardless of how it is produced, a standard colour composite has the spectral characteristics of an infra-red photograph and is superior to the black and white individual bands for most applications (Sabins, 1978). The typical colour signature of a standard colour composite is as follows: red for vegetation, blue or light green for water, white for snow and clouds, blue or yellow, depending on its nature, for bare soil.

Basically, the manual and visual interpretation of Landsat MSS photographic products is carried out using one or more of the following non-stereoscopic viewing instruments: monocular magnifiers, light-tables and optical and electronic enhancement systems.

Monocular magnifiers and light tables are the cheapest of the above instruments, the former have lenses of various powers set into convenient frames and the latter are designated for the unmagnified direct viewing of positive and negative transparencies.

> Optical colour combining equipment, ranges in complexity from standard manual slide projectors to specialized additive viewers, made specifically for viewing of colour composites. The equipment utilizes black and white or multiband imagery and functions by using additive colour theory. The advantages of this system are: ease of operation, uniform brightness and high resolution. Its major advantage is that it is difficult to achieve interface with computers for further interpretative data manipulation. (Estes and Simonett, 1975, pp. 899-900.)

The electronic enhancement systems are usually an integral part of electronic image processing equipment. Their major advantages are: high versatility and computer compatibility; their disadvantages are: lower resolution and much greater operating cost.

3.2 Interpretation of digital products

Each MSS Landsat scene covers a ground area of 185 x 185 km and is made up to 7.5 million digital pixels per spectral band. Because the data are acquired in digital form, a digital computer can be used to handle what would otherwise be an unmanageable amount of information.

MSS Landsat digital data products are available in the form of computer compatible tapes (CCTs). An entire scene or just a subscene of the CCT can be computer-aided processed.

Basically, two techniques have been developed and used for computer-aided analysis of the data: enhancement and classification. Both techniques have been widely used for forest type mapping.

3.2.1 Enhancement techniques

In some cases, visual study of original Landsat images may be disappointing because of a low contrast between objects present on the image or of inherence recording defects (Fontanel et al, 1975). This is the reason behind the various processing routines (numerical techniques) that have been used to enhance Landsat data: contrast stretching, density slicing, spatial and directional filtering, simulated normal colour images, principal components analysis, ratioing. Contrast enhancement and density slicing have been the most used processing techniques and both are applied individually for each black and white band, in order to emphasize subtle gray level variations.

Contrast stretching creates a new black and white image by expanding (or contracting) the maximum and minimum gray tones in the defined area over nearly the full (or predetermined) black and white dynamic range of the display. Contrast stretching can also be applied to Landsat transparency (Harris, 1973; Best and Smith, 1978), although digital methods are more satisfactory than photographic techniques because of the precision and wide variety of digital processing.

Density slicing converts the continuous gray tone of an image into a series of different intervals, or slices, each corresponding to a specific digital range. Each digital slice may be displayed into a separate colour or gray tone or line printer symbol.

3.2.2 Classification Techniques

Classification is the process in which a set of rules is used to assign each ground resolution element to one of several classes by machine or human methods. The classification method requires the use of selected characteristics (Lawrence and Herzog, 1975). In the particular case of human interpretation, the common characteristics used for the classification are: tone or colour, texture, pattern and shape. These characteristics are used to identify similar regions or classes. Whereas, for computer classification of Landsat data, the main characteristic is the magnitude of the four spectral bands.

The main advantages of the computer classification over human classification are: the computer classification produces a map automatically and rapidly yields the area occupied by each class, eliminates repetitious judgement and increases the detail of the classification and the performance is carried out in a short space of time. Otherwise, the main disadvantage of the computer classification is that the class (that is to be mapped) has to be sufficiently homogeneous, in order to produce results within reasonable bounds of accuracy.

The fundamental assumption for Landsat computer-aided classification is: two seasonally identical areas on the earth will produce the same spectral signature and contrasting regions will have different spectral signatures. Thus, classification techniques can be successfully applied in fields of agriculture, land use and forestry. An example of this, is that for two reforestation areas, with approximately the same characteristics in species, date of plantation, distance between the trees, forest management, etc., their spectral reflectance will be nearly the same.

> In the field of geology, classification techniques, in general have not been so successful. This is primarily due to the inhomogeneity of geologic units, presence of gradational boundaries, confusion influence of both vegetative cover and soil mantling and similarity of the spectral signatures of different lithologies. (Siegal and Abrams, 1976, p. 326.)

These problems are absent or not so pronounced in some remote sensing studies in land use, agriculture and forestry.

Landsat computer-aided analysis is based on spectral pattern recognition. Looking for the mathematical or statistical set of rules used for feature extraction in the classification procedure, there are two basic approaches supervised and unsupervised techniques. A brief comment is given about each one of them. An extensive and comprehensive review about pattern recognition (which mathematically is a classification problem) has been given, as for example, by Watanabe (1969), Patrick (1972), Young and Calvert (1974).

3.2.2.1 Unsupervised Technique

Commonly referred to as cluster techniques, unsupervised techniques use only the statistical properties of the image data (spectral reflectance) as a basis for classification.

All the image data, which represent the area of study, is divided into a number of spectrally different classes using a clustering algorithm. In other words, the clustering algorithm looks for natural cluster of similar spectral classes. The number of spectral classes (groups) into which the data will be divided is specified by the analyst. Normally, after the classification is completed, the analyst will identify the meaning of each spectral class using available "ground truth" information.

The unsupervised technique is widely used for wildland areas and for areas without enough reference data available as for areas showing continuous fractional variations.

The main limitation of the unsupervised techniques is the difficulty of knowing how many spectral classes might be represented by one species or cover type (Hoffer, 1976).

There are many different methods of cluster analysis. A comprehensive review about these methods has been given, as for example, by Everitt (1974) and Hartigan (1975).

3.2.2.2 Supervised Techniques

With the use of supervised techniques, the analyst must select a representative training area (also called a training field) for each class of interest in the image. The accuracy of the classification scheme depends directly upon the quality of the training areas. Generally the training areas are selected through careful visual comparison between the image and the available "ground truth" information.

In order to carry out successful supervised classification processing, each spectral class must possess two basic requisites: be actually separable and contain valid information. No apparent benefit will derive from establishing classes which are indistinguishable in practice or whose classified points will be too few.

The algorithm often used for the remote sensing data supervised classification is the maximum likelihood classification program that uses Bayesian theory to statistically determine the class in which a picture element (pixel) belongs. Each pixel of the image is compared to the probability density function that describes the training areas for each of the spectral classes and finally, is assigned to the class where its probability is maximal.

The main limitation of the supervised classification applied to Landsat, is selecting homogeneous training areas which will represent all possible variations in spectral responses for each of cover types of significance.

CHAPTER 4

FOREST COVER TYPE MAPPING USING MSS LANDSAT IMAGES

Since the launch of the first Landsat satellite into space, research around the world has been carried out in order to evaluate the usefulness of Landsat imagery for forestry and in particular for forest cover type mapping. In order to carry out a review of the literature about forest cover type mapping using Landsat imagery, the subject was approached through the following three topics: meaning of forest cover, Landsat classification and classification accuracies, and practical examples of forest mapping using visual interpretation and computer-aided interpretation.

4.1 Meaning of cover type

The term cover type refers to a plant community that actually exists on the land surface, regardless of its ecological position or its relation to other cover types. A cover type is one of the smallest units in the vegetation classification. It can be related to a single specie or to a community of different species of plants. Often it is named by the dominant species present in the community (Laubenfelds, 1957).

The importance of forest cover type maps was already discussed in the introduction of this thesis.

An easy, accurate and quick way to produce forest cover type mapping is from the interpretation of remote sensing imageries. For example, with conventional aerial photographs, timber stands can be classified according to forest types, species composition, species distribution, size classes and height (Thorley, 1975). Although, it is not possible to acquire the same detail of information from the Landsat imagery, it may provide information for two basic points: the geographical position of the forest and the area covered by various forest types.

4.2 Classification systems and classification accuracies

> Classification systems attempt to group similar land use/land cover patterns in a rational linkage or hierarchy based on common attributes. A methodological classification can be developed only through the establishment of hierarchies of classes and such classes also permit inductive generalizations. (Avery, 1977, p. 159.)

The expressions land use and land cover are not necessarily synonymous. Remote sensor data register information about land cover.

A Land Use and Land Cover Classification System for Use with Remote Sensor Data, published by Anderson et al (1976) has been used in most thematic mapping carried out with Landsat imagery. Among others, this classification system adopts the separation between rangeland, agricultural and forest lands. The classification system for forest only can be resumed as: Level 1. forest land; Level 2, classification of the forest land into three broad categories, namely: deciduous, evergreen and mixed (deciduous-evergreen) forest land.

The Anderson classification system is capable of further refinement on the basis of more extended and varied use. So, for the third level could be proposed the mapping of specific stands of trees which are dominant in the overstorey of the forest. The use of dominant trees only is justifiable, because most of the energy reflected from the vegetation or from the forest and that captured by the sensor, came from the upper canopy of the forest (Morain, 1971). Other classification systems were formulated to suit the needs of the mappers (as for example, Kan and Dillman (1975) and Erb* (1973)).

Classification accuracies** are highly dependent upon the level of vegetation organization which is to be classified. When the classes are sufficiently different to create contrasting spectral signatures on the Landsat images (as for example, forest, shrubland and grassland) the classification accuracy may be in the 90 per cent range. This was substantiated by the results found by Kirby (1973) and Oswald (1974), using manual interpretation of the images, and also by Heath (1974) and Hoffer and staff (1975) using computer-aided classification. Say-Wittgenstein (1977) believes that only the reconnaissance level (Level 1) can be satisfactorily achieved with Landsat data applied to forest mapping. In addition, Carneggie and DeGloria (1973) noted that only gross vegetation types as forest land, rangeland and meadow were discriminated on the visual analysis of the Landsat images. They also noted the resolution of the Landsat imagery does not permit detailed mapping needed for evaluating management problems or making management decisions.

---

* Erb adopted the following classification system: Level 1: forest, water and other. The Level 2 for forest was: standing and cut over timber. The Level 3 for standing timber was: pine established and hardwood established, while the Level 3 for cut-over timber was: pine cutover, pine site prepared, pine regenerated and cutover hardwood. Finally, for Level 4 was established only for cutover timber: pine site prepared and pine site prepared/vegetation.

** Classification accuracies are generally evaluated through two quantitative techniques. One technique refers to the comparison of the area estimates of the classes as given by the computer classification and by that acquired from aerial photographs or forest maps. The second technique refers to the accuracy of the computer classification evaluated in selected parts of the area of study. Thus, the same training areas used for the initial definition of the classes may be used for the evaluation of the results, and when this is used is given the term self-classification accuracy. Otherwise, test areas for each class can be selected through any statistical sampling design.

Considerably less accurate results have been reported by classifying timber types. For this level of mapping, computer-aided classification has been more successfully attempted than manual interpretation. Conversely, after testing a number of visual and computerized methods, Heller (1975) concluded that present satellite data are useful primarily for Level 1, although he obtained more detailed results, but not consistently. Fleming and Hoffer (1978), reporting the results of a series of investigations carried out at the Laboratory for the Application of Remote Sensing, Purdue University, pointed out that with Landsat data, deciduous and coniferous cover, as well as other major cover types, could be classified and mapped with a reasonable degree of accuracy (75-85%). However, they pointed out that the classification and mapping accuracies for individual forest cover types were much lower. The same degree of accuracy for coniferous and deciduous mapping were also found by Kirvida and Johnson (1973) and Kan and Dillman (1975).

4.3 Examples of forest mapping using MSS Landsat data

This paragraph will be devoted to a review of the practical examples, in the literature, about forest cover type mapping using Landsat imagery. The examples to be related will be grouped into two groups according to the way in which the imagery was analysed: manual and visual interpretation and computer-aided analysis.

4.3.1 Examples with manual and visual interpretation

Nielsen and Wightman (1974) discussed the possibilities of using Landsat 1 imagery for the production of regional forest maps. Without using any interpretation aids, two interpreters delineated what they considered forest-type boundaries in the imagery covering the Province of Ontario in Canada. A posteriori, this Landsat interpretation map was compared with the official forest classification map for the area. The authors concluded:

> although Landsat 1 imagery permitted mapping of the boundaries of some of the major forest types, its use in the applications is more limited than had been expected. A significant factor in this limitation was the inconsistency of the imagery. Differences in quality were pronounced among black and white as well among colour scenes. These qualitative differences were due primarily to a combination of variables related to image production and date of data acquisition.

One of the easiest applications of Landsat imagery in the forest cover mapping, and one important for forestry policy and management decision, is for updating forest maps that cover larger areas. This would correspond to the mapping of Level 1 in the Anderson classification, i.e. the separation of forest land from all the other classes. This was carried out in Brazil for the evaluation of coverage of forest land in Parana State. For this was used black and white copy of MSS band 5 at a 1:250,000 scale. The results showed that for 1973, only 11.83% of the State land was covered by any sort of forest. This was contrasted with the results (30.27%) obtained in 1966 from the aerial photo-interpretation (Centro de Pesquisas Florestais, 1974). For Thailand, Klankamsorn (1976), using photographic prints of bands 5 and 7 at 1:1,000,000, evaluated at 41.4% the quantity of forest land in the whole country. The country had 55% forest land in 1961. Carneiro

(1980) reported the use of photographic prints of bands 5 and 7, at scales of 1:250,000 and 1:1,000,000 for the evaluation of the deforestation in the whole Brazilian Amazon Forest. The rate of depletion of the forest, in the period between 1975 and 1978, was 2.00%.

In the literature of the remote sensing, there are examples of more detailed level of forest classification, at least in Level 2 in Anderson's classification. In almost all of the examples, the authors used some reference data (vegetation map or aerial photograph) to differentiate one major forest cover type from another in the Landsat images. The next examples report this trend.

Nosseir _et al_ (1975) elaborated a natural vegetation map of central-east part of Brazil using prints of the four Landsat MSS bands at 1:1,000,000 scale. The vegetation was mapped into three classes, namely: forest, cerrado and grassland. Subclasses also were established for each of the classes mentioned. In a report published by Superintendencia do Desenvolvimento da Região Sul (1978), a vegetation map of the southern region of Brazil was produced from the interpretation of prints of bands 5 and 7 at a scale of 1:1,000,000. The vegetation was classified in the following six classes: forest, grassland, coastal vegetation, agricultural land, reforestation areas and National Park areas. In the mentioned classification system, the first four classes were subdivided into different levels. Yassoglou (1973), based on the study of the gray scale levels and spatial characteristics of the RBV and MSS Landsat images and of the colour composite images, produced a land use map of the central part of Greece. In the system of classification the forest land was classified as: dense and thin stands of fir, austral pine and Aleppo pine, dense and thin shrub lands. Salas et al (1973) reported the results of the interpretation of Landsat images for the analysis of vegetation and land use for central parts of Venezuela. Six photomorphic units were identified according to the geographical position of humid and dry tropical forest.

Sheda (1978) reports the areal results of the mapping of Tectona grandis ("teak") that was carried out in two areas supporting tropical dry deciduous forest, in India. The mentioned stands were mapped using prints of MSS bands and also colour composites at 1:250,000 scale. Carneiro and Hildebrandt (1978), using prints at 1:200,000 scale of the MSS bands, did not get much information about forest typing in one test area in the south of Germany. However, coniferous and deciduous trees in bands 5 and 7 could be separated in almost 100% of the cases. They found that

> colour composite interpretations besides being easier, added more information in forest typing and its overall accuracy (boundary delineation) was similar to the interpretation of black and white MSS prints.

DeSteiguer (1975), beyond the mapping of three broad cover types (mixed hardwood, cottonwillow and cypress tupelo), compared the results acquired from the Landsat images with that derived from colour infra-red high altitude and Skylab photography. Photographic prints of only MSS band 7, at a scale of 1:250,000, were analysed. The Landsat imagery yielded the least accuracy map with 60.7% of overall accuracy, while the other mentioned imageries yielded 71.4 and 66.7% of accuracy, respectively.

4.3.2 Examples with computer-aided analysis

As mentioned before (p. 36), Landsat computer-aided analysis are based on spectral pattern recognition and generally supervised and unsupervised techniques have been used for classificatory programs. Examples, from the literature, will be reported separately for each classificatory program. Also, considerations and examples will be given about the use of microdensitometer for Landsat forest mapping.

4.3.2.1 Examples with supervised classification

Kivida and Johnson (1973), Joyce and Pendleton (1973), Kan and Dillman (1975), Dodge and Bryant (1975) and Lee (1977) used supervised classification methods for mapping gross forest types, i.e. for the mapping of coniferous and deciduous cover types.

Kalensky and Scherk (1975) report the results of a two year study of forest mapping using supervised classification. They pointed out, that for the same level of classification mentioned above, the overall classification accuracies ranged from 67 to 81% for single-date imagery, while accuracy for multidate imagery analysis were consistently above 80%. They also stressed that the definition of ground truth and selection of training areas were among the most important factors affecting the classification and mapping accuracies of digital image processing.

Computer classification has not been used only to map and classify cover types in natural forest. Shimabukuro _et al_ (1980) report the classification of reforestation areas. They could separate areas supporting _Pinus elliottii_ from other areas supporting other species of Pinus, and also classify two age-classes of _Eucalyptus_ sp (from eight months to two years and another class representing areas with over two years). The achieved average pixel classification accuracy was 81.8%, while the average areal estimation difference was 6.3%

The spectral reflectance of the forest types are subject to many changes depending on the season of the year, the phase of vegetation and atmospheric pass. From the three above-mentioned aspects, the first appear to be one of the most important. Say-Wittgenstein (1977) stressed that an evaluation of Landsat is not complete until multidate imagery has been considered. Joyce and Pendleton (1973) found the results of classification more accurate using winter scene (January scene) than summer scene (August scene) to map pine and hardwood forests. Kan and Dillman (1975) found that February (phenological early spring) and May (phenological late spring) were better months than November (phenological late winter) for remote sensing forest features in the south-eastern United States. Cleusters et al (1978) reported that there was only a small difference between the late winter scene recorded at the end of March and the spring scene of May for mapping deciduous and coniferous forests in Belgium.

4.3.2.2 Examples with unsupervised classification

In general, unsupervised classification methods have been less used than the supervised method for forest cover type mapping.

Beaubien (1979), in a study of forest areas in Quebec (Canada) using unsupervised classification, found it was generally possible to map hardwood, mixedwood and two or three types of softwood stands depending on the area. He also pointed out that apart from the forest species, the factors which play the largest role in the softwood class distribution were age and density, and percent and exposure of the slope. The unsupervised classification was used instead of the supervised classification because the areas of study were large and with a complex topography and vegetation cover. The author also mentioned that in Canada, Landsat images will be used for vegetation mapping of vast inaccessible northern regions where unsupervised classification is necessary, unless it is decided simply to colour-enhance the image using digital or photographic methods. Messmore et al (1975) also used unsupervised classification for mapping forest vegetation due to inadequate ground truth information on the distribution of vegetation within the area of study.

Todd et al (1980), reporting the quantitative results of wildland mapping using unsupervised classification, found that there was less confusion between aggregated (more generalized) resource classes grouped on the basis of soils, terrain and vegetative cover, than detailed resource classification. The authors also pointed out the following three principal categories of classification errors: geometric and radiometric problems related to the pre-processing technique of the Landsat scene, the detail of classification scheme and finally the analysts' decision taken during all the steps of the classification.

Fleming et al (1975) pointed out the results of the evaluation of three approaches to computer-aided classification of Landsat 1 MSS data from a test site in rugged, mountain terrain. The approach compared included non-supervised (clustering), supervised and modified clustering (hybrid of the supervised and unsupervised methods). Test areas results indicated classification accuracy of 78.5%, 70.0% and 84.7% respectively for the three analysis techniques. The modified clustering* proved to be optimal computer-aided analysis technique of those tested because of minimal computer time required, highest classification accuracy and most effective analyst/data interaction.

4.3.2.3 Use of microdensitometer for Landsat forest mapping

The microdensitometer is used to digitize the optimal density data on a transparency format by scanning it in a single line across the image or in a rectangular area. For the first case, scanning in a single line across the image, it is possible to show crudely the variations of spectral reflectance of different forest cover types and land uses crossed by the line (an example of this has been reported by Say-Wittgenstein and Kalensky (1974) and Dörfel (1978)). This has often been presented as an illustration about the cover types available in the area of study.

The most useful application of the microdensitometer for Landsat imagery is to scan rectangular areas of its transparencies. Thus, for the digital data obtained this way, a posteriori, it is possible to apply any technique of computer-aided analysis. The following examples report the use of microdensitometer scanning in studies of Landsat forest cover type mapping.

Rennie and Burth (1974) did not obtain satisfactory results in the mapping of forest cover types (pine, hardwood and mixed) and volume class in one forest land in Tennessee (U.S.A.). The 24 cm format negative of the MSS bands were scanned by a microdensitometer with

---

* The basic sequence for the modified clustering method is: select areas to be clustered, cluster each area independently, combine the cluster classes into information spectral classes and finally classify the area of interest using supervised classification method.

an aperture size of 100 μm, which corresponded to a ground spatial resolution of nearly 0.4 hectares. They pointed out two reasons for the low accuracy (63%) of forest type mapping. The first reason was due to the difference in the time of the year that the ground truth and aircraft imagery were acquired. Thus, a better correspondence was found between ground observation and Landsat imagery than early-spring aircraft imagery and mid-autumn Landsat imagery. The second reason was due to the degradation of data in the Landsat transparency format and the lack of good registration of the same point (as resulted from the microdensitometer scanning) from one band to another.

Ashey and Rea (1974) report the results of the evaluation of densitometry methods to access forest vegetation changes on relatively small areas from Landsat MSS transparency images. The 24 cm format transparency of the MSS bands 5 and 7 were scanned by a microdensitometer with different aperture sizes. The range of aperture size varied from 0.4 to 3 mm, which corresponded to a ground spatial resolution of from 9 to 530 hectares, respectively. They concluded that aperture size of 0.4 mm can be used successfully to make readings to portray forest vegetation changes.

Flouzart and Monchart (1978) report the results of areal determination of mapping fir forests using Landsat MSS bands. The area of study had a size of 12 x 16 km. The ground spatial resolution, from the microdensitometer scanning, was 2.5 hectares. They concluded that the forest was not satisfactorily identified only on the bases of its spectral signatures; also the spatial resolution of the whole processing procedure was responsible for the errors (with a mean value of 20%) in surface measurements.

DeSelm and Taylor (1973) and Kamat <u>et al</u> (1977) used microdensitometer scanning of images of Landsat MSS bands for forest mapping, but only qualitative analyses was carried out between the microdensitometer scanning outputs and the forest maps.

SECTION B : PARANA PINE STANDS

CHAPTER 5

ARAUCARIA FOREST AND PARANA PINE

5.1 Araucaria forest: distribution and characteristic features

Araucaria forest is a type of wet subtropical forest whose distribution shows a close relation to elevation. In Parana State, Araucaria forest seldom occurs in areas of elevation less than 500 m.

Araucaria forest occurs in Brazil and Argentina (Figure 1), also in Paraguay and Chile. The largest area of distribution of the above-mentioned forest is in the south of Brazil. According to Maack (1968), Parana State may be divided into five natural geographic regions (Figure 2). These regions are coastal zone, The Serra do Mar, the first plateau, the second plateau or Ponta Grossa plateau and the third plateau or Trapp Plateau. The plateaux are separated by escarpments. Araucaria forest is widely distributed over the first and second plateaux and also occupies part of the third plateau (compare Figure 2 with Figure 5).

Araucaria forest is characterized mainly by the presence of the Parana Pine, but large quantities of plants and forest trees can also be found in association with the above-mentioned tree. In a forest survey carried out the Araucaria forest of the south of Brazil it was found that there were 169 economically important trees growing in association with Parana Pine (Instituto Brasileiro de Desenvolvimento Florestal, 1978).

Aubreville (1949) observed that Araucaria forest is composed of

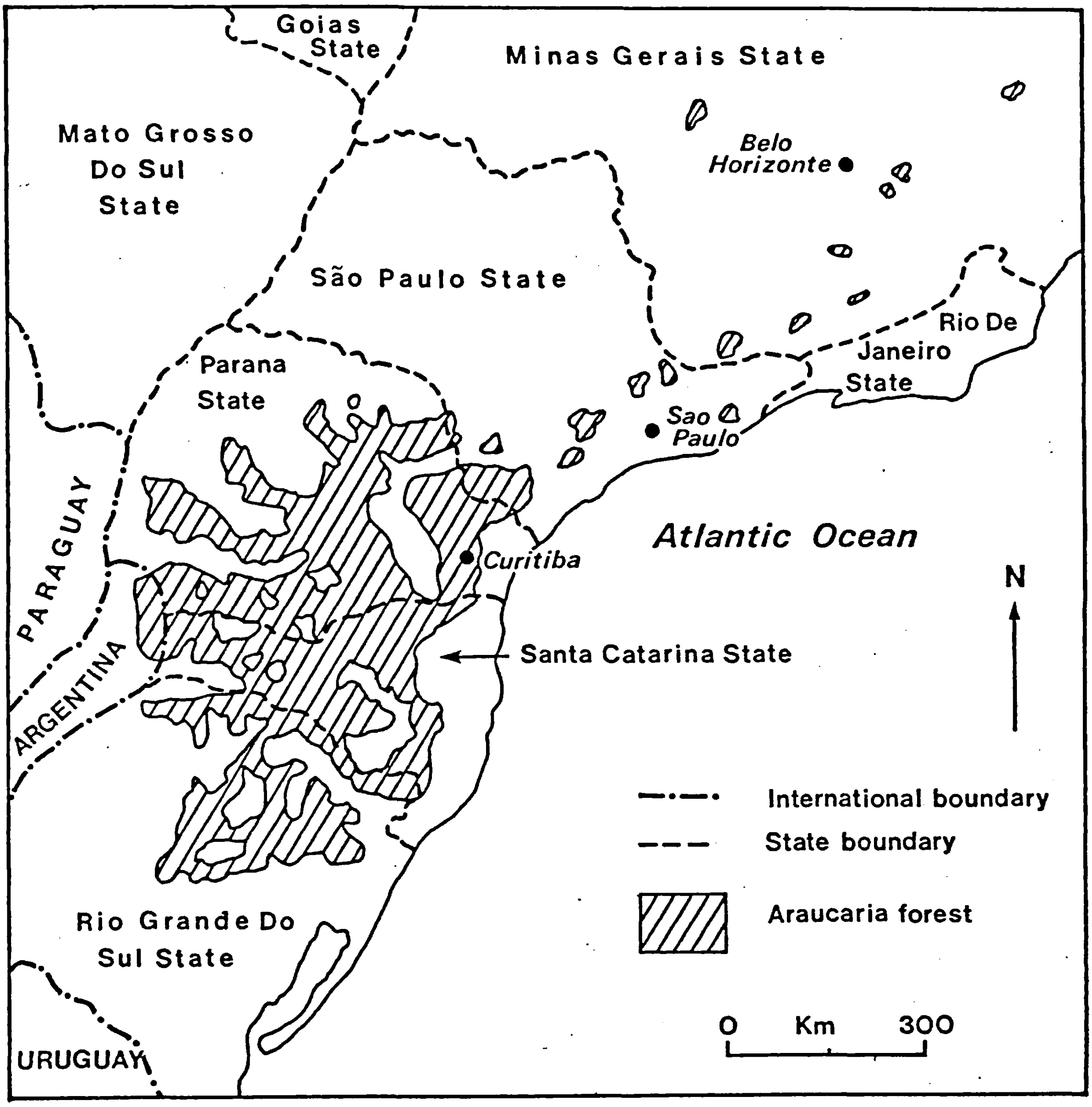


Fig I Distribution of Araucaria forest in Brazil (after Hueck 1953)

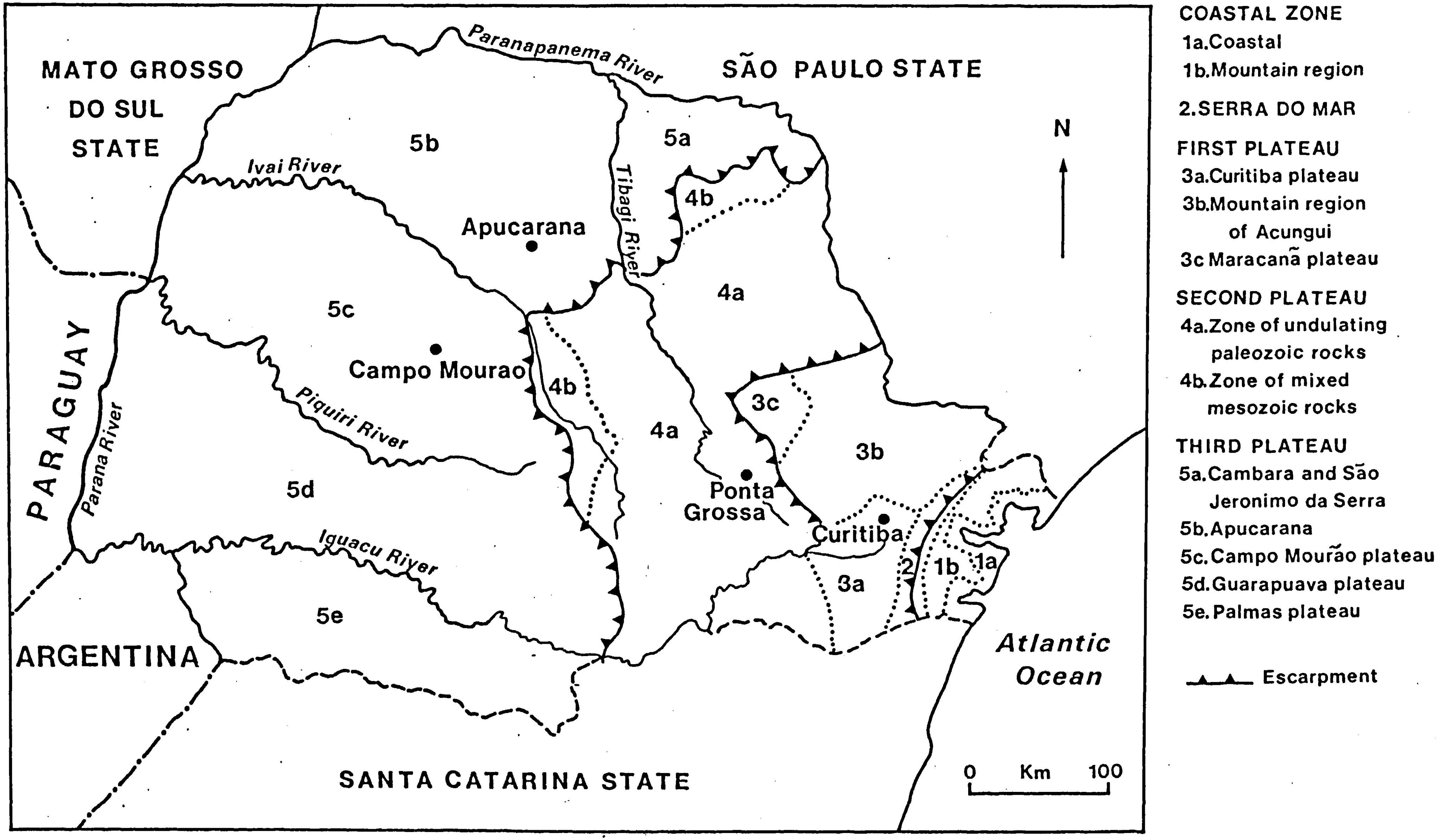


Fig.2 Natural geographical regions of Parana State (after Maack 1968)

two strata. Old age Parana Pine trees form the upper stratum and there is also a less dense stratum of smaller dictotyledonous trees.

The trees represented in the upper and lower canopies of the Araucaria forest vary in species, number and size according to the local environment and the stage of development of the forest. Hueck (1972) pointed out that the highest canopy of the Araucaria forest in the Rio Grande do Sul state is composed mainly or exclusively of Parana Pine or associated with *Cedrela fissilis* Vell. ("cedro") and other crown trees. For Parana State, Maack (1968) mentioned that Parana Pine is found in association with *Ocotea porosa* (Nees) L. Barroso ("imbuia"), *Ilex paraguariensis* St. Hill. ("erva-mate"), *Nectrandra* sp ("canela"), *Ocotea pretiosa* (Nees) Mez. ("canela sassafraz") and many other tress, including two coniferous trees known as "pinheiro bravo" (*Podocarpus lambertii* Klotz. and *Podocarpus sellowii* Klotz.). According to Hertel (1962) the Araucaria forest can be represented by the following association: Araucaria - Podocarpus - Ilex - Ocotea.

Some trees in the forest of Parana State, including in the Araucaria forest, lose their leaves during the winter time. The most common trees in which this occurs are: *Cedrela fissilis* and *Cedrela* sp ("cedro rosa"), *Tabebuia* sp ("ipe amarelo, branco and roxo"), *Cecropia* sp ("embauba"). The forest is partially evergreen.

5.2 Basic considerations about Parana Pine

The Parana Pine (*Araucaria angustifolia*) was described for the first time by Bertoloni in 1819 as *Colymbea angustifolia*. Three years later, Richard, unaware of Bertolani's classification, named the tree *Araucaria brasiliana* (Hueck, 1972). In 1883, it was finally classified as *Araucaria angustifolia (Bertoloni) Otto Kuntze*.

Parana Pine is one of fourteen species of the genus Araucariaceae. This genus, within the family Pinaceae, occurs only in the Southern Hemisphere. Parana Pine is also known by the following vernacular names: Araucaria , Pinheiro do Parana, Pinho.

Parana Pine is an evergreen tree 30 m or more high with a tall, straight trunk terminated by a flat head of gaunt, horizontal branches with the branchlets in terminal clusters. The branches are usually arranged in whorls of 4-8 (Dallimore and Jackson, 1966). The leaves are oblong, lanceolate, much attenuated at the point, loosely imbricated and dark green. At their largest in the central areas of the branches, the leaves are 3 to 4 cm in size. According to Hueck (1972) the leaves remain on the branches for between 6 to 10 years. For the first 3 to 4 years they are green, later becoming dried.

According to Klein (1960), Parana Pine, in the several forest associations in which it occurs, is the tallest tree. Parana Pine has a dark green umbelliform crown and these crowns form a characteristic canopy which is very easy to distinguish. The tree can reach a height of 30-35 m, mature and old age trees having a diameter at breast height of 80 to 120 cm.

As before mentioned, the Parana Pine has a wide area of geographic distribution. The tree can be found in many different vegetational associations, being either in forest or grassland. According to the ecological conditions of the environment, Parana Pine may be the dominant specie or may occupy the secondary position in the landscape. In the grassland areas ("campos"*), the Parana Pine, with other forest trees, occurs in "capoes" or, in general, following the drainage lines.

---

* "Campos" was originally denominated by savannas. Maack (1968) ratified the term savannas by "estepe de gramineas baixas" or the equivalent of grassland in English.

The density of Parana Pine in the natural forest varies from place to place. For Parana State, according to Jankauskis (1973) and Siqueira (1980) the number in dense stands is 25-45 per hectare.

Parana Pine is economically important because the timber is of good quality and a larger proportion of the trunk may be used. The wood is used for furniture, house construction and paper making.

5.3 Geographic factors influencing the distribution of Parana Pine stands

The distribution of the Parana Pine stands is directly related to the climate, which is conditioned by the relief and by the elevation.

The natural habitat of the Parana Pine stands are in the meridional plateaux of Brazil. Since the stands extend from the south to the north, there is an increase in the lower elevation at which the stands occur. According to studies carried out by Reitz and Klein (1966), Maack (1968) and Matos (1972), Parana Pine stands occur in areas between 500 and 1800 m elevation, being the lower limit applied to the three states of southern Brazil. In Sao Paulo State the lower limit is 800 m and in the border between Sao Paulo and Minas Gerais States the limit is above 1,000 m elevation. The climatic conditions required by the stands (low temperature in the winter and high precipitation) is rewarded by the increasing elevation (Romariz, 1974). The Parana Pine stands are found in the higher areas - mountain tops and higher parts of the plateaux. In general, the stands are not found in river valleys.

Parana Pine stands occur in areas of humid mesothermal climate, a C climate in the Koeppen climatic classification. In this, the warmest month of the year has a mean temperature above 10°C and the coldest month has a mean between -3°C and 18°C. According to Oliveira (1948) and Matos and Laboriau (1948) the climate of the southern states of Brazil can generally be described as type Cf (Koeppen classification) since the rainfall is well distributed throughout the year.

The temperature in the south of Brazil is characterized by contrasting hot and cold seasons. Between May and August the temperature is low, July being the coldest month. The temperature is high between November and March with January the hottest month. Oliveira (1948) pointed out that the average temperature, occurring in the Araucaria forest, in the summer time is between 20° and 21°C, while in the winter time it is between 10°C and 11°C.

According to Magnani (1963) there are between 10 and 25 frost nights each year in the areas of highest concentration of Parana Pine stands. Rogers (1953) states that throughout the area of distribution of Araucaria forest the average rainfall is not less than 1,250 mm a year. In the area of Araucaria forest there is an adequate rainfall in all the seasons of the year.

Parana Pine stands occur in many different soil types. According to Rogers (1953) the stands can be found in soils derived from granites, basalts and diorites. Oliveira (1948) pointed out the following three aspects of the relationship between Paran Pine stands and the soils: the soils of the area of distribution of stands are mainly silts and clay types; the stands do not display adequate development in sandy soils, perhaps displaying adequate development in clay-sand soils; the stands occur in soils excessively acid, in general with pH less than 6.

The region of Parana Pine distribution in the south of Brazil does not yet have all the soils well characterized and mapped. It appears that the natural habitat of Parana Pine stands is in latosols and the three following soil factors are important, namely: great depth of soil, low degree of base saturation and high degree of exchangeable aluminium (Instituto Brasileiro de Desenvolvimento Florestal, 1978).

5.4 Crown characteristics in Parana Pine and its significance in photo interpretation

In photo interpretation the size and the shape of the crown are used as diagnostic features to recognize and to identify the dominant and canopy-forming individual tree species in natural forests and in forestry plantations. Say-Wittgenstein (1960, 1978) explained the importance of crown characteristic for tree-species recognition as a function of image scale. In large and medium scale aerial photography, Parana Pine is identified mainly by its crown characteristics. In addition to the importance of crown charactertistics, Avery (1977, p. 235) wrote that:

> ... as a minimum, the interpreter should be familiar with the branching characteristics, crown shapes and spatial distribution patterns of important species in the locality.

The crown of Parana Pine has a characteristic candelabra shape but this begins to appear as the tree approaches middle age. This feature persists into old age. The young Parana Pine has a triangular crown shape, the branches are regular and inserted horizontally or in acute angles to the trunk. On average, trees of 10 years old still have a triangular shape and at this age trunks without branches are uncommon. At the age of 12 to 20 years, the crown begins to be flatter and lower branches are lost. The horizontal branches remain and in the mature tree the crown reaches the candelabra shape. The change in the shape of the Parana Pine crown is related to the relative rates of growth of the trunk and branches of the trees. In the first decades the trunk grows more than the branches, giving a triangular shape to the crown, whilst later the opposite occurs, resulting in the characteristic candelabra shape (Hueck, 1972). Plate 1 shows the contrast between a young and a mature Parana Pine, while Plate 2 shows a young-mature Parana Pine.

The measurement of the size of Parana Pine crowns was considered by Volkart (1969), Silva (1977, 1978) and Longhi and Fahser (1979). These authors studied the relationship between the diameter at breast height and the diameter of the crown. All the measurements were taken from the ground. Figure 3 shows this relationship as measured by Volkart. For all the studies mentioned above, the maximum crown measured was near 15 m. This relationship has not been studied using aerial photographs.

Silva (1977) pointed out that the width of the crown of dominant and codominant Parana Pine in one natural forest in the south of Brazil, was practically constant and was close to 1/10 of the total height of the tree. He also stated that the average surface area of 188 measured Parana Pine crowns was 122 m^2. Figure 4 shows the vertical projection surface of one 135-year-old Parana Pine.

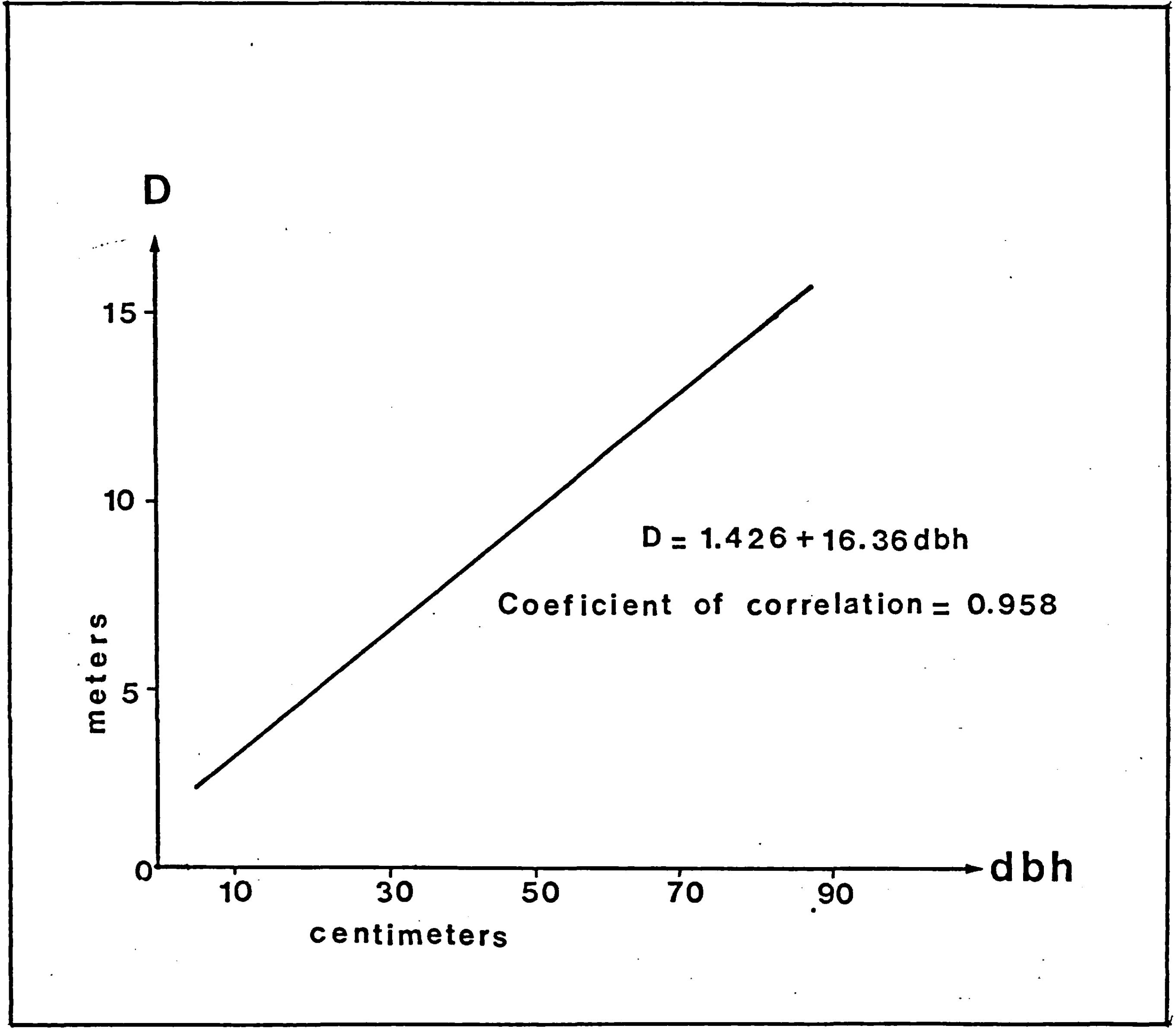
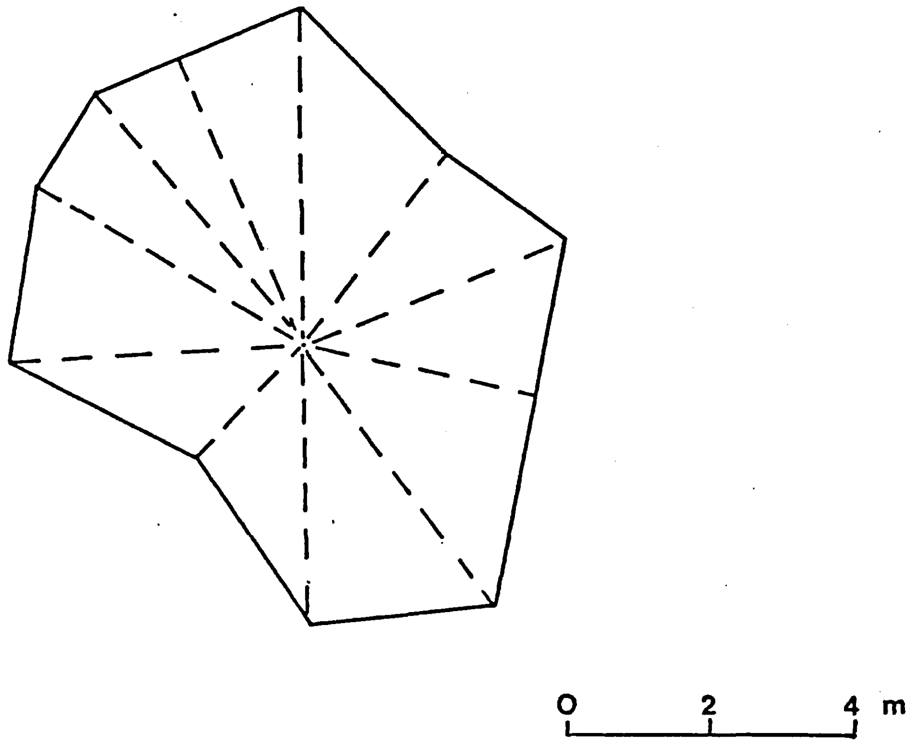


Fig 3 Relationship between diameter at breast height (dbh) and crown diameter (D) for Parana Pine (after Volkart,1977)



Height of the tree = 28,0 m

Trunk height = 24,0 m

Diameter at breast height = 80,0 cm

Age = 135 years

Fig 4 Crown surface of one Parana Pine (after Silva, 1977)

Plate 1. An old age (central left) and a young Parana Pine (foreground) with various trees-shrubs in the understorey. Photo taken in Curitiba.

Plate 2. A young-mature Parana Pine (central), with crown triangular shape and without some lower branches, and reforestation area of <u>Pinus taeda</u> (background). Photo taken in the Quedas do Iguacu area.

CHAPTER 6

MAPPING OF PARANA PINE STANDS AND AREAS OF STUDY IN PARANA STATE

6.1 Mapping of Parana Pine stands in Parana State

The mapping of the distribution of Paraná Pine stands has been the subject of a number of studies since the first phytogeographic map of Brazil was published in 1840. Hueck (1972) includes maps by Cavalcante, Ruhle and Philips concerned with the distribution of Araucaria forest in South America. These maps were constructed in 1908, 1928 and 1946 respectively. There are considerable differences in the three maps.

The benchmark of Araucaria forest mapping is the contribution from Reinhard Maack (1931), who, in 1931 published a map at 1:1,975,000 showing the natural vegetational regions in Parana State. The state was divided into four vegetational regions, namely: a coastal zone, a forest region, a savanna region and secondary exploited forest. The forest region comprised the tropical rain forest of the coast, the inland tropical rain forest and subtropical forest. Araucaria forest was included in the subtropical forest. The map by Maack is reproduced here (Figure 5) with slight modifications. The Maack article was summarized in English by Preston (1933).

Maack (1949) published the phytogeographical map of Parana State at 1:750,000 scale in which more detail of vegetation and forest types is given than in his 1931 map.

Maack (1968) published a further map at 1:2,000,000 scale showing

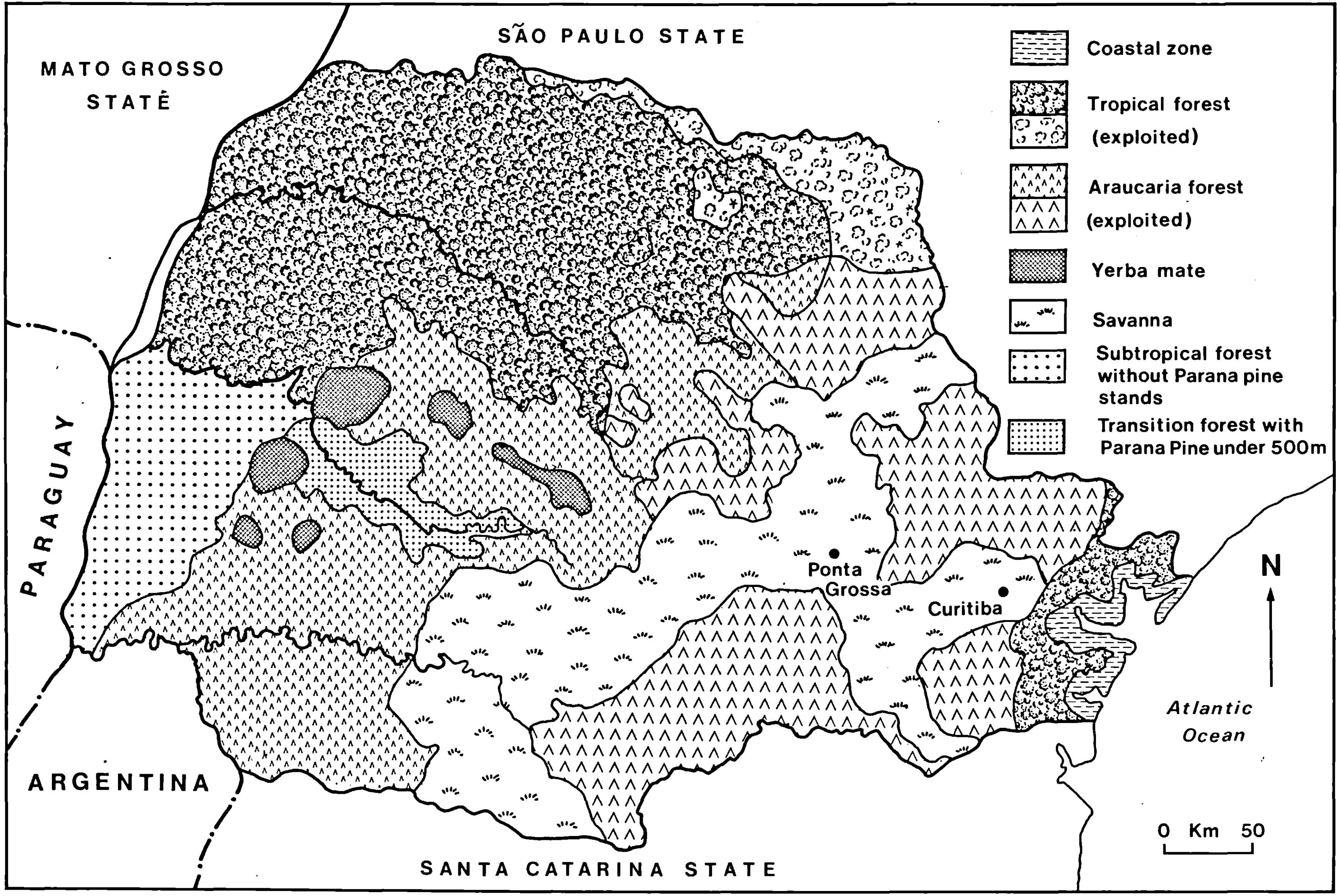


Fig.5 Vegetational regions in Parana state (after Maack 1931 modified)

the distribution of the phytogeographical regions as at October 1965. This map is reproduced here (Figure 6) with modifications. A comparison of the 1931, 1950 and 1968 maps shows substantial change caused by the exploitation of the forest. According to Machado and Siqueira (1979) the main reason for the devastation of a large part of the forest in Parana State have been the indiscriminate use of forest fire for the development of new agricultural areas and the large number of sawmills for the exploitation of the forest.

Detailed mapping of Parana Pine stands started in 1966. The results of a reconnaissance forest inventory of the Araucaria forest remaining within a total area of about 7 million hectares in the south-western part of the Parana State were published under the auspices of Comissao de Estudos dos Recursos Naturais Renovaveis do Estado do Parana (CERENA). A total of 1,763 aerial photographs were interpreted to produce a forest cover type map for the above mentioned area, which is given in Figure 7. Concurrently another map was published showing the distribution and spatial position of the forest in the whole State. Both maps were drawn from the interpretation of black and white aerial photographs at a scale of 1:70,000 acquired during 1963-64. The following classification scheme was adopted for the photo-interpretation: Parana Pine type I, Parana Pine type II, tropical forest, subtropical forest and grassland. The Parana Pine type I comprised unexploited stands with a relatively high number of Parana Pine trees per hectare (the field measurements showed an average number of 48 Parana Pine per hectare). The Parana Pine type II had a smaller number of trees (19 per hectare). Most of this stand was already exploited with the best Parana Pine having been removed.

In 1974, PROSPEC S/A published the PhotoInterpretation and

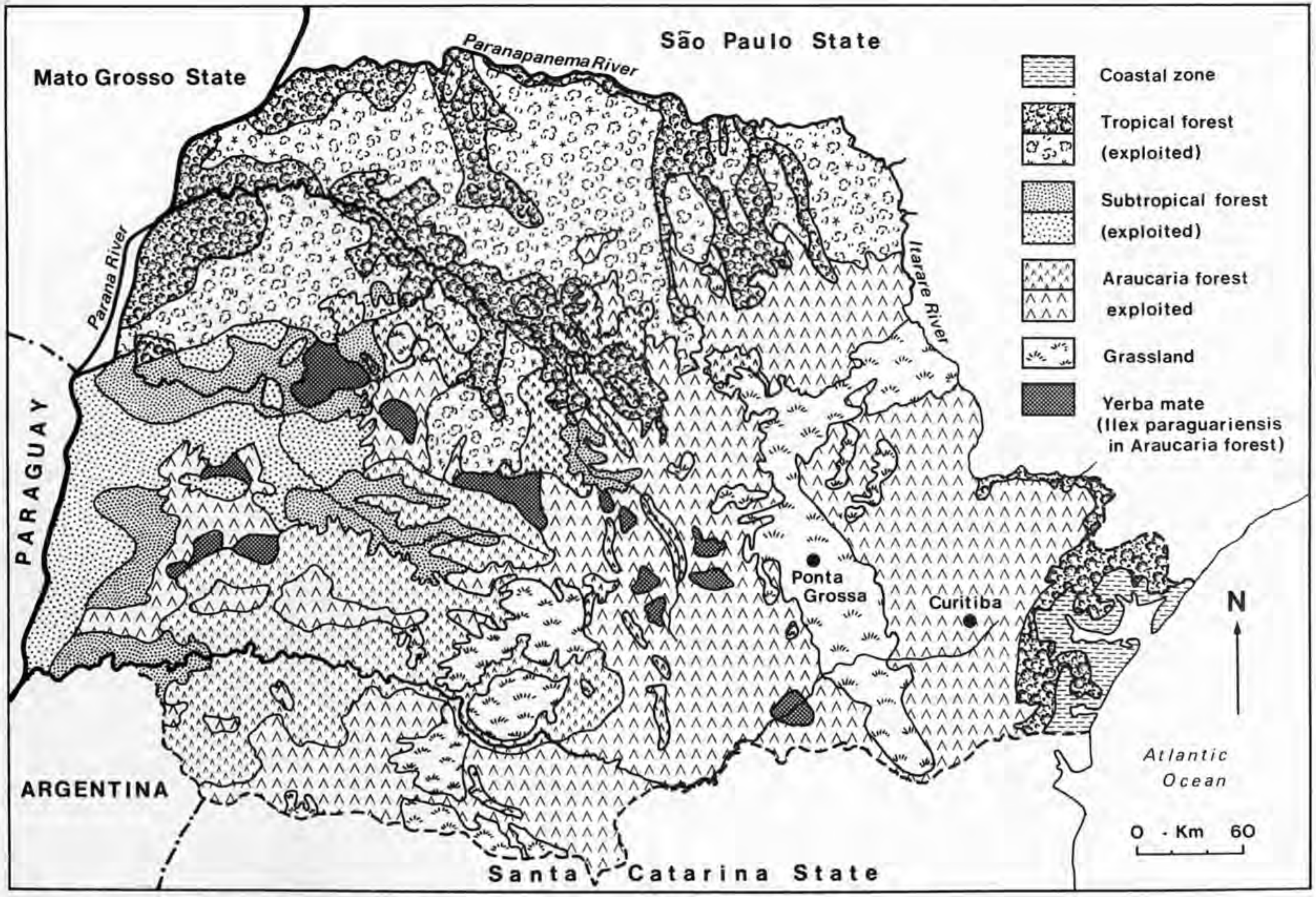


Fig 6 Natural Vegetational regions in Parana state (after Maack 1968, modified)

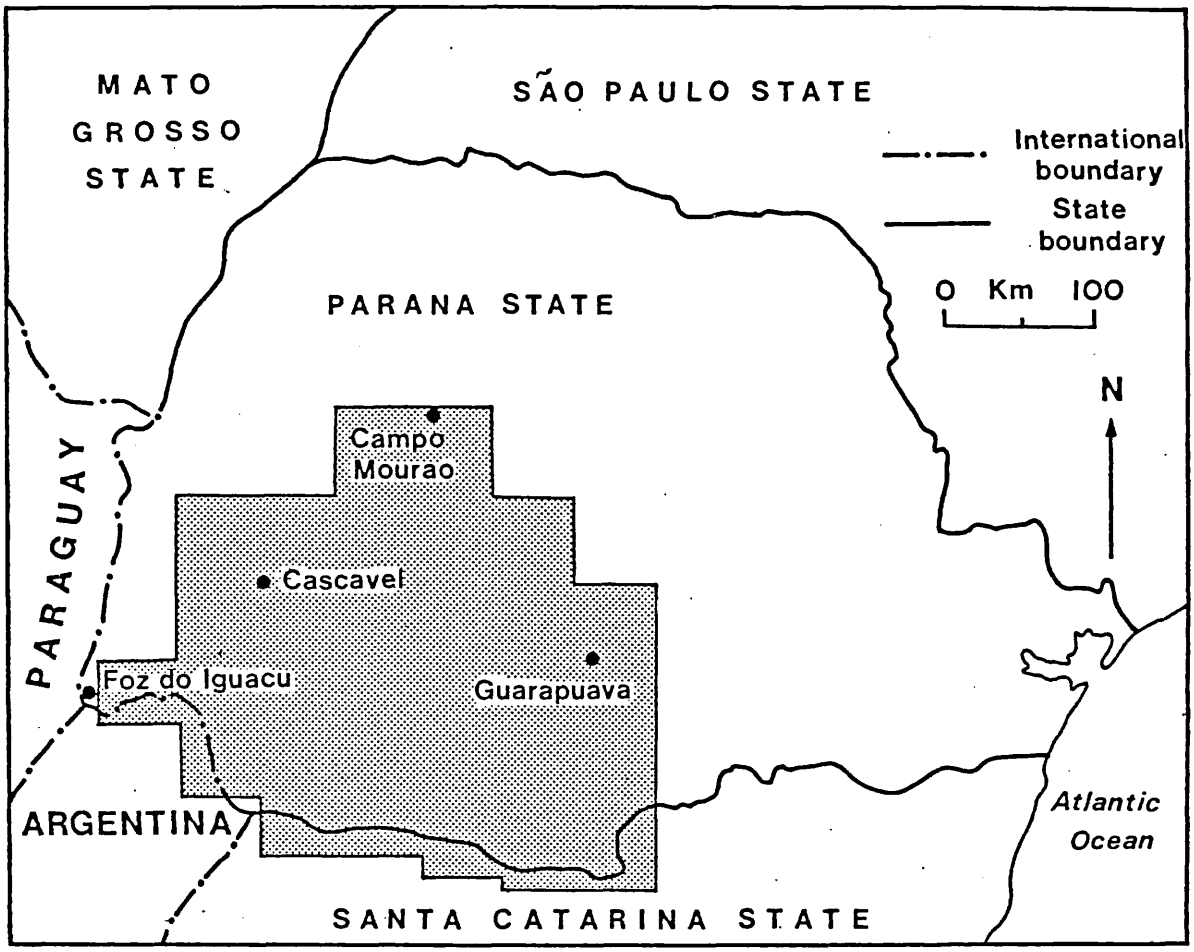


Fig. 7 Area covered by the 1966 forest inventory of Parana Pine stands

Mapping of Araucaria Forest carried out for parts of the three states of the south of Brazil. The survey area in Parana State was approximately the same as that reported in Figure 7. Black and white infrared aerial photographs at 1:50,000 acquired between 1971 and 1974, were interpreted and forest cover type maps were drawn at 1:250,000 scale, using the following typology for Parana Pine stands:

a) Parana Pine type I: unexploited Parana Pine stands,
b) Parana Pine type II D: stands with a relatively high number of Parana Pine trees,
c) Parana Pine type II R: stands with low number of Parana Pine trees,
d) Parana Pine type III: mixed Parana Pine with softwoods,
e) Parana Pine reforestation areas.

For this survey no field measurements were carried out.

In 1974 was published another forest survey for Parana State. At this time it used images at 1:250,000 scales of the Landsat MSS bands for the interpretation. The survey basically reported the quantity of the forest in all the State and also the rate of Araucaria forest destruction between 1965 and 1972 (Centro de Pesquisas Florestais, 1974).

In 1978 was published the results of the "Araucaria Forest Inventory of Southern Brazil" (Instituto Brasileiro de Desenvolvimento Florestal, 1978). For this survey, Landsat colour composites were interpreted visually. These colour composites were directly photographed from the display of the interactive digital processing General Electric Image 100 which can process Landsat CCTs. From the interpretation, final maps were produced at a scale of 1:250,000. The area covered by the survey was the same as that for the Prospec survey. The following classification scheme was used for Parana Pine stands:

a) Parana Pine type I: unexploited Parana Pine stands,

b) Parana Pine type II: stands of Parana Pine with crown density between 50 and 80%,

c) areas of forest with low crown density of Parana Pine stands,

d) Parana Pine reforestation areas.

Many other Araucaria forest surveys and Araucaria forest inventories have been carried out for small areas in Paraña State, using mainly aerial photographs at large and medium scale. Unfortunately, most of them have not been published because they were done by private companies.

Machado and Siqueira (1979), using basically the data reported by Maack and Forest School surveys, produced Table 2, which illustrates the rate of Araucaria forest destruction in Parana State.

Table 2. Rate of Araucaria forest destruction in Parana State between 1930 and 1977

Year	Area in Km^2	% of original area	% exploited
Original	73,780	100.0	0.0
1930	39,580	53.6	46.4
1950	25,254	34.2	65.8
1965	15,932	21.6	78.4
1973	4,336	5.9	94.1
1977	3,166	4.3	95.7

For the period 1973-1977 the rates of destruction were: 6,542,2 hectares a year for Parana Pine type I and 22,707,9 hectares/year for Parana Pine type II.

Although Araucaria forest has a large physical ecological area of distribution in the State, only the areas which contain the most representative forest (that is in the south-west) have been evaluated since 1966. In other parts of the State the Araucaria forest has been transformed to agricultural land or has been intensively exploited and only small immature Parana Pine trees have been left.

In summary, since 1931 Araucaria forest distribution has been mapped in Parana State. A better approach to Parana Pine cover type mapping started in 1966 with the reconnaissance forest inventory that estimated the volume, number of trees per hectare and annual wood increment of Parana Pine stands. This was renewed in 1978. The results of all the Araucaria forest surveys and inventories have been used as a basis for the development of policies and for decision making by the Brazilian government authorities.

6.2 Areas of study in Parana State

Two areas in Parana State supporting natural Araucaria forest were selected for detailed studies using Landsat images. Both areas are located in the south-west of the State (Figure 8). The study areas have been given the names of the closest towns, Quedas do Iguaçú and Mangueirinha. Both areas of study are near to the Iguacu River; Quedas do Iguaçú is located on the north side while Mangueirinha is on the south side of the river.

According to the natural geographical regions of Parana State

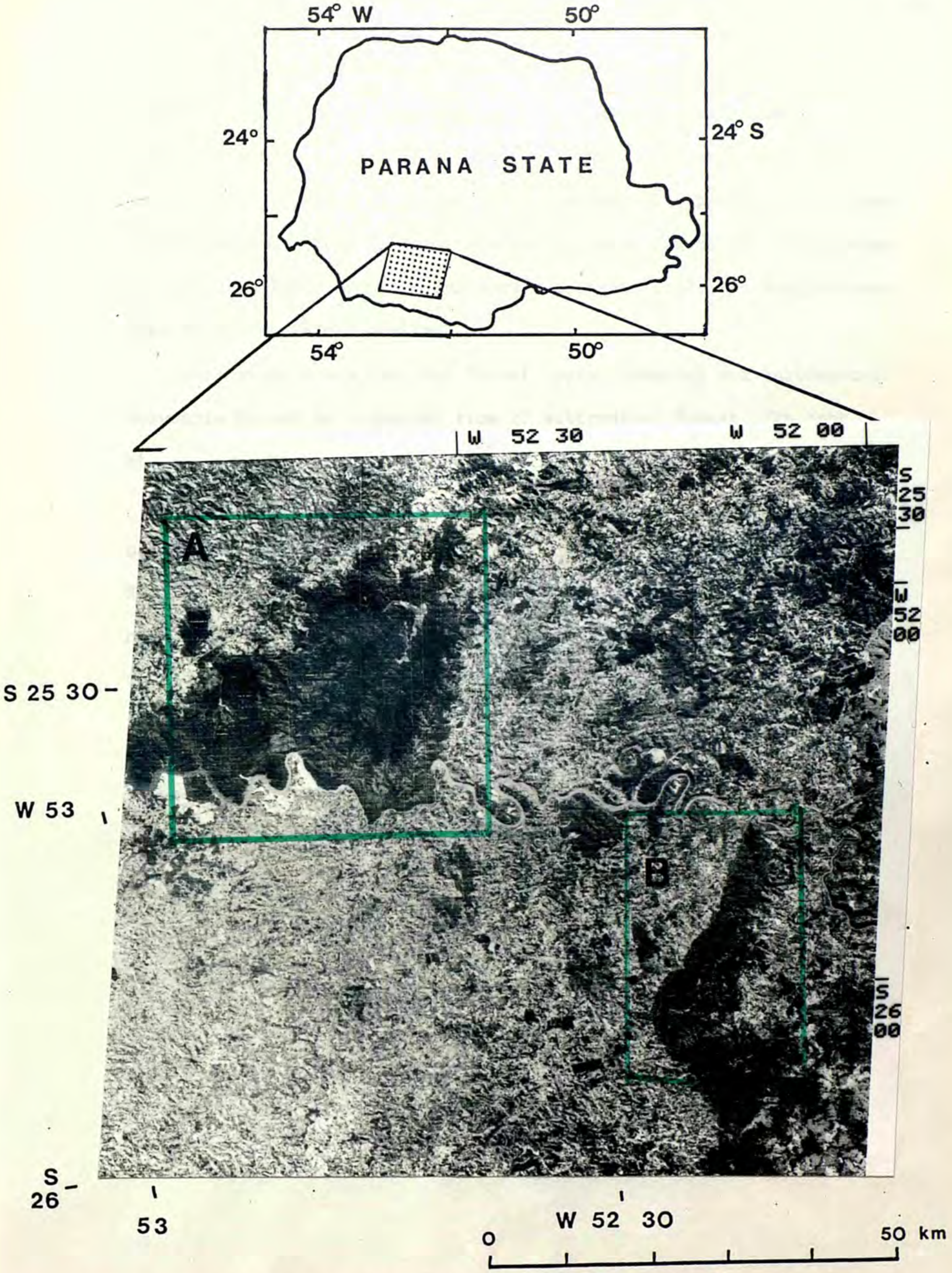


Fig. 8 Location of the Quedas do Iguaçú (A) and the Mangueirinha (B) areas of study in Parana State

the areas of study are situated on the third plateau (compare Figures 2 and 8). The plateau is geologically uniform, being composed of extensive basaltic lava flows. The lava has weathered to clay soils, which are rich in iron, titanium and manganese. The plateau is divided into five main blocks by major rivers (see also Figure 2). The Quedas do Iguacu is located on the Guarapuava plateau, while the Mangueirinha area is on the Palmas plateau.

Both study areas have two forest types, tropical and subtropical. Araucaria forest is a special type of subtropical forest. In both study areas Parana Pine is the dominant tree in the landscape.

The tropical forest is a variation of the tropical forest of the coastal region of the State. It occurs in the valley of the Iguacu River and in its main tributaries where the humidity is constantly high because of rainfall. The tropical forest gradually changes into the subtropical forest (Maack, 1968).

SECTION C : QUEDAS DO IGUAÇÚ AREA

CHAPTER 7

THE QUEDAS DO IGUAÇÚ AREA OF STUDY

7.1 Initial considerations

7.1.1 The Physical Background

The Quedas do Iguaçú is located in the south-west of Parana State. Its climate is classified by Koeppen as Cfb. The average temperature in the winter (from May to August) is 14.9°C, whilst in the summer (from December to February) the average is 22.8°C. The annual average temperature is 18.9°C and the annual rainfall is 1,714 mm. The driest months in the year are May, July and August, with an average of 87 mm of rainfall. The wettest months in the year are January, February and October with an average rainfall of 203 mm (Instituto Agronomico do Parana, 1975). In the area there is no moisture deficit because the amount of precipitation is far over the amount of evapotranspiration during the whole year (Figure 9).

The range of elevation in the area of study is between 400 and 800 m, being the lowest elevation close to the Iguaçú River (Figure 10).

The Quedas do Iguaçú area is characterized by four main classes of soils, namely: latosol rosso, terra bruna estruturada, terra rossa estruturada and lithosols (Figure 11).

Latosol rosso are deep soils derived from basaltic lavas; they are characterized by a generally diffuse transition of horizons. The

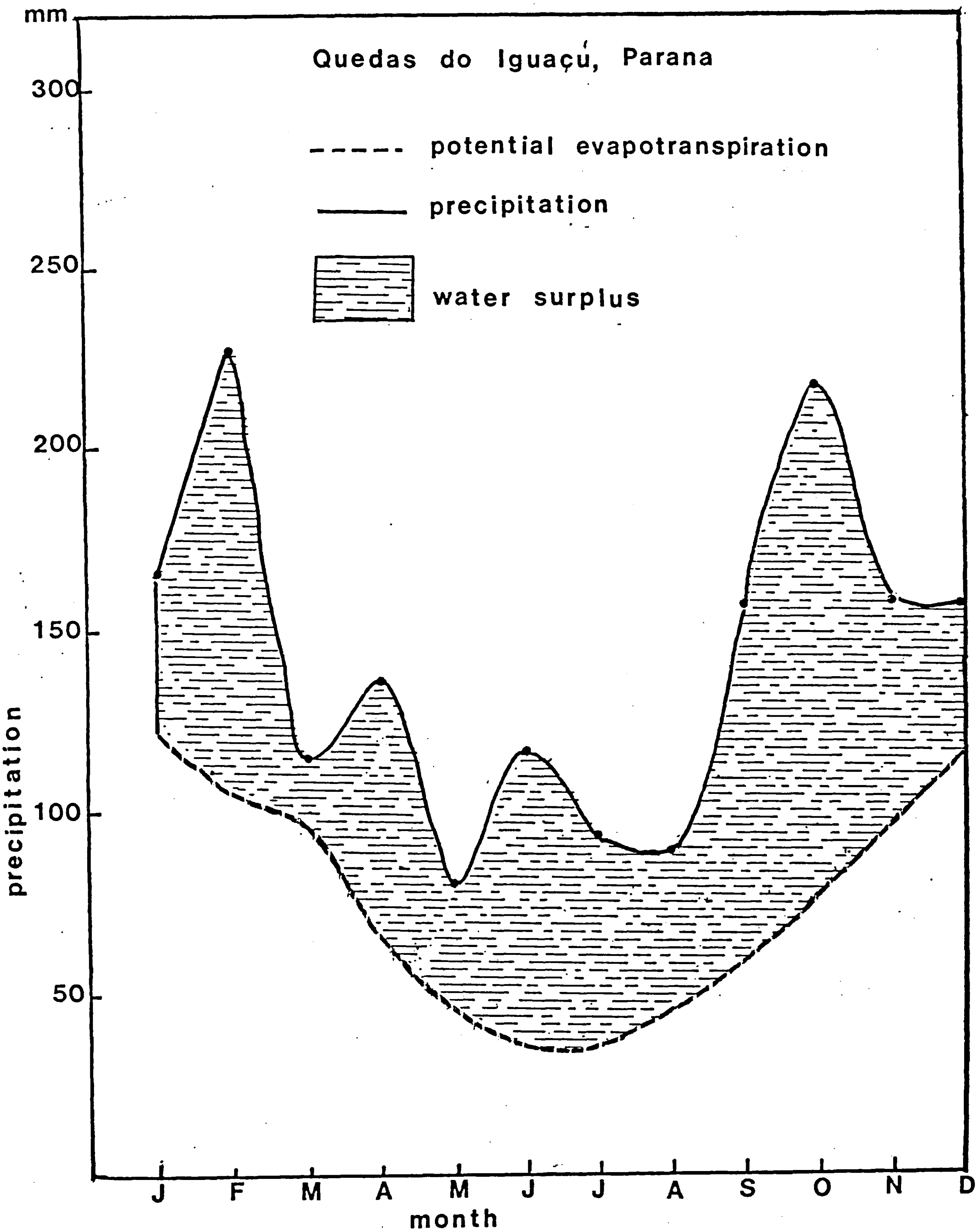


Fig. 9 Potential evapotranspiration and precipitation for Quedas do Iguaçú

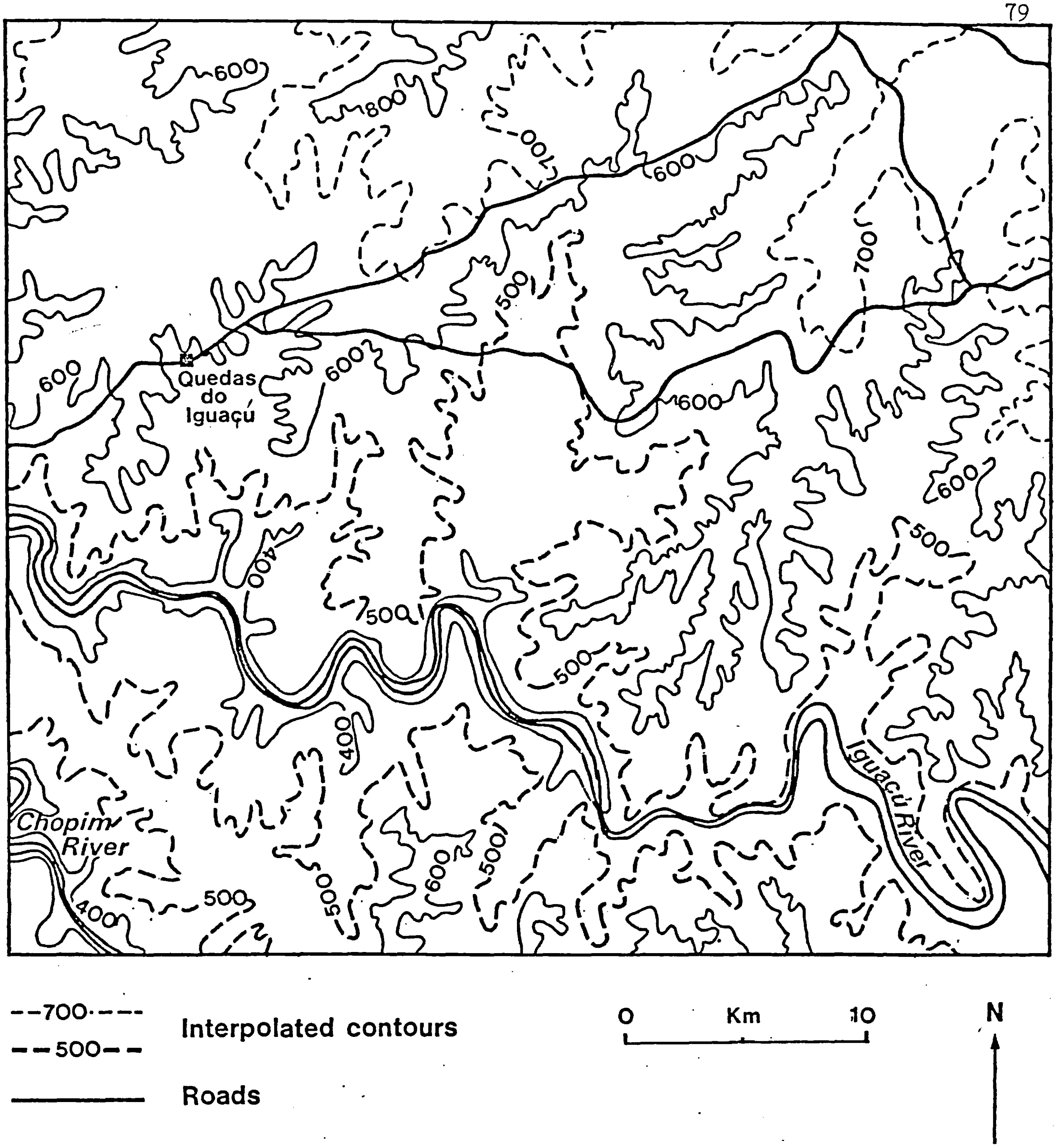


Fig.10 Relief of the Quedas Do Iguaçú

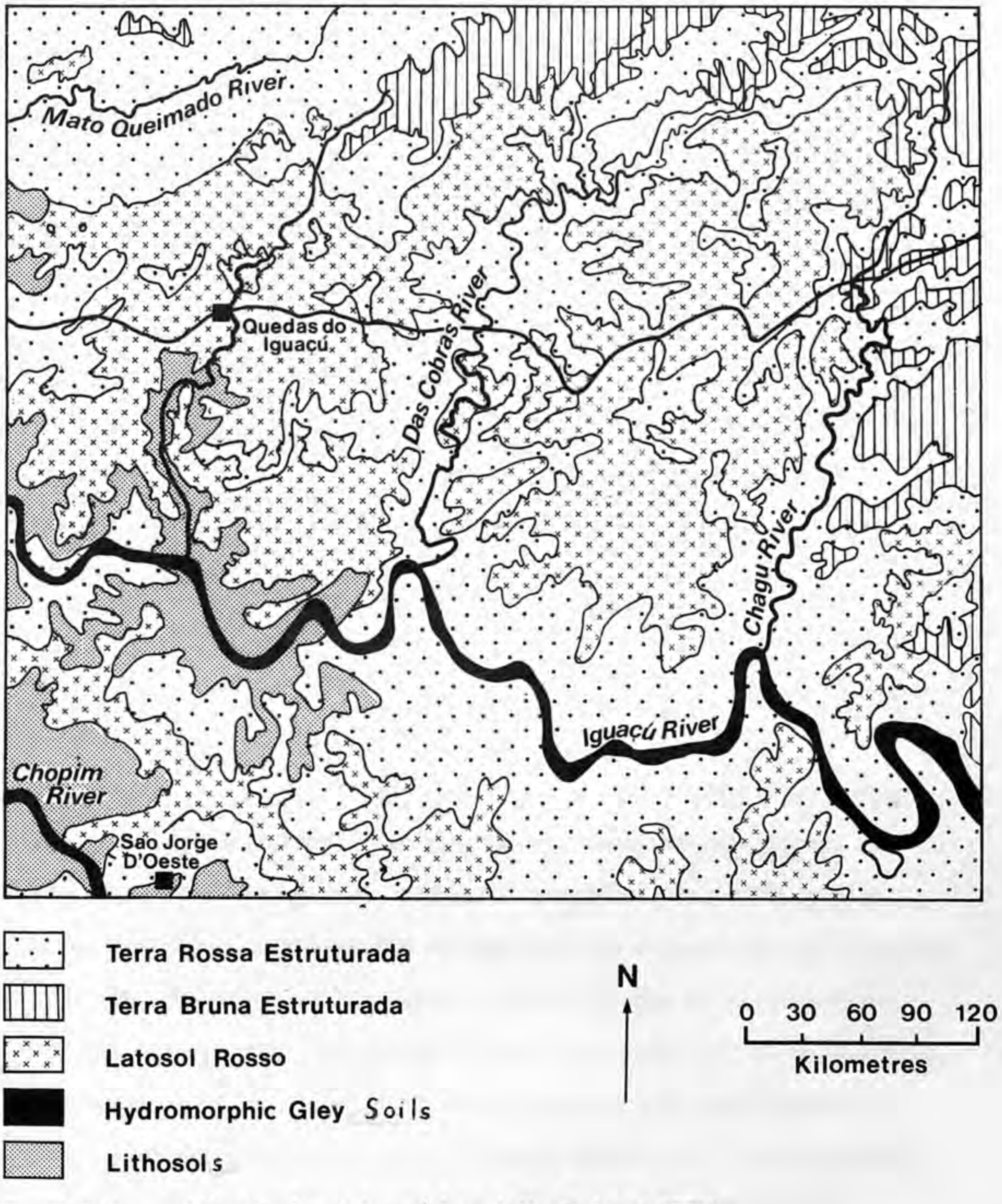


Fig. 11 Soil map of the Quedas do Iguaçú Area (after Embrapa 1975)

texture is uniform throughout the profile and with high concentration of clay in the A and B horizons. Terra rossa estruturada are also deep soils and derived from basaltic lavas but are characterized by a textural B horizon. The soils show a succession of A, B and C horizons. Terra bruna estruturada have similar profile characteristics of terra roxa estruturada, but presents A horizon chernozenic. Lithosols are shallow soils consisting only of A horizon or small C horizon between A horizon and parent material (Empresa Brasileira de Pesquisa Agropecuaria, 1975).

The study area is in one of the richest natural Araucaria forest regions in Parana State. It contains two basic types of forest (tropical and subtropical forests) within which there are many different growing environments. The subtropical forest is mainly represented by a large occurrence of Parana Pine stands. In the study area there is also man-made forest (reforestation) of Parana Pine and _Pinus elliotti_ and _Pinus taeda_.

Prior to the interference of man, the natural forest including the tall Araucaria forest had reached the vegetational climax. At that time, the average age of Parana Pine stands was estimated as being 240 years, although the oldest tree was between 500 and 600 years old. The dense Parana Pine stands had an average 45 trees/hectare. For the exploitation the average commercial height of the Parana Pine was taken as 23 m. Outside the forest there is an easy access by a large number of secondary roads. Inside the natural forest, however, movement is very difficult owing to the dense vegetation, and especially the heavy presence of bamboos in the lower strata. The practical experience acquired from the forest inventory carried out in the area revealed that penetrability in the unexploited forest was one kilometre a day (Jankauskis, 1973).

A comparison of the forest cover type map with the topographic map, covering the area of study, shows that Parana Pine stands generally begin to appear in areas above 500 m elevation (Figures 12 and 10). A comparison of the forest map with the soil map shows that approximately 75% of Parana Pine stands are located on latosol rosso, 24% of the stands on terra rossa estruturada and only 1% on the lithosol (Figures 12 and 11).

7.1.2 Aims and materials of study

The aims of the study of the Quedas do Iguaçú area were to assess and to evaluate the usefulness of Landsat imagery available in CCT and transparency formats in order to map Parana Pine stands and reforestation areas. No effort was made to map different cover densities of Parana Pine stands or different species in the reforestation areas.

The study was carried out in the following stages:

a) visual qualitative temporal analysis of the Landsat scenes in transparency format,

b) supervised computer classification of one selected test site, with a size of 191 x 221 pixels on Landsat CCT,

c) supervised computer classification, of the test site mentioned in the previous step, using data generated from the microdensitometer scanning of the transparency of Landsat MSS bands.

For the present study the following maps and satellite images were available:

a) forest cover type map at 1:250,000 scale (Figure 12),

b) soil map, of part of south-west Parana State, at 1:300,000 scale (Figure 11),

c) topographic maps at 1:100,000 covering the area of study,

d) Landsat images as listed in Table 3.

7.1.3 Interpretation and computer analysis of the Landsat MSS images

An outline of the step by step procedure that was used for the analysis of each area of study is shown in Figure 13. Slight modifications occurred in the course of the interpretation and classification of each area. Such modifications are outlined where appropriate. Basically, each area was analysed throughout manual and visual interpretation and computer-aided analysis.

Initially, the area of study was defined on the 1:1,000,000 print of the MSS band 5. The corresponding digital data (data set) was located on the Landsat CCT. Subsequently, the data set was catalogued in a work computer tape; this would save effort and computer processing time in future manipulations of the data set.

In order to produce imagery for each MSS band, it was necessary to slice the range of the values (digital counts) recorded in each MSS band. In all the produced images the total range of values was divided into 10 equal-sized parts. The image produced was in microfilm plot and could be in negative and/or positive format. Each equal-sized part was represented by a pre-set intensity level on the scale of shading, which ranged from black, through shades of gray, to white. On the positive image, the black level represented lowest digital counts, while the white level represented highest digital counts in the data set.

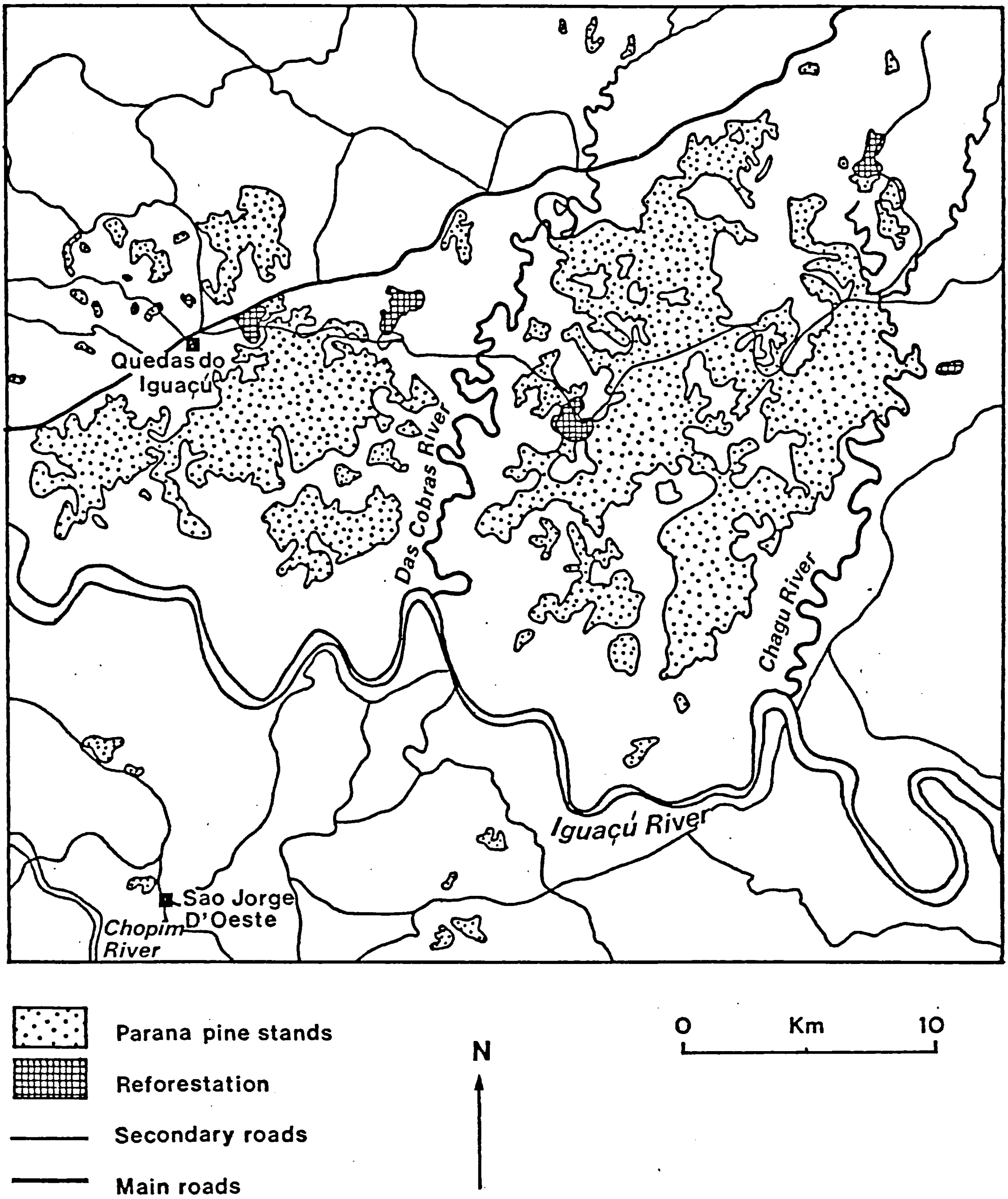


Fig.12 Forest cover of Quedas do Iguaçú region (after Prospec 1974)

Table 3. Landsat data for the Quedas do Iguaçú area

Landsat Identification Number	Landsat	Data (Season)	MSS Bands	Sun Elevation Angle	Sun Azimuth Angle	Time of Observation	Format*	Acquired from
81556/12533580	1	30/Jan/74(summer)	4,5,7	49°	87°	12h 53m	Transparency	NASA
275214/124538	2	02/Aug/75(winter)	4,5,6	29°	48°	12h 45m	Transparency	INPE
275214/124538	2	02/Aug/75(winter)	4,5,6,7	29°	48°	12h 45m	CCT	INPE
82606/12370500	2	19/Sep/76(spring)	4,5,7	40°	62°	12h 37m	Transparency	NASA
82948/12213500	2	27/Aug/77(winter)	4,5,7	31°	58°	12h 21m	Transparency	NASA
378117-124530	3	27/Apr/78(autumn)	4,5,7	33°	50°	12h 45m	Transparency	INPE
378333-124711	3	29/Nov/78(spring)	4,5,7	54°	90°	12h 47m	Transparency	INPE

* All the available transparencies were in 70mm negative format

When the image was produced following the above sequence, the image, in general, lacked tonal contrast because the excessive proportions of pixels were allocated in few equal-sized parts. In this sense, it was necessary to enhance the image in order to extract the maximum information that was potentially represented in the data set. In order to do this, a histogram showing the distribution of the total range of the digital counts, in 20 equal-parts, for each MSS band was produced. An analysis of the histograms allowed the subjective selection of the parameters to be used in the contrast stretching for each MSS band. Then, microfilm plots were produced for each MSS band as initially explained. In almost all cases these images had more tonal contrast than those initially produced without contrast stretching. These positive images, with contrast stretching, were used in the posterior steps of the interpretation. The negative images were used to produce prints.

In the case of the microfilm plot (image) for each individual MSS band from the CCTs, corrections were made for skew and distortion. The correction of skew was necessary due to the eastward rotation of the Earth during the scanning time of the scene; after the application of the correction the image was skewed $3^{o}3'$ toward the west. The distortion factor was applied due to the east-west overlap between adjacent pixels. After the correction, the pixels of the image were rectangular in shape, and were representing a ground size of 56 x 79 m. For the Landsat digital data from the microdensitometer scanning the two mentioned corrections were not required because the transparency had already been corrected for these factors.

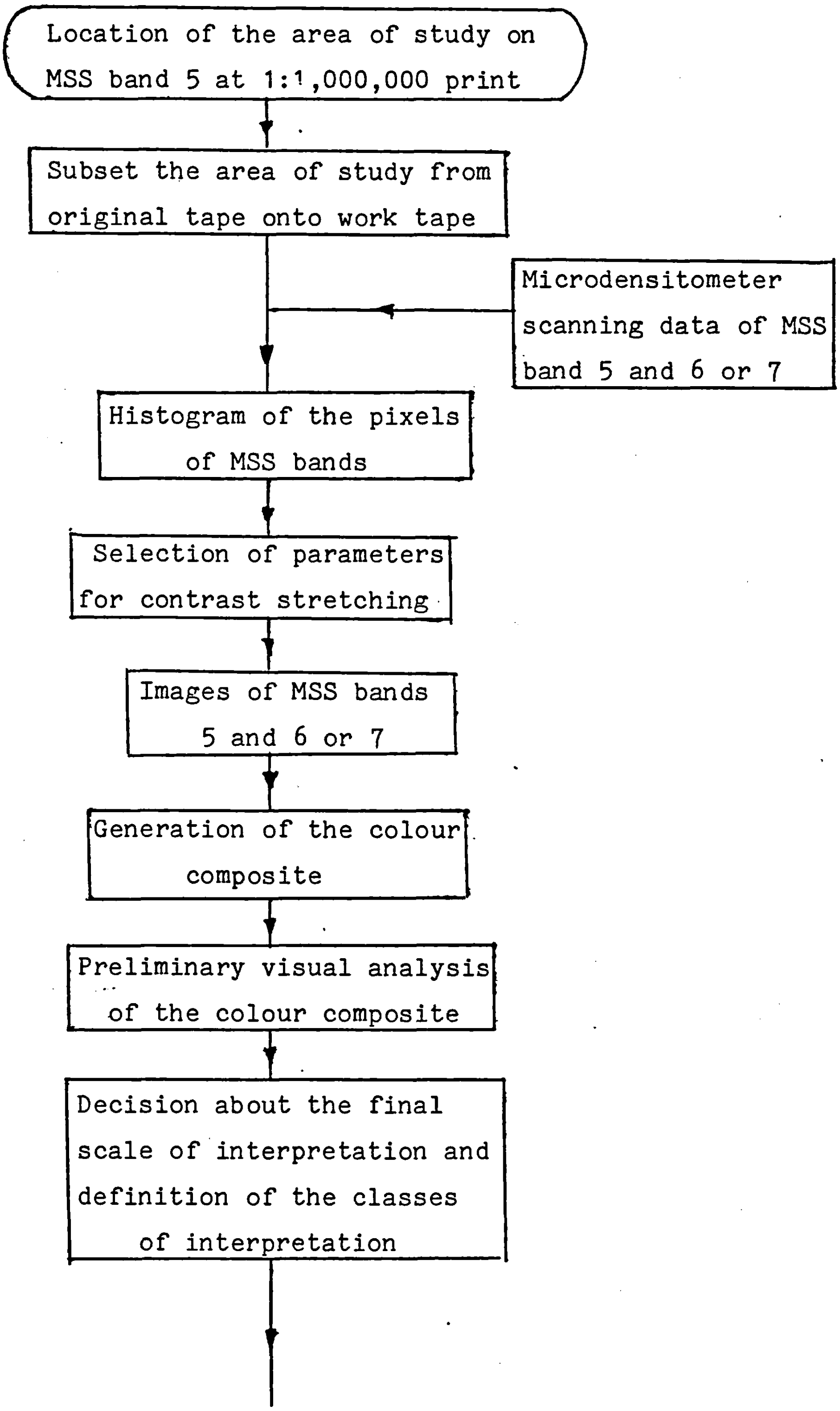
Visual interpretation was carried out either for individual MSS bands (represented by a positive image) or colour composite (generated using two or three positive images of the MSS bands through the additive viewer). The first case resulted in maps showing broadly areas with one of the three classes of gray tone: darkest, dark to medium and medium to light tone. Those maps were visually compared with the forest cover type map in order to find a meaning of each density of gray tone. Meanwhile, for the second case, i.e., interpretation of the colour composite, the following four maps were drawn:

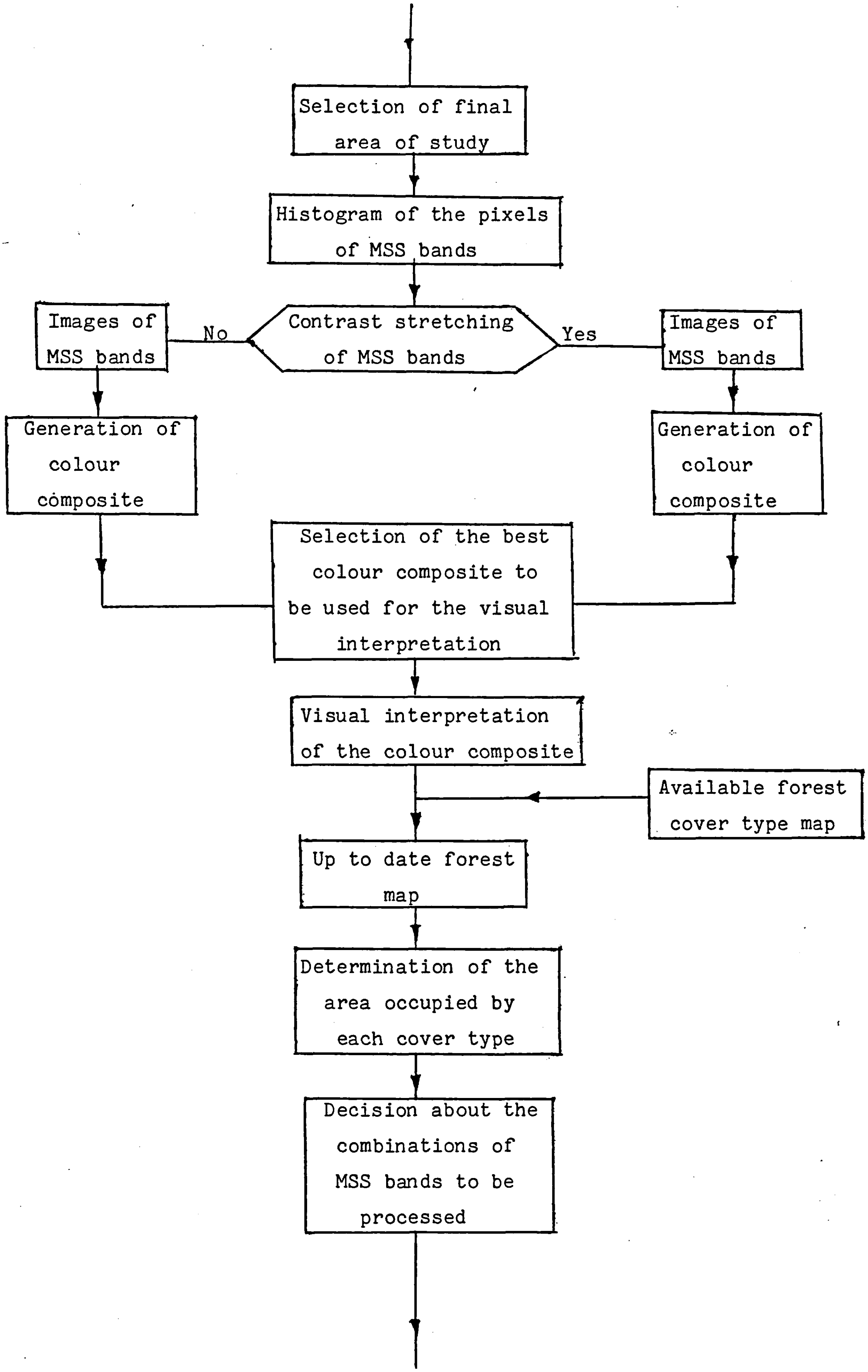
a) the first map showed the areas with different colours that it was possible to differentiate on the colour composite. In order to represent the different tones and colours on the map a "Key of multispectral codes" formulated by Cole and Owen-Jones (1977) was used. In this, the tones were recorded in number from 1 to 9, 1 being the lightest tone and 9 the darkest tone. The colours are designated by a letter (Table 4). For areas containing several colours, the letters are recorded in their order of dominance and the density comes first, i.e. as example 3 ade;

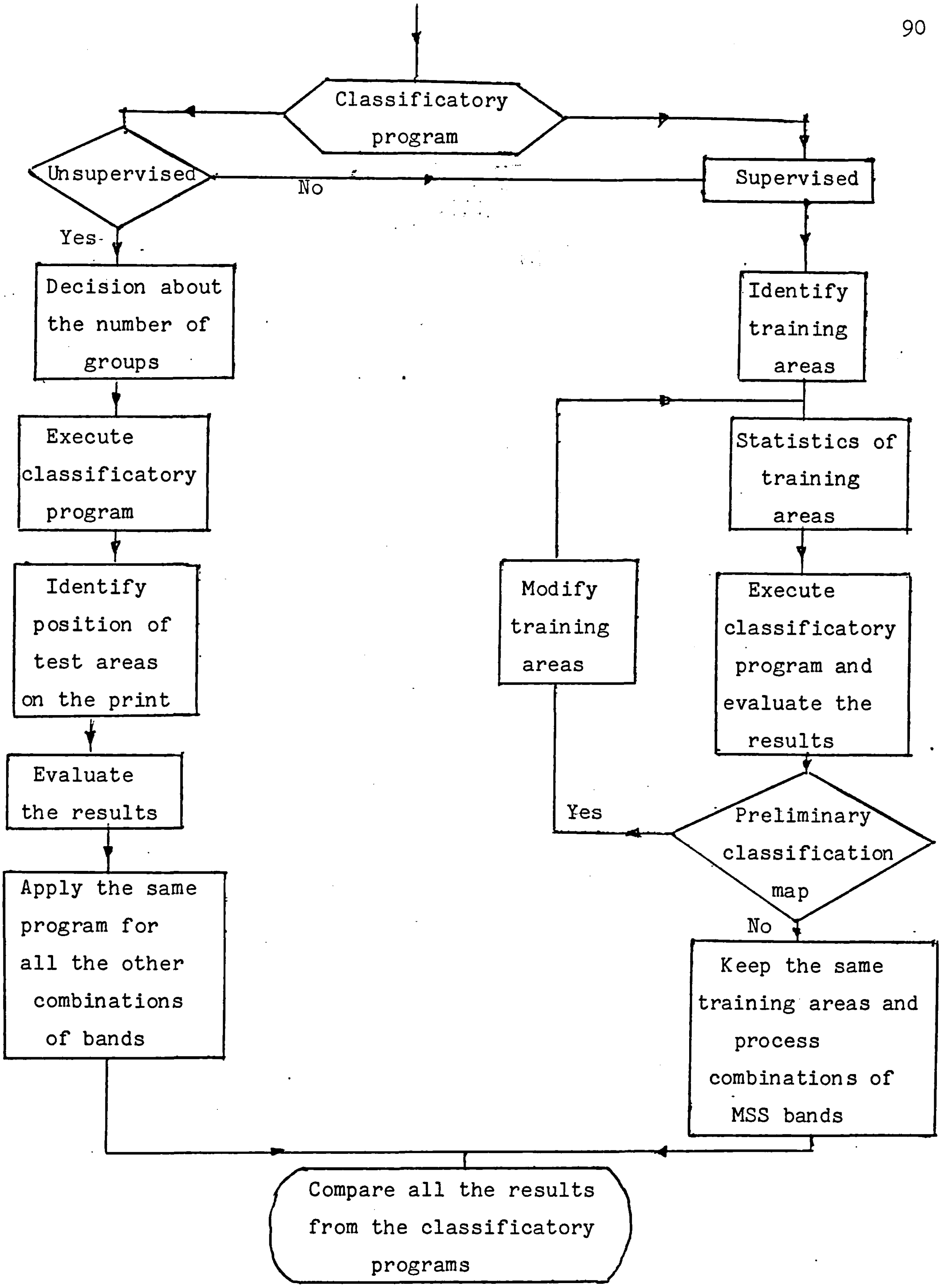
Table 4. Key to Landsat multispectral signature codes

TONE		COLOURS	
1		a	red
2	↓ tones of increasing density	b	orange
3		c	yellow
4		d	green
5		e	blue
6		f	indigo
7		g	violet
8		h	pink
9		k	brown
		n	cyan
		p	emerald
		w	grey
		x	white
		z	black

Figure 13. Step by step procedure for the computer analysis of the Landsat scenes for the area of study




Selection of final area of study
Histogram of the pixels of MSS bands
Contrast stretching of MSS bands
No
Yes
Images of MSS bands
Images of MSS bands
Generation of colour composite
Generation of colour composite
Selection of the best colour composite to be used for the visual interpretation
Visual interpretation of the colour composite
Available forest cover type map
Up to date forest map
Determination of the area occupied by each cover type
Decision about the combinations of MSS bands to be processed


Classificatory program
Unsupervised
No
Supervised
Yes
Decision about the number of groups
Execute classificatory program
Identify position of test areas on the print
Evaluate the results
Apply the same program for all the other combinations of bands
Identify training areas
Statistics of training areas
Modify training areas
Execute classificatory program and evaluate the results
Yes
Preliminary classification map
No
Keep the same training areas and process combinations of MSS bands
Compare all the results from the classificatory programs

b) the second map was drawn to show only areas with red colours, which was subdivided into three broad density categories, namely: dark red, red/pink, and light red/pink. A third map showed areas with green colour and the other remaining colours. The red and green (with other remaining colours) colour spectral signatures were representing, respectively, forest and non-forest areas on the Landsat colour composite;

c) the fourth map showed only those areas considered by visual interpretation as having the same colour spectral signatures as stands of Parana Pine.

After this series of maps had been drawn the forest cover type was redrawn to the scale of the Landsat colour composite. All the discernible points, drainage lines and forest cover types were transferred to this new map, using the mono zoom transferscope. A posteriori, this resulting map was visually compared with the Landsat colour composite to identify the forest areas that had been exploited or cleared and converted to non-forest areas. Only gross comparison was made. The exploited areas and forest areas converted to non-forest areas were represented in different colour spectral signature, i.e. in mixed green-red, yellow or green. This updated forest map,to the data of acquisition of the Landsat scene,was regarded as ground truth map. In it, the areas of different cover types were measured using the grid method. Each point of the grid was representing the same area covered by one pixel on the Landsat scene. These areas values would be used as one way to evaluate the results of the computer-aided classification.

For the test site computer classification it used supervised and

and unsupervised programs.* It was necessary to select training areas for the class of interest to be mapped only for the supervised program. The available unsupervised program works strictly with the data set and because of this it was necessary only to define the number of spectral classes (groups) into which the data would be divided.

Visual analysis was carried out in the Landsat colour composite, displayed on the screen, in order to select representative and homogeneous training areas for the classes to be mapped. The cartesian co-ordinates of the corners of the training areas for the individual

---

* These classificatory programs were available in the Bedford College Image Processing Library. The supervised program applies the quadratic decision rule as the strategy of the classification. The quadratic decision rule is a maximum likelihood decision rule in which a series of pairwise decisions are made to minimize the distance between each individual pixel value and its class mean. This decision procedure is repeated for each pixel until all the pixels have been assigned to one of the classes whose vectors were initially defined by the training areas.On the other hand, the unsupervised program available is based on polythetic divisive method. Polythetic classification means that samples (i.e. pixel digital counts) may be grouped together as a result of the similarity between only some of their attributes and not necessarily between all of them. The total population of pixel digital counts (data set) is initially divided into the two most dissimilar groups. The decision on where to split the group is accomplished by calculating the shortest distances (i.e. euclidean distances) between pixel density counts and ensuring that the variance (based on mean distance of each observation from the relevant mean value) between each group exceeds the variance within each group. From these two groups, that one which possesses the largest variance is subdivided into a further two groups. So that three groups are present in the whole population. This procedure is repeated until all the pixels are classified into a number of groups initially specified. Detailed information about these two classificatory programs and also about other non-classificatory programs used are reported by Chandler (1977) and Maizels (1977).

classes were perforated on computer cards. These cards were joined to the basic deck cards necessary to process the supervised program. The output of the classification reported the mean digital counts and standard deviations of each MSS band for each class and the covariance matrix , the number of pixels allocated in each class and the computer classification map, which could be in microfilm format or through the printer line of the computer.

The mean digital counts* of the MSS bands for all classes, as supplied by the computer program, were plotted on paper. This provided a better display of the spectral separability between classes and better understanding of a possible area of conflict of the classes in each MSS band.

The results of the two classificatory programs were evaluated through three techniques, one of them qualitative in approach and the other two quantitative.

For the qualitative evaluation, the computer classification map was visually compared with the forest cover type map.

For the quantitative evaluation, two approaches were used:

a) estimates of the total area of various forest cover types obtained from the computer-aided classification of the Landsat data were compared with estimates made from the up to date forest map;

---

* NASA divides the original radiation brightness values of ground objects into 128 levels, i.e. with the digital counts ranging from 0 to 127. However, in the CCT produced in INPE the range of digital counts is from 0 to 255. The Bedford College Image Processing Library adopts a conversion factor to extend the NASA range from 0 to 999. Accordingly, a computer program was written (Appendix 1) to extend the range of digital count from the INPE CCT also from 0 to 999.

b) through self-classification, i.e. the pixels of the training areas initially defined for each class were compared with the same correspondent pixels on the computer classification map.

A computer program was written to report the results of the self-classification accuracy for all the classes mapped through supervised classification (Appendix 2). The program reported the number of pixels and the correspondent percentage of the pixels correctly classified in each class. It also reports the number of pixels classified as belonging to other defined classes.

The training areas defined for the classes in the supervised program were used to evaluate the results of the unsupervised classification. The position of the training areas were located on the photographic print of the microfilm output of the unsupervised classification. The classification accuracy for each class was acquired simply by the counting of the correct number of pixel classified in those defined areas.

The supervised program was submitted different times with changes in the position of the training areas, until the results of the classification were considered as acceptable. Initially, only a combination of bands 4, 5 and 7 was tested. When the results showed that increase in accuracy would be difficult, the training areas were retained as definitive and the supervised program was submitted to the other combinations of MSS bands. Conversely, the unsupervised program could be processed only once due to the strategy used in the program.

7.2 Visual qualitative temporal analysis of the Landsat transparency scenes for the Quedas do Iguaçú area

As six scenes for the area of study were available, it was possible to carry out a qualitative temporal analysis of the Landsat scenes available in transparency format. The scenes were acquired during the four seasons of the year, although three scenes were from the winter time (see Table 3).

An ideal approach would be a quantitative temporal analysis of the forest area using Landsat CCTs, instead of qualitative temporal analysis using transparencies of the MSS bands. However, the cost of the CCTs precluded their use in this phase of research.

According to Landgrebe (1978a) the knowledge of temporal variation is useful in three ways. Firstly, it helps in determining the optimum time for deriving information relative to the class of interest, in this particular case the Parana Pine stands. Secondly, the requirement is simply for a time of what takes place. Thirdly, it is useful for the multivariate approach to data analysis. For the present study, the temporal analysis will be limited to the first two ways as mentioned above, since no multivariate approach was considered.

The forest land in Quedas do Iguaçú is under severe exploitation. The visual analysis concentrated only on those main areas with Parana Pine stands. The concentration of the stands in some places facilitated their spatial location and the visual analysis. The forest cover type map, which was in original 1:250,000 scale, was enlarged to 1:100,000 scale. It was used for the confirmation of the presence of Parana Pine stands as identified on Landsat scenes. In order to meet the requirement for projection at 1:100,000 scale, each negative transparency MSS band was enlarged to 1:1,000,000 scale in the photographic laboratory and the corresponding area of study was photographically copied in transparency. These enlarged transparencies were used in the additive viewer, in order to generate colour composites on screen at 1:100,000 scale.

The visual qualitative temporal analysis of the scenes was performed twice. Firstly, the scenes were analysed in the chronological sequence in which they were acquired, for the reason that it was to elucidate a time history of what takes place. In the second instance, the scenes were evaluated according to the season of the year in which they were acquired, beginning with the summer scene. This was in order to take into account the difference between the dry and the rainy season and also the variations of sun elevation and azimuth present in the scenes for each season.

In order to express the qualitative results of the visual analysis of the Landsat scenes the terms 'detectable' and 'identifiable' were used. Each term was subdivided into three categories, namely: easily, marginally, and not identifiable or detectable, according to the visual analysis of the image of the class of interest. Both terms and subdivision were used by Krumpe* (1973) in the study of wildland landscape in California.

7.2.1 Results of the visual analysis

In the individual MSS bands 5 and 7 and in the colour composite of Landsat, 30 January 1974 overpass, the tropical forest close to the valleys of the main rivers was represented by a spectral signature of lighter tone and in a lighter red spectral signature than Parana Pine

---

* Krumpe defined detection as: the ability to discriminate an image entity from the surrounding tone matrix. Identification was defined as: the ability to classify and assign a name to an image determined by its unique characteristics such as colour, tone, texture, shape, pattern, size, association or other quality.

stands. Figure 14 shows the area of study as seen on MSS band 7; on the image are outlined areas supporting tropical forest (points A, B and C) and large Parana Pine stands (points D, E, F, G and H). The points D, E and F are located close to the town of Quedas do Iguaçú which is not easily detectable on the image. The points G and H are located in dissected areas. The east central part of the image is covered by clouds. Point I shows the image of the cloud and its dark shadow reflected on the surface.

January had been one of the hottest months in the year. The average temperature* in the month was: maximum = 29.7°C and minimum 17.3°C. There was 223.7mm of rainfall during the month and there was 5.0mm of rainfall recorded for the day of the Landsat overpass. The road that crosses the area and the town of Quedas do Iguaçú was easily identifiable only on MSS band 5 and on the colour composite; this identification was unique to this scene. The colour composite had good image contrast since "during the wet summer season rainfall removes the dust, producing a clear atmosphere and good image contrast" (Grootenboer, 1973, p. 654). When the Landsat scene was acquired the area covered by vegetation was in full leaf. It was also the growth period and Parana Pine stands were easily detectable on the MSS images of the Landsat scene.

The Landsat scene from 02 August 1975 was one of the best scenes available for the study, although the main road and the urban area

---

* The January 1973 meteorological data was acquired from a station located on the junction of the Iguaçú and Chopin rivers. These data were supplied by COPEL ('Companhia Paranaense de Energia Eletrica'). However, all the other meteorological data mentioned were supplied by the Cia Giacomet-Marodin Ind. de Madeiras S/A and related to the town of Quedas do Iguacu.

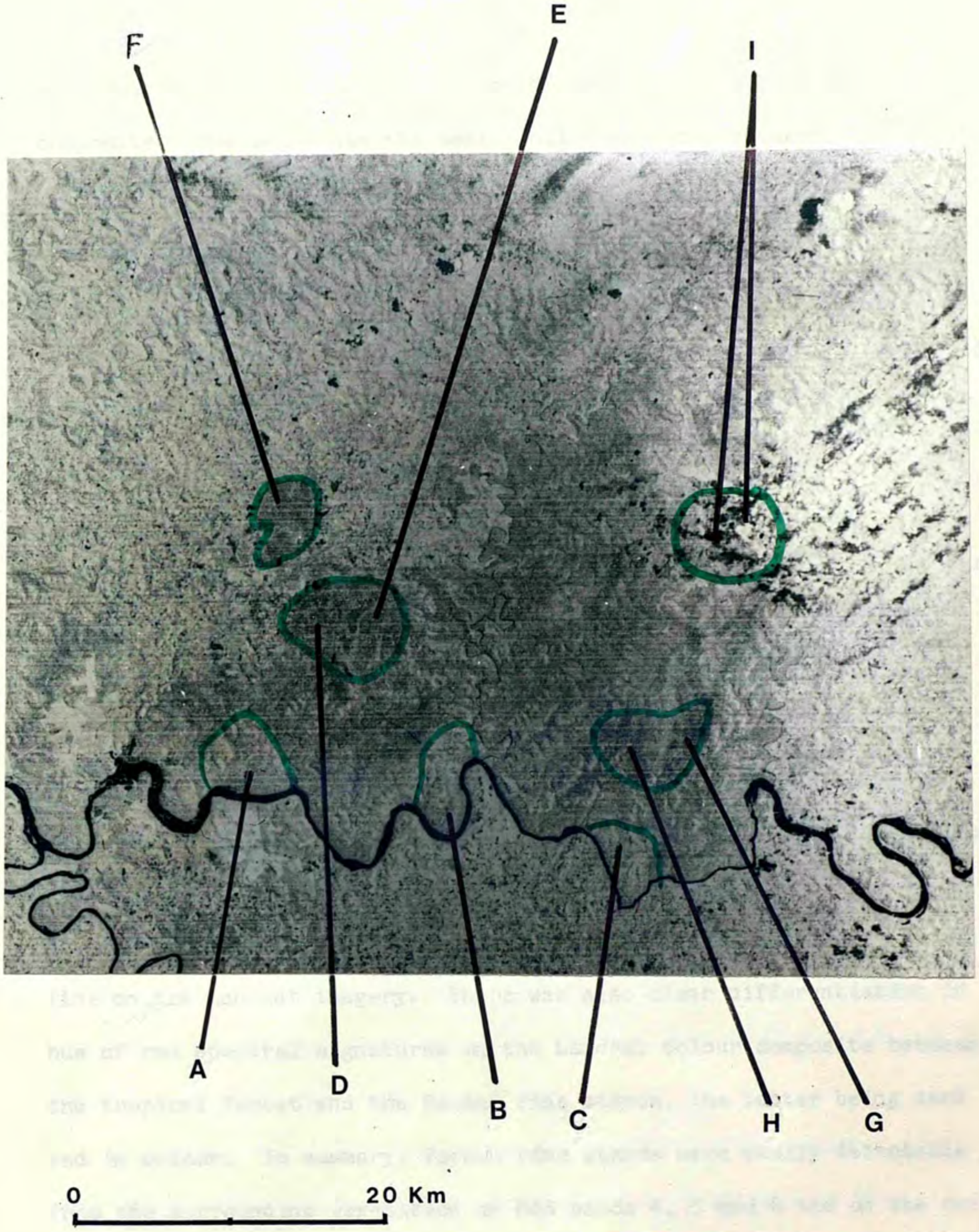


Figure 14. Part of the Landsat 2 image from 30 January 1974 overpass, MSS band 7, showing the Quedas do Iguaçú area (see text for meaning of the letters).

were only marginally identifiable on MSS band 5 and on the colour composite. The scene had the best tonal contrast for vegetation mapping.

Part of the image of MSS band 5 for the 02 August 1975 Landsat overpass, covering the Quedas do Iguaçú area, is shown in Figure 8. In it, it is possible to locate the five points outlined on Figure 14 that identify Parana Pine stands, although the points are not indicated on the figure.

No substantial change in temperature was registered between 31st July and 1st and 2nd August 1975; the average values were: mean maximum = 28°C and mean minimum = 10°C. No rainfall was observed during these three days. However, earlier in July snow covered the south of Brazil. This resulted in heavy damage to agriculture. DaSilva (1978) reported that at that time in the area near 20 km west of the town of Quedas do Iguaçú there was severe frost for three consecutive days, followed by four hours of snow. This led to sharp contrast between the vegetation (probably dried or severely damaged owing to the unusually low temperature and the weather conditions) and the evergreen Parana Pine on the Landsat imagery. There was also clear differentiation in hue of red spectral signatures on the Landsat colour composite between the tropical forest and the Parana Pine stands, the latter being dark red in colour. In summary, Parana Pine stands were easily detectable from the surrounding vegetation on MSS bands 4, 5 and 6 and on the colour composite generated from MSS bands.

On the Landsat scene for 19 September 1976 Parana Pine stands could again be detected on the individual MSS bands 5 or 7 or on the colour composite. For the days 17th, 18th and 19th September the mean temperatures were: maximum = 27°C and minimum = 9°C. No rainfall was observed during the three days before the scene was acquired. The scene was acquired in late spring and the vegetation was in its initial growth phase.

In the scene from 27th August 1977 Parana Pine stands were not detectable on band 5, although the MSS band expressed a clear contrast between forest and non-forest areas. The main road and the town were marginally identifiable on the image.

Figure 15 shows a cloud free image of MSS band 7 for the area of study with the same points indicated as in Figure 14. Point A shows a dark grey tone image different from the rest of the tropical forest. This is as a result of the substantial increase in soil moisture due to the flood issuing from the hydroelectric dam; the same is reported for the next two Landsat scenes available for 1978. Points B and C supporting tropical forest continue to show lighter tone than Parana Pine stands. The Parana Pine stands, represented originally by the points D and F close to the town, had been severely exploited and with most of the forest were cut, and as a result showed contrasting and lighter tones than the dense Parana Pine stands in point E. Points G and H continue to represent dense stands of Parana Pine.

The scene was acquired in the middle of winter. For the 25th, 26th and 27th August the average maximum temperature was 20°C and the average minimum temperature was 9°C. On the 24th of August 12mm of rainfall had been recorded.

A comparison of the images for 30th January 1974 (summer) and 27th August 1977 (winter) shows that seasonal variations in the reflectance are evident in the infra-red MSS bands (Figures 14 and 15). On the images acquired in winter (as for example, Figure 15) geological lineaments are more evident than on the summer images (as for example, Figure 14) due to the lower sun elevation and azimuth angle.

On the Landsat scene for 27th April 1978, Parana Pine stands were also not detectable on the image of MSS band 5, although the stands

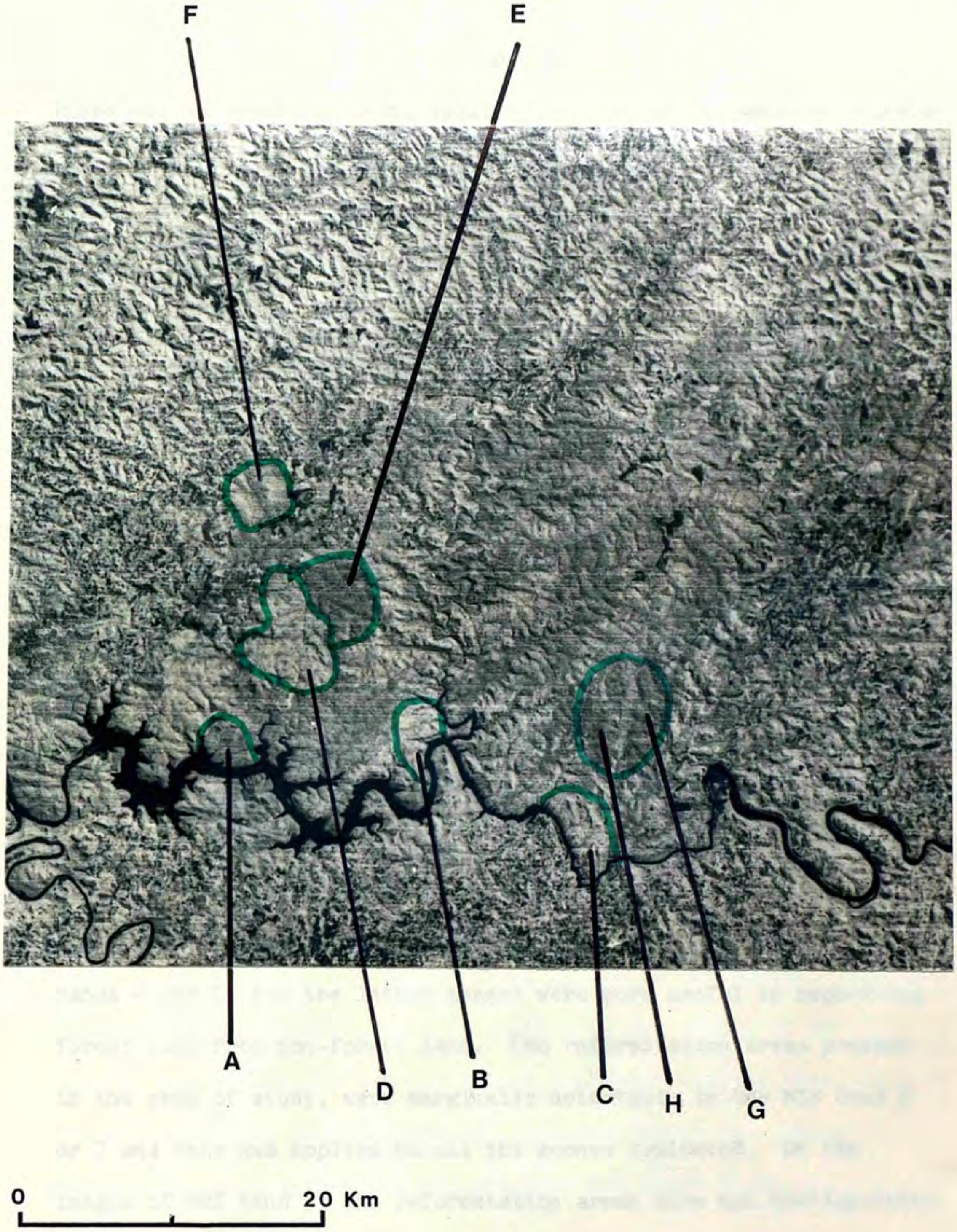


Figure 15. Part of the Landsat 2 image from 27th August 1977 overpass, MSS band 7, showing the Quedas do Iguaçú area (see text for meaning of the letters).

were detectable on the image of MSS band 7 and on the colour composite. There was no rainfall during April 1978. The period between December 1977 and July 1978 in Parana State was characterized by a severe dry period and it was followed by severe frost in July and August. Thus, in the ground, the vegetation was probably severely affected due to the severe dry period.

There was little contrast in the colour composite of the Landsat image for 29th November 1978 of the Quedas do Iguacu area. The town of Quedas do Iguaçú and some small non-forest areas were represented in green colour in colour composite, whilst the bulk of the area was represented in red colour. This was apparent on the image of colour composite on the screen at the 1:100,000 scale for the area of study as well as for the full scene of Landsat projected at 1:250,000 scale. A detailed analysis, however, on the 1:100,000 scale revealed that Parana Pine stands were detectable and separable in the forest context on the image of MSS band 7, but not in the MSS band 5.

On all the six Landsat scenes evaluated, the image of the MSS bands 6 and 7 gave more contrast in terms of vegetation than MSS bands 4 and 5, but the latter images were more useful in separating forest land from non-forest land. The reforestation areas present in the area of study, were marginally detectable in the MSS band 6 or 7 and this was applied to all the scenes evaluated. On the images of MSS band 5, the reforestation areas were not distinguished from the Parana Pine stands. On the images of MSS bands 6 or 7, the reforestation areas were represented by lighter gray tone than Parana Pine stands.

In all the scenes evaluated, the Parana Pine stands were represented by the darkest tone on the images of MSS band 5 and by dark gray tone on MSS band 6 and 7. The stands could be detected but were not identified. For all the six scenes, the Parana Pine stands were easily detectable on the MSS bands 6 or 7, but on the image of MSS band 5, they could be easily detected only in the considered images acquired in 1974, 1975 and 1976. On the other three images of MSS band 5 acquired in 1977 and 1978, Parana Pine stands were not detectable, because all the vegetation was expressed by the same darkest gray tone in the image. An analysis of these negatives revealed that there was not enough contrast in gray tone related to the forest area of study. Also, prints of those negatives on different photographic papers, including a high contrast paper, revealed no successful way in which to discriminate Parana Pine stands from the vegetation.

In summary, for the qualitative analysis of the Landsat scenes available in transparency format, it was possible to apply the term 'easily identifiable' only to forest land and to the main rivers such as the Iguaçú and the Chopin (as seen on the image of individual MSS bands 4 and 5, or generated colour composite). On the image of MSS bands 6 or 7 only the rivers could be easily identified. The Parana Pine stands were easily detectable in the images of the MSS bands 6 or 7 in all the Landsat scenes available for the four seasons of the year. Only in three scenes, from a total of six, could the stands be easily detected on the image of MSS bands 4 and 5.

7.3 Computer-aided analysis of a selected test site

7.3.1 Selection of particular test site for detailed studies

The forest land in the Quedas do Iguaçú was represented by an area of

760 x 450 pixel size on the Landsat CCT. The Bedford College Image Processing Library can only handle a desired area that does not exceed 500 x 500 pixels or pixel groupings (Maizels, 1977). Hence, in order to process the data set covering the whole forest area in one operation the original data set was reduced to a smaller file size. This was done by combining every group of 4 pixels (two in x direction and two pixels in y direction) into a single value. The final microfilm output had a dimension of 380 x 225 pixels. However, visual analysis of the colour composite generated from the MSS band 5 and 7 revealed loss of detail of information; the Parana Pine stands were not consistently represented as compared with partial microfilm outputs with one pixel grouping.

It was decided therefore to select a test site supporting different land use/land cover classes to be computer processed, i.e. an area with great spectral contrasts and readily identifiable ground truth features. Thus, an area of 221 x 191 pixel size, located inside the Quedas do Iguaçú area, imaged on 02 August 1975 scene (Landsat ID 275214/124538) was selected for an attempt to map the following classes: Parana Pine stands, the urban area of the town of Quedas do Iguaçú and reforestation areas.

The position of the test site was easily located on the forest map by reference to the position of the town, to the road that crosses the area and to the two large reforestation areas present in the area of study.

One reforestation area of 175 hectares (as determined from the forest map) was located close to the town. The main species were Parana Pine and Pinus elliottii, planted between 1965 and 1970. The average height of the tallest trees, as measured during the fieldwork, was approximately 14m. All the stands were dense, well formed and supported an average of 1500-2500 trees per hectare. The second reforestation area covering 215 hectares (acquired from the forest map) was composed mainly of Pinus elliottii and Pinus taeda planted between 1967 and 1972. The average height of the tallest trees was 12m; all the stands were dense with between 1500 and 2500 trees per hectare and well formed.

7.3.2 Method of Analysis

The selected test site, in the Quedas do Iguaçú area, was processed by computer classification using Landsat digital data from CCT and from the microdensitometer scanning of transparencies of MSS bands.

The initial intention was to classify the test site, with data originated from the CCT, using only the computer facilities at Bedford College. During the course of the fieldwork however, the author had access to the interactive image processing system Image 100 at 'Instituto de Pesquisas Espaciais' (INPE) in Brazil and used this equipment to extract thematic information and enhance multispectral imagery.

Initially, the data set of the test site was processed at INPE. The corresponding image of the colour composite, generated from the stretched MSS bands 4, 5 and 7, was displayed on the screen of Image 100. From this colour composite, training areas for each land use/land cover classes (Parana Pine stands, reforestation areas, urban areas, forest without Parana Pine stands and non-forest areas) were selected carefully, so that they could be considered to be representative of the respective classes. The training areas were selected with the aid of the forest cover type map; the knowledge acquired during the preliminary analysis of the images of the Quedas do Iguaçú area and during the fieldwork also contributed to the selection of the training areas. The data set was finally classified using the supervised program (MAXVER*) available in on-line-mode on the Image 100. Thereafter, the supervised computer classification map was displayed on the screen of the Image 100 and photographically recorded on 35mm film (slides).

Subsequently, the same test site was processed by the supervised classification program available at Bedford College. The position of the training areas for the classes, previously defined on the screen at Image 100, were correspondingly identified on the colour composite on the test site generated from the use of the images for MSS bands 5 and 7 on the additive viewer. This assured that the same training areas were used in the classificatory program.

The figure 5.0 was used as threshold value** for the MAXVER program. That value is commonly used in the classificatory programs

---

* Pixel-by-pixel Maximum Likelihood Gaussian Classifier (MAXVER). This algorithm assumes that each class, which is defined by the training areas set, is represented by a multivariate normal distribution. For each pixel of the data set, is calculated the following expression related to each class, $d^2 = r^2 + \log |C|$, where r^2 is the euclidean distance and C is the covariance matrix. The algorithm transforms the data of each defined class for the particular case in that the variance matrix is equal to the matrix unity and the mean of the class coincides with the origin regarding the digital counts of the MSS bands. With these transformations being carried out, r^2 can be calculated as an euclidean distance between the point considered (pixel) and the origin (Velasco et al, 1978). The pixel is allocated to the class which produced the smaller value for d^2.

** When for a considered point (pixel), the value for $d^2 = r^2 + \log |C|$ is bigger than 5.0, the pixel is not allocated in any defined class. "Thresholding allows the researcher to arbitrarily screen out those picture elements not demonstrating a high degree of correlation with user-designated spectral classes" (Messmore et al, 1975, p. 332).

carried out at INPE (Moreira, 1980). However, no value for threshold was established for the program at Bedford. In these two classification programs, the four MSS bands were processed together.

Six Landsat scenes in transparency format were available for the study of the test site (as reported in Table 3). A microdensitometer scanning for the area of the test site, represented on each individual transparency of the MSS bands, for all the Landsat scenes would have been very time-consuming. Two scenes were selected. The scene for 02 August 1975 was chosen because it was available in CCT and in transparency formats. The scene for 19 September 1976 was selected from the available scenes because Parana Pine stands were detected on its images of MSS bands 5 and 7.

In each of the selected Landsat scenes, the corresponding area of the test site on the transparency of the MSS band 5 and on the transparency of the MSS bands 6 or 7 was scanned and digitized on the Joyce Loebl microdensitometer model MK3 CS in the Physics Department of Bedford College. The MSS transparency was translated to the source/receiver optics of the microdensitometer in a flat plane.

The aperture size (pixel width) for the scanning was 0.06mm (60 µm) corresponding to a ground 'pixel' of dimension 202 x 202m. The aperture size of 0.06mm was selected in order to accommodate near the maximum pixel measurements* into a single paper tape and to scan an area of reasonable size (9mm x 9mm) inside which was the test site. The smaller the aperture size used, the smaller the area of scan in

---

* The area scanned in each MSS transparency resulted in 150 x 150 pixels. The total of digital density values for each scanning was 150 x 150 = 22,500. These values were digitized in a single paper tape, which can accommodate a maximum 28,000 values.

the MSS transparency and the more difficult the accurate location of the area on the transparency. The ERTS Data User's Handbook (NASA, 1976) points out that only macrodensity work should be undertaken and recommends 1mm as minimum size aperture for 70mm transparencies. This aperture size would correspond to a ground area of nearly 700 hectares. In the present study each pixel was representing a ground area of 4.08 hectres.

No correction was made for the differing solar elevations between different Landsat overpasses in the original density values. All the adjustments on the microdensitometer (variations of gray level, pen damping, speed and differential control) were kept the same for all the scanning.

The density values, in each of the paper tapes, were also transferred and stored on a computer tape. This would save effort and computer time in the subsequent steps of the analysis. Since the data was suitable for computer processing, it was possible to follow the steps for the computer analysis as outlined in Figure 13.

A colour composite was generated from the images of the MSS bands for each scene. A visual analysis of each colour composite showed that slightly different areas had been scanned in each MSS transparency. Perhaps, the area of the test site was present in the colour composites produced for the two different scenes. Only the area corresponding to the test site was needed for the computer analysis; the other parts of the colour composite were eliminated for the analysis. The final size of the test site was the same for all the two different scenes and was represented by an area 58 x 70 pixel size.

Only supervised classification was used in order to map Parana Pine stands and reforestation areas. No attempt was made to map urban areas, which was represented in too few pixels to be classified.

7.4 Results and analysis of the results

7.4.1 Supervised classification using CCT data

Training areas were defined for six different classes, as seen on the colour composite on the T.V. screen of Image 100 (Figure 16). Three classes were related to forest, namely: Parana Pine stands, reforestation areas and forest land; all the classes were characterized by red spectral signatures. The other three were non-forest classes, one of them named urban area and the other two classes namely non-forest areas, which were selected according to their colour spectral signatures, i.e. green and yellow.

Noise in the data image, caused either during the data acquisition by the multispectral scanner, or in the transmission of the data to the ground receiving station or in the processing of video data and consequently production of CCT, was not eliminated for the digital processing. This noise was represented by light green colour areas on the colour composite (see Figure 16), most of these within the forest areas.

The 221 x 191 pixels of the data set were represented on the screen of Image 100 by 512 x 512 pixels. The areal results of the classification were later converted to the real number of Landsat pixels.

There is a remarkably close correspondence between the forest cover type map (Figure 17) and the Landsat colour composite reported in Figure 16. In the last Parana Pine stands and the reforestation areas were clearly defined while areas of exploited forest and urban development land use had distinctive and contrasting spectral colour signatures.

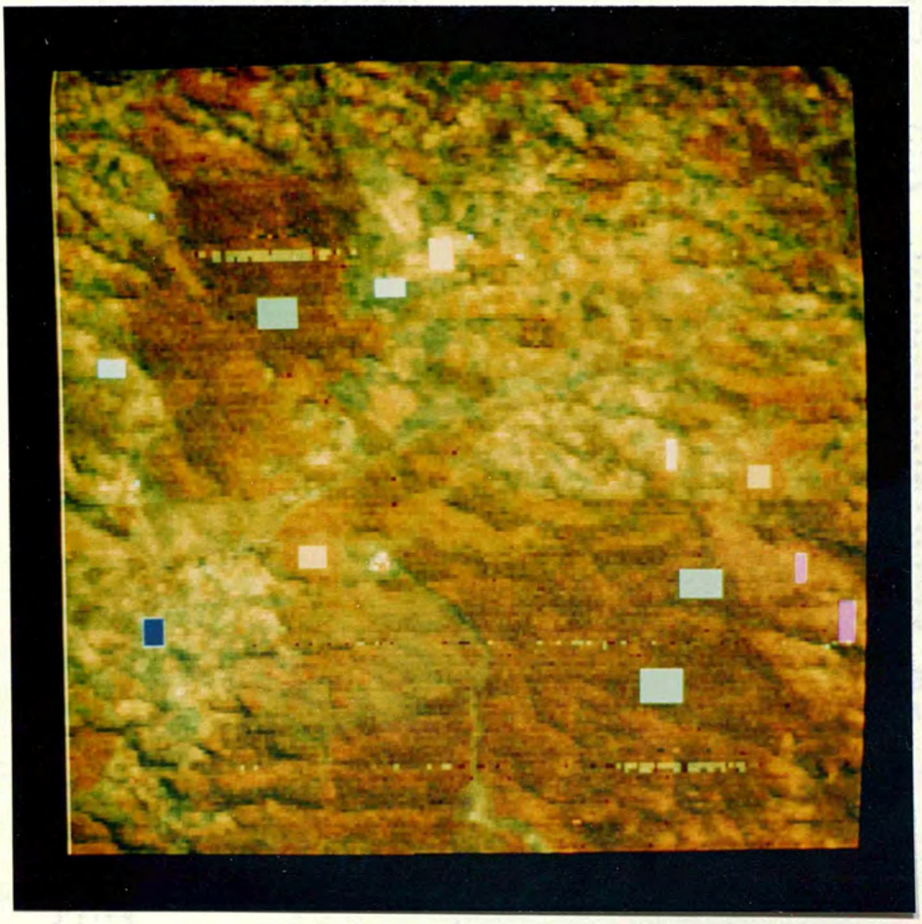


Figure 16. Selected test site in the Quedas do Iguaçú area. Colour composite, generated from the MSS bands 4, 5, 7 showing the position of the training areas for the classes used in the supervised classificatory program. Landsat 2 of 02/August/1975 overpass.

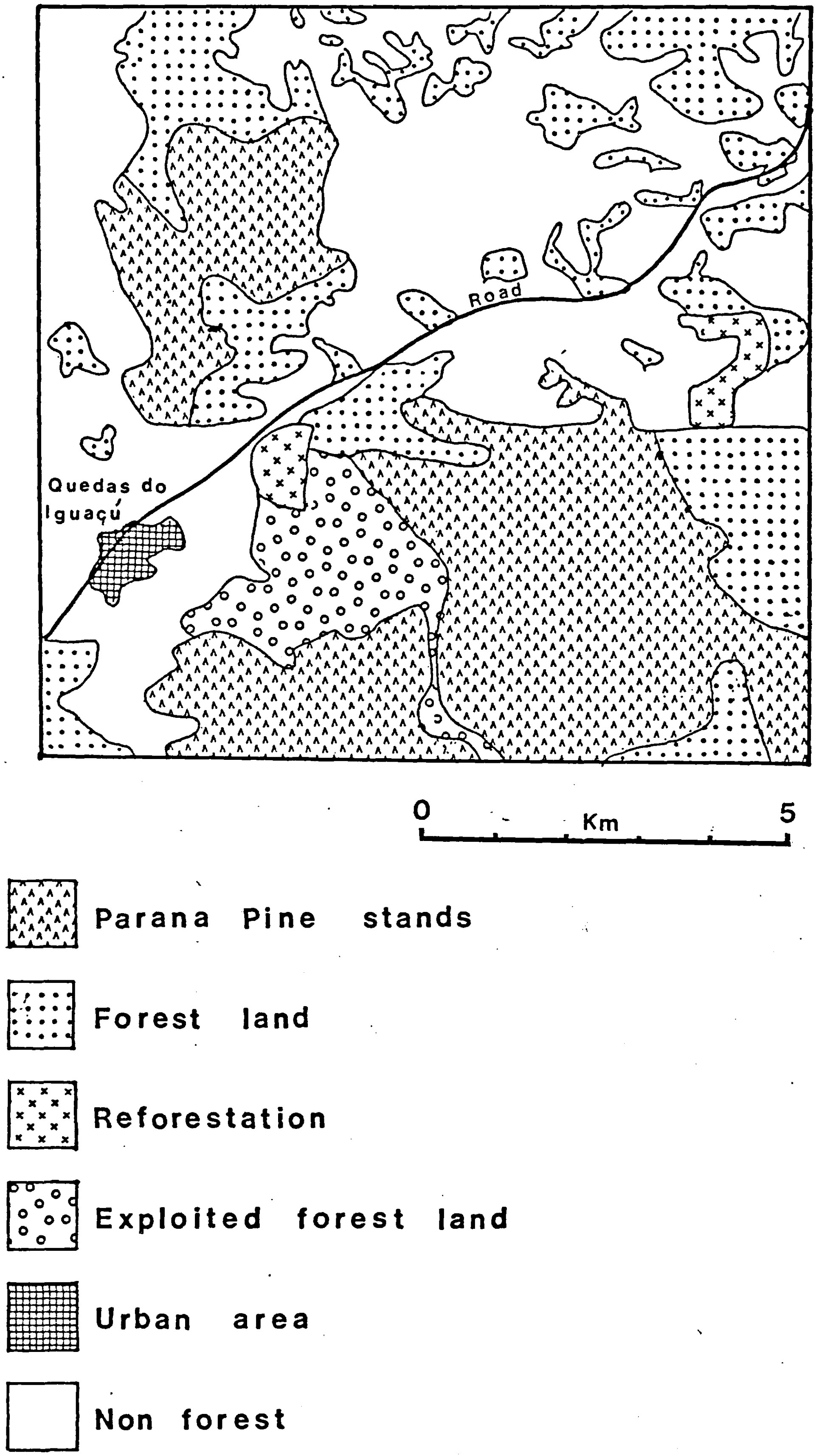


Fig. 17 Forest cover type map of the selected test site in the Quedas do Iguaçú area (based on figs. 12 and 16)

The results of the supervised classification carried out on the Image 100 is shown (Figure 18). Each class was assigned a different colour. Later, the same test site was classified using the supervised classification program available in Bedford College and the resultant computer classification map is outlined in Figure 19. The quantitative results of the classificatory programs, either in classification accuracy or in areal estimates, are reported in Table 5. Also, the number of pixels used as training areas for each class that were derived from the program at Bedford is indicated.

The results of the supervised classification carried out on the Image 100 indicated very well the information that could be extracted from a detailed visual analysis of the colour composite. Although, no training areas had been used for the exploited areas, they were largely classified as non-forest areas. The noise was not classified into any of the established classes and was represented in black colour as seen in Figure 18.

Through qualitative analysis there is no clear difference between the two outputs resulting from the different classificatory programs (Figure 18 and 19), except in the visual method, i.e. one in colour and the other using shading pattern to represent each class of spectral signature.

Using the classification accuracy for individual classes, there was a difference in the results given by the classificatory programs only for the non-forest classes. This difference was 10%. Conversely, the achieved individual class accuracy was near the same, using the two classificatory programs, for mapping Parana Pine stands, reforestation areas and forest without Parana Pine stands.

The mapping of non-forest areas using the Bedford College program yielded less accuracy than that from the Image 100 (86% against 96%).

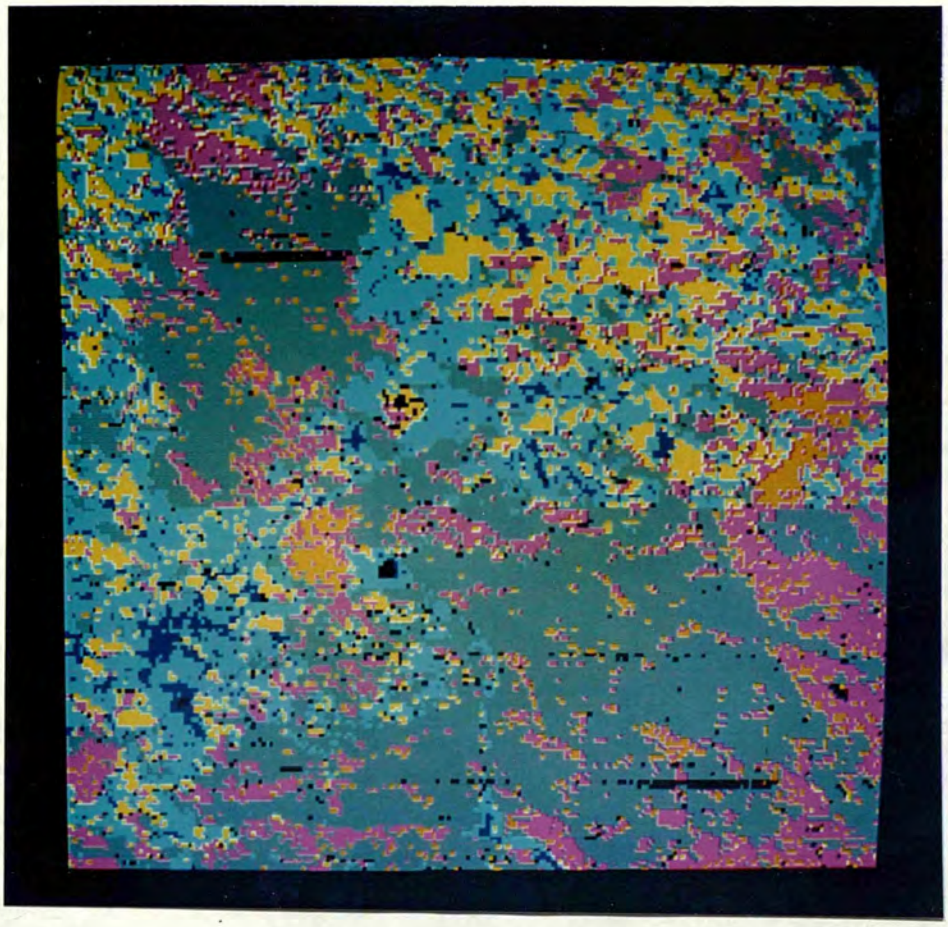


Figure 18. Computer classification map for the selected test site in the Quedas do Iguaçú area. (Dark blue = urban areas; medium blue = Parana Pine stands; light blue and yellow = non forest areas; purple = forest land; orange = reforestation areas; black = non classified areas). Classification carried out in the Image 100.

```
QUEDAS DO IGUACU INPE(02/AUG/75)  X=(40.260)  Y=(180.370) STRIP 5
  6 GROUPS-SOUPED NO BIN 15/08/80 FROM  TSI -QUEDAS DO IGUACU FEITA NO INPE

GP SHADING        POINTS          GP SHADING        POINTS
 1 G               13615           5 H                7623
 2 EF               1248           6 -               13818
 3 EFGIJ            1740
 4 -                4167
```

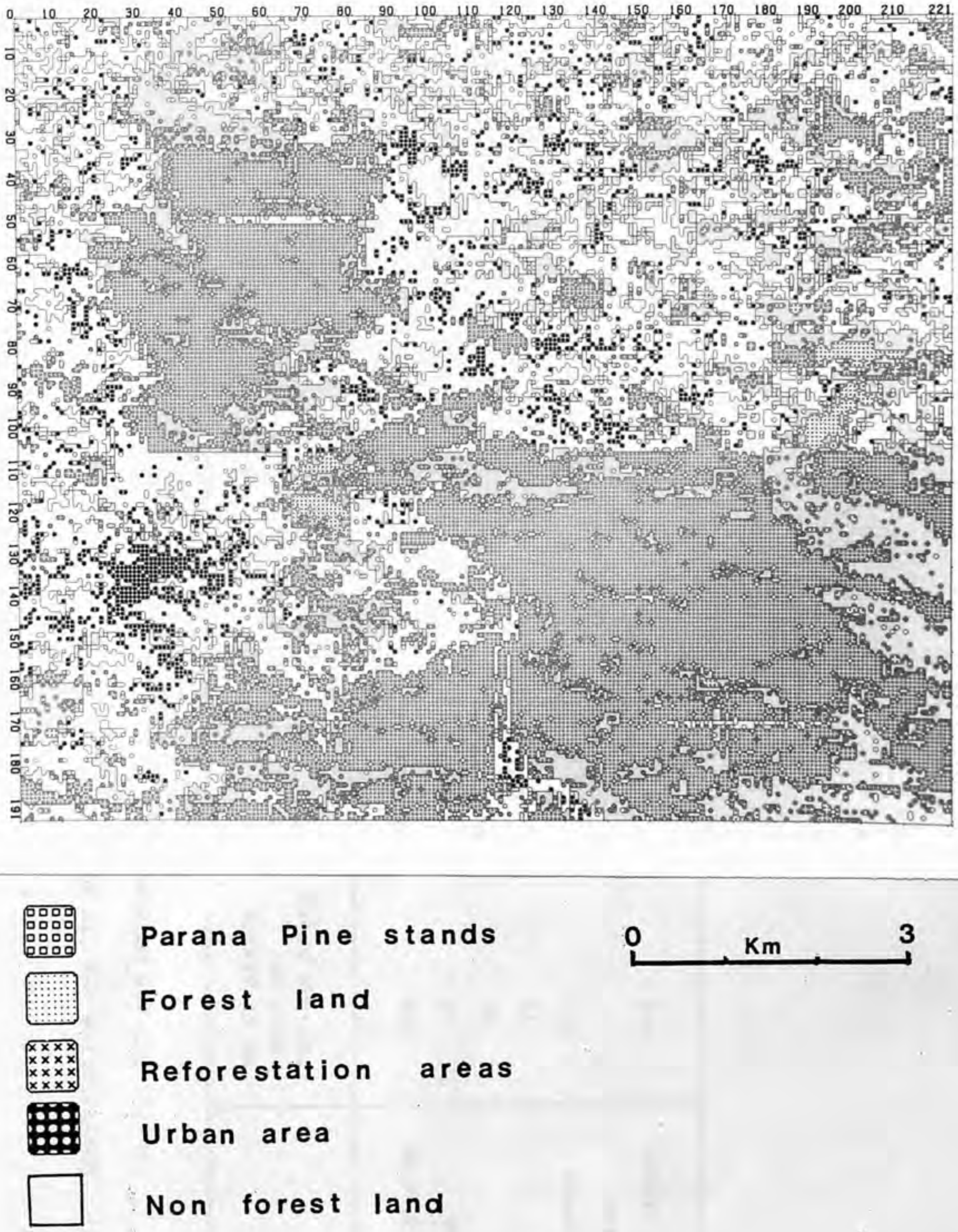


Fig 19. Computer classification map for the selected test site in the Quedas do Iguaçú area. Classification carried out using the supervised program at the Bedford College Remote Sensing Library.

Table 5. Quantitative results of the supervised classification programs using digital data from Landsat CCT and related to the selected test site in the Quedas do Iguaçú area.

CLASS	No of pixels used as training areas	Accuracy of the classification(%)		No.of pixels allocated on the class	
		INPE	BEDFORD	INPE	BEDFORD
Parana Pine stands	269	97.7	95.9	15,936	13,615
Reforestation	40	91.7	92.5	1,714	1,248
Urban area	20	88.5	85.0	1,170	1,740
Forest land	72	87.2	87.5	7.206	7.623
Non-forest areas	157	95.7	85.6	14,842	17.985
Non-classified	-	-	-	1,343	-
Total no.of pixels	558	-	-	42,211	42.211

The reason was that for one of the non-forest classes (areas with green spectral signatures), almost 20% of its tested pixels were misclassified as being urban areas, whereas with the INPE program the misclassification was only 7%. The spectral overlap between both classes was more accentuated using Bedford than using the INPE program.

When the classificatory programs were evaluated through areal estimates (number of pixels allocated to each class) some difference emerged between the results of the programs. Only the forest without Parana Pine stands class had approximately the same results using both classificatory programs. For Parana Pine stands there was a difference in results of more than 2,000 pixels which would represent an area on the ground of more than 800 hectares. Without up-to-date aerial photographs contemporaneous with the Landsat overpass there is no way to substantiate which is the better result.

The analysis of areal estimates can only reveal that for the classes, reforestation and urban areas, the results were over-estimated, according to the forest cover type map. The total area of reforestation was almost 400 hectares on the ground; from the Image 100 classification it was 745 hectares (86% above the real value), whilst from the Bedford classification it was almost 550 hectares (i.e. just over 40% compared with real ground value). For the urban areas the results from the INPE classification over-estimated almost by a factor of two, while from the Bedford classification by almost three.

Visual analysis of the classification map confirms the above quantitative results, since it was possible to detect isolated, or groups of pixels, representing urban and reforestation areas in incorrect positions. Despite the over-estimated areal results, however, both classes were well represented on the maps.

Figure 20 is a graph of the mean digital counts for the six classes used in the classification program using the Bedford Remote Sensing Library. These mean digital counts were derived from the training areas. Analysis of the graph revealed that:

a) Parana Pine stands had the lowest mean digital counts, in all the four Landsat MSS bands, in relation to the other five classes;

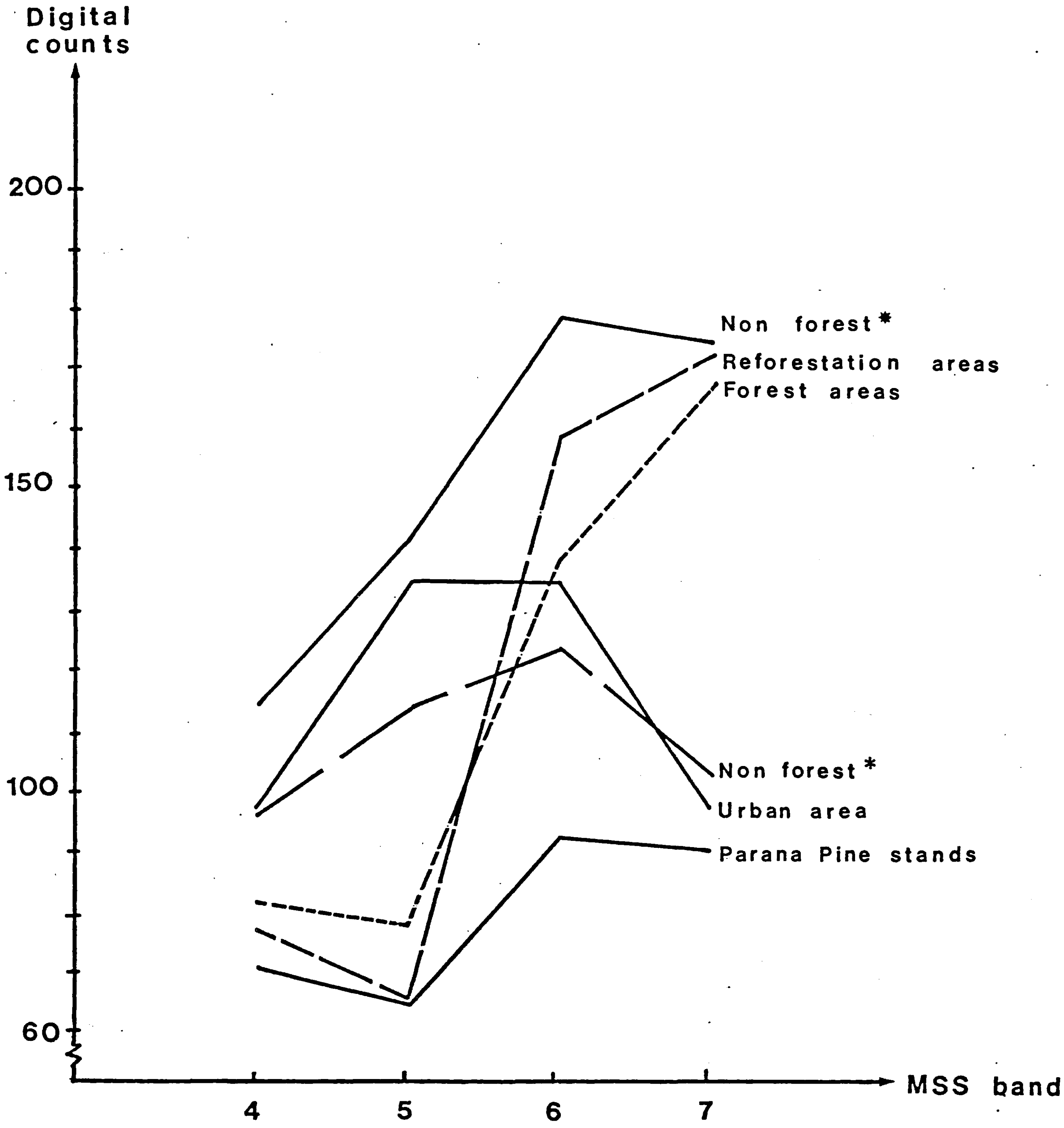
b) only in the MSS band 7 could Parana Pine stands be misinterpreted as being urban areas or of the non-forest class (i.e. areas with green spectral signatures as observed in the generated colour composite);

c) Parana Pine stands and reforestation areas had close mean digital counts on MSS band 5, although they had the maximum separability in MSS band 7;

d) forest land had the highest digital counts on the MSS band 5 when compared with the other two forest classes. Moreover, in the MSS bands 6 and 7 its mean digital counts were much closer to reforestation areas than to the Parana Pine stands;

d) the separability between urban areas and one of the non-forest classes (areas in green spectral signature in the colour composite) was greatest in MSS band 5 and the minimum in MSS bands 4 and 7.

These five above-mentioned points confirm the evidence acquired during the visual analysis of the individual Landsat MSS bands in transparency formats. The lowest mean digital counts (representing Parana Pine stands) on the CCT were represented by darkest tone on the positive transparency of the individual MSS bands. Also the information represented on the graph can assist in understanding the spectral overlap between the classes and consequently to explain the errors present in the classification.



✱ Represented by yellow in colour composite generated from MSS bands 4,5,7

* Represented by green in colour composite generated from MSS bands 4,5,7

Fig. 20 Graph of the mean digital counts of the classes used in the supervised classification of the test site in the Quedas do Iguaçú area

The difference in spectral reflectance, reported in terms of mean digital counts on the Landsat scene, between the considered classes in the computer classification is associated with the nature itself of the classes. Also, the time of year that the scene was acquired may play an important role.

In the MSS band 5, Parana Pine stands had nearly the same mean digital counts as reforestation areas, although it had different values from forest land. The crown of the Parana Pine is identified in the forest mainly because it has a distinct format and dark green colour compared with the crown of other forest trees. Parana Pine and Pinus (composed mainly of reforestation areas) stands have evergreen leaves, although Parana Pine leaves have slightly darker green colour compared with the needle-leaves of Pinus.

> The spectral reflectance of green vegetation is distinctive and quite variable with wavelength. In the visible wavelength, pigmentation dominates the spectral response of plants; chlorophyll is specially important (Hoffer, 1978, p. 231).

In this sense, according to the difference in colour of the leaves, Parana Pine stands had different spectral signatures from the other forest cover types. The difference in colour between forest areas with and without Parana Pine stands was maximum in the time that the Landsat scene was acquired due to winter time and adverse weather conditions in July 1975 (see p. 99).

On the bands 6 and 7, Parana Pine stands had low digital counts from reforestation areas and from other forest cover types.

> It has been generally assumed that the gray tones on infrared film result from the degree of infrared reflectiveness of an object rather than its true colour. According to this theory, broad-leaved vegetation is highly reflective and therefore photographs in light tones; coniferous or needle-leaf vegetation tends to absorb infrared radiation and consequently registers in much darker tones (Avery, 1977, pp. 8-9).

This explains the mean digital counts reported for Parana Pine stands and for the forest land. But quite surprisingly, reforestation areas had nearly the same mean digital counts as forest areas. According to the cell structure of the coniferous leaves, the reforestation areas should absorb more infrared radiation than the forest broad-leaves, but this did not happen.

In summary, the two supervised classification programs resulted in nearly the same classification accuracy for mapping Parana Pine stands and reforestation areas, but with different areal estimates for the classes. This difference is attributed to the different decision region boundaries defined itself by the strategy used in the classificatory programs. In the colour composites generated from the MSS bands, which were available in digital data in CCT format, the Parana Pine stands and reforestation areas were easily detected. The reforestation areas and urban areas had their spatial position correctly reported in the computer classification maps, perhaps their computer areal estimates were over-estimated according to the ground value acquired from the forest map.

7.4.2 Supervised classification using the microdensitometer data

The position of the training areas used in the supervised classification of the data set from the microdensitometer scanning of the images of the August 1975 scene were the same as those defined during the classification of the same test site using the digital data from the CCT. In processing the data set from September 1976 scenes new training areas for the Parana Pine stands class were defined because some parts of the forest had been exploited. Consequently, some of the training areas, defined before using the digital data from the CCT, were not more representative for the stands. New training areas were also defined for the two non-forest classes.

The quantitative results of the classification for the two different data sets are reported in Table 6.

The computer classification map in the data set related to the scene of August 1975 is reported (Figure 21). In the map, the following classes were represented: Parana Pine stands, reforestation areas, forest land and non-forest areas. There was good visual correspondence between Figure 21 and the results originated from the computer classification using the data from CCT (Figures 17 and 18). The average classification accuracy for all the classes before mentioned, was almost 96% and for all the classes the individual classification accuracy was better than 90%. The computer estimates of the area for reforestation areas was under-estimated by a factor of four (i.e. 27 pixels x 4.08 hectares = 101.1 hectares against the ground value of 400 hectares). Despite the well defined shape of the supposed reforestation areas in Figure 21 and a nearly 92% classification accuracy, a large quantity of their pixels were misclassified as being forest land. In addition to the analysis of the data set from the August 1975 scene, the colour composite generated from the images of MSS bands 5 and 6 scanned through the microdensitometer was compared with that colour composite generated from the enlarged MSS transparency bands.* The comparison was made at 1:50,000 scale. The colour composite originated from the digital data from the microdensitometer scanning was less informative than that from the MSS transparency bands in two ways:

---

* The enlarged transparency MSS bands were the same as those used for the qualitative analysis carried out at the 1:100,000 scale for the Quedas do Iguaçú area.

Table 6. Quantitative results of the supervised classification using digital data from the microdensitometer scanning of the MSS images from two Landsat scenes of the selected test site in the Quedas do Iguaçú area.

Landsat overpass / Class	02 August 1975			16 September 1976		
	Training areas (number of pixels)	Classification accuracy in %	No.of pixels allocated to the class	Training areas (number of pixels)	Classification accuracy in %	No.of pixels allocated to the class
Parana Pine stands	30	100.0	1,164	21	95.2	677
Reforestation	14	91.7	27	12	66.7	626
Forest land	12	92.6	576	12	91.7	132
Non-forest areas	26	100.0	2,293	37	100.0	2,625
Total no.of pixels	-	-	4,060	-	-	4,060

```
2/AUG/75 BAND(5+6) PIXEL=202 M.
 5 GROUPS-SOUPED NO BIN 14/08/80 FROM  TSI -QUEDAS 2/AUG/75 PIXEL= 202 M.

OP SHADING        POINTS          OP SHADING       POINTS
 1 O                1164           5 -                394
 2 H                 576
 3 EF                 27
 4 -                1899
```

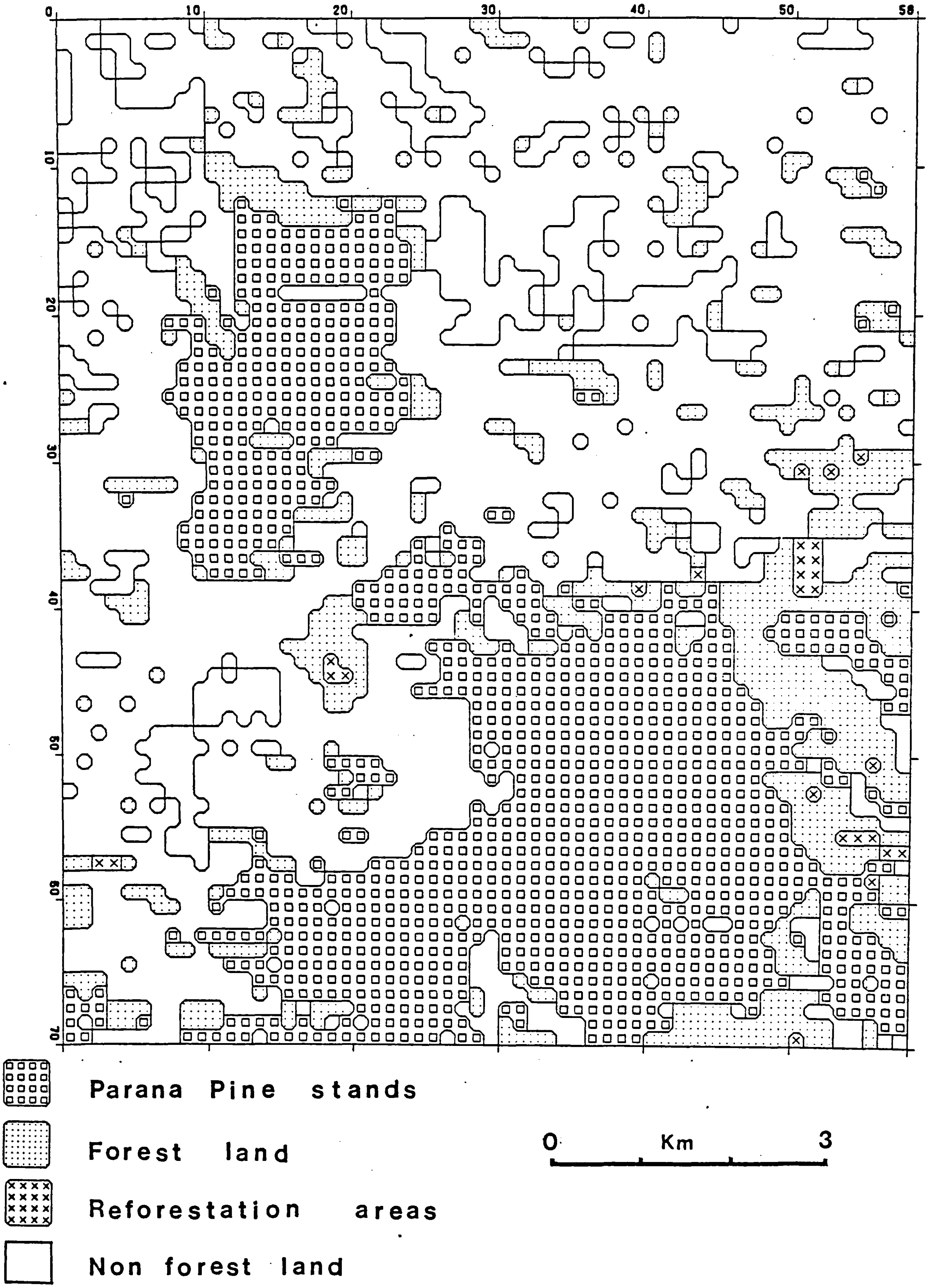


Fig 21. Computer classification map of the selected test site in the Quedas do Iguaçú area using digital data from the microdensitometer scanning of the images of MSS bands 5 and 6 of the 02 August 1975 Landsat scene.

a) the road that crosses the test site area was not well defined. This was due to the size of the pixel width of the scanning (i.e. 202m) which was much larger than the width of the road (i.e. 10m).

b) the two large reforestations areas were only marginally detected on the colour composite. Conversely, in the colour composite, from the enlarged MSS transparency bands the two reforestation areas were easily detected and show different red spectral signatures from Parana Pine stands and forest without Parana Pine stands.

With the data set from the microdensitometer scanning of the images of the September 1976 scene, Parana Pine stands and forest without Parana Pine stands were classified with an accuracy of up to 90%. The classification accuracy showed that there was no spectral overlap between both-mentioned classes as defined through the training areas. Opposite to this results,for the mapping of reforestation areas the results were not reliable, with respect either to classification accuracy or areal estimates. In the first method of the quantitative analysis the accuracy was 66.7%. From the twelve pixels that should be classified as reforestation areas, four pixels were misclassified as belonging to the other two forest classes. In the second method (computer estimates of the area) the results were over-estimated more than six times the real ground value.

The failure of mapping reforestation areas may be partially attributed to the fact that the areas were not detected on the colour composite generated from the enlarged MSS transparency bands. Consequently the microdensitometer scanning of these transparency images of the MSS band 5 and 7 provided digital data values for reforestation areas with nearly the same values as that for areas representing Parana Pine stands or forest land. Due to this, the results of the computer classification was not reliable for mapping reforestation areas. There is no way to guarantee that the reforestation areas would not be correctly mapped, using data from CCT.

Some parts of the forest land had been exploited between the Landsat overpasses of 02 August 1975 and 19 September 1976. These exploited areas were easily detected on the visual analysis of the images of MSS bands of the 1976 scene as in the images resulting from the microdensitometer scanning.

In summary, Parana Pine stands were correctly classified using the data set from the microdensitometer scanning of the images of August 1975 and September 1976 scenes. Computer areal estimates for the stands were not taken into account for the evaluation of the results. Perhaps a visual analysis of the computer classification maps revealed a close correspondence of the achieved results with that from the forest map. On the other hand, the mapping of reforestation areas were not successful. Neither in qualitative nor in quantitative ways were the results of the computer classification reliable.

The limited success obtained for mapping reforestation areas posed problems since two factors strongly suggest that the areas should present different spectral signatures from the other forest cover types. Firstly, both reforestation areas represent large areas (as for example, exceeding 100 hectares) and constitute well established pure stands of trees of uniform density and height. Secondly, the areas surrounding the reforestation areas comprised not only forest areas which might have a similar spectral signature, but also non-forest areas. Explanations for the difficulties in detecting the reforestation areas on the Landsat images were sought in an examination of the ground truth information including field studies undertaken in February 1980.

The difficulties of mapping reforestation areas can not be attributed to the characteristics of the areas, i.e. species, age and height of the trees, nature of understorey, etc. But, it appears to be related to the loss of detail due to the microdensitometer scanning of the third generation of MSS transparency bands. This was clearly pointed out from the analysis of the colour composites generated for the Landsat scene of August 1975. The reforestation areas were easily detected on the colour composites generated from the MSS bands using CCT data and from the enlarged MSS transparency bands, but the areas were only marginally detected using data from the microdensitometer scanning.

In addition to the difficulties of mapping reforestation areas, the large area (4.08 hectares) covered by each pixel from the microdensitometer scanning reduced substantially the number of pixels related to the class. Consequently, there was not much flexibility in order to select training areas for the class. This is important because the selection of the training areas in one of the most important factors affecting the classification and mapping accuracies of digital image processing.

The field studies also revealed that near to the reforestation areas close to the town of the Quedas do Iguaçú further reforestation had been undertaken since 1974. This new reforestation covered an area of nearly 220 hectares. The area was not detected in any of the six Landsat scenes. Two factors appear to have been responsible for this, namely:

a) a large part of the reforestation has not been successful due to the ant attacks. Replanting has been effected but until the time of the field studies course (February 1980) the new trees had not dominated the natural vegetation;

b) indication of tree growth (non-forest areas regenerated to forest land by natural or artificial methods) will appear in three to five years after planting (Aldrich, 1975).

SECTION D : MANGUEIRINHA AREA

CHAPTER 8

THE MANGUEIRINHA AREA

8.1 Initial considerations

8.1.1 The Physical background

The Mangueirinha area is characterized by a climate classified as Cfb by Koeppen The nearest meteorological station to the study area is in Coronel Vivida, a town situated some 20km to the west. The average temperature in the winter (May to August) is 14.2°C, whilst in the summer (December to February) the average is 22.9°C. The annual average temperature is 18.6°C and the annual rainfall is 1,847mm. The driest months in the year are May, July and November, with an average of 118mm of rainfall. The wettest months in the year are January, February, September and October with an average rainfall of 191,0mm (Instituto Agronomico do Parana, 1975). In the area there is no moisture deficit because the amount of precipitation is far over the amount of the evapotranspiration all the year (Figure 22). In the Mangueirinha area the elevation ranges from 440m to 960m, the lowest elevation being close to the Iguaçú River (Figure 23). The relief characterizes two different areas, one in the south and another in the north. The first is flat or gently sloping while the second is heavily dissected and with watershed and hillcrests very narrow and small in area.

There is no official soil map for the study area. A preliminary soil map made in 1972, indicated the presence of the following main soil

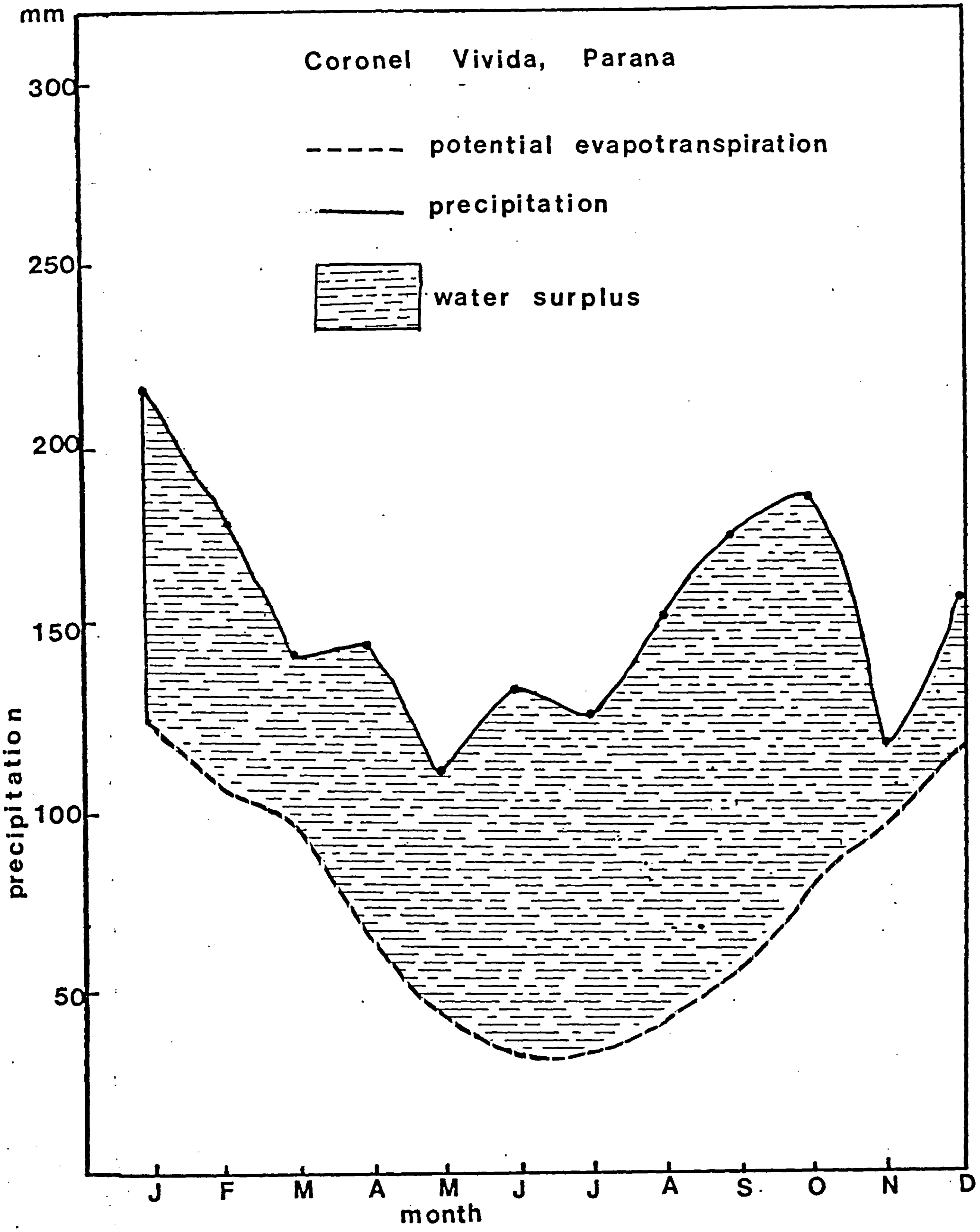


Fig. 22 Potential evapotranspiration and precipitation for Coronel Vivida

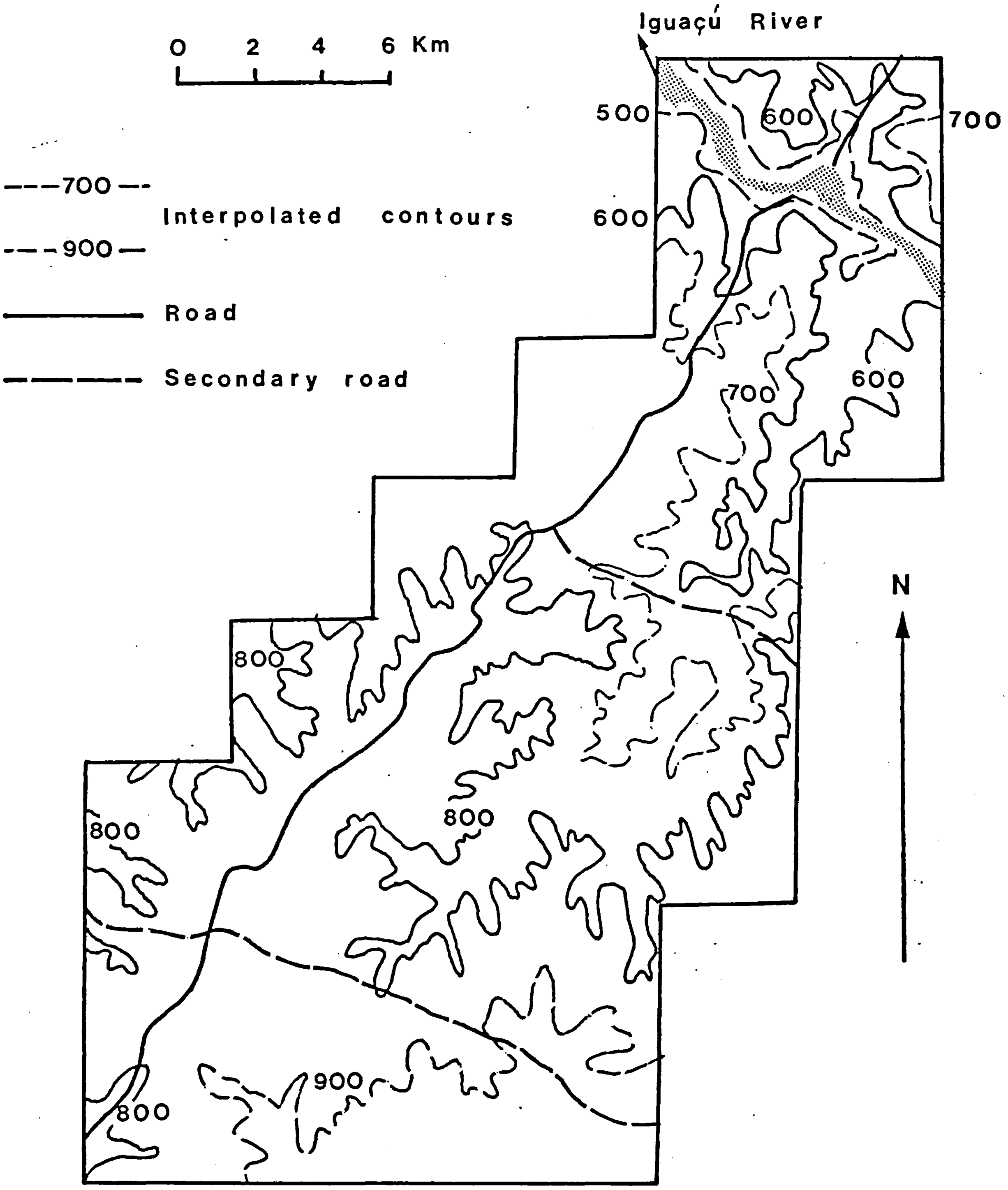


Fig. 23 Relief of the Mangueirinha area

types: reddish brunizem , lithosols developed over basalt and latosol rosso. The first two types occur mainly in the valley of the Iguacu River, whereas the latosol rosso characterizes the upland (Fundacao Nacional do Indio, 1974). The reddish brunizem are soils derived from basaltic lavas, not hydromorphic; they are characterized by a chermozenic A horizon and a textural B horizon. The soil shows succession of A, B and C horizons (Empresa Brasileira de Pesquisa Agropecuaria, 1975).

The lithosol and latosol rosso are similar to those described in the section on the physical background of the Quedas do Iguaçú area. Plate 3 shows latosol rosso soil in the area of study. In 1972 a forest inventory was carried out in order to determine the volume of timber of the main tree species occurring in the Araucaria forest of the Mangueirinha area. At 94 sampling points spread over the area, dendrometric measurements (diameter at breast height (dbh) and commercial height) were carried out on trees with dbh bigger than 20 cm. According to the condition of the forest, each point was classified into one of the broad types: unexploited, semi-exploited and exploited forest.

Seventy per cent of the total of 746 trees measured were Parana Pine trees. The average dbh for Parana Pine trees was 84cm. Twenty nine other tree species were measured and the data for the most common trees found in the survey is given in Table 7.

The field survey disclosed that in some parts of the Araucaria forest Mimosa scabrella Benth ('bracaatinga') was present (DaSilva et al, 1975). This tree belongs to the Leguminosae family. It forms pure stands and is often an indicator of a disturbed site. Areas burned within the previous 20 years frequently have dense bracaatinga stands, often with a Parana Pine understorey which will eventually

Plate 3. Latosol rosso soil in the Mangueirinha area.
Dense stands of Parana Pine in the background.

Table 7. Average number of trees per hectare for the five most common trees in Araucaria forest in the Mangueirinha area

Name of the tree (vernacular name - botanic family)	Araucaria forest		
	Unexploited	Semi-exploited	Exploited
Araucaria angustifolia (Bert.) O. Ktze. (Parana Pine - Araucariaceae)	46	30	18
Nectranda sp. (Canela - Lauraceae)	29	10	7
Matayba elaeagnoides Radlk. (Camboatã - Sapindaceae)	11	4	2
Diatenopteryx sorbifolia Radlk. (Maria preta - Sapindaceae)	11	4	1
Prunus sp. (Pessegueiro bravo - Rosaceae)	12	4	2

overtop and shade out the bracaatinga.

8.1.2 Material of the study

For the study of the Mangueirinha area there were the following two different remote sensor data: aerial photographs and Landsat images.

The aerial photographs* were black and white, panchromatic, taken in 1972 with a 153mm focal length camera. The photographs were printed at a 1:10,000 scale. An airphoto mosaic of the area at a scale of 1:50,000 was also available. The area was covered by 477 aerial photographs taken on 20 flight paths oriented in a north-south direction.

Two Landsat images in CCT format were available. One Landsat CCT was acquired a day before that Landsat CCT scene used for the study of the Quedas do Iguaçú area. The other Landsat image had only a near equivalent image used for the study of the Quedas do Iguacu area. The characteristics of the images are given in Table 8.

8.2 Interpretation of the aerial photographs

The basic aim of the manual and conventional interpretation of the aerial photography for the Mangueirinha area was to provide a basic forest cover type map showing the spatial position of Parana Pine and bracaatinga stands. This forest map was used as a reference 'ground truth' for the interpretation and analysis of the Landsat images.

8.2.1 Method of analysis

The interpretation of the aerial photographs was carried out on a Sokkisha MS-27 mirror stereoscope, at x3 magnification.

---

* Aerial photographs were available also at the 1:70,000 scale. These air photos had been taken between 1962 and 1967. They were used in the later stages of the study.

Table 8. Characteristics of the Landsat images for the Mangueirinha area

Identification number	75213/123955	8264112300500
Landsat	2	2
Data (season)	01/August/75 (winter)	24/October/76 (spring)
% of clouds in the scene	10*	20*
Sun elevation angle	29°	48°
Sun azimuth angle	49°	77°
Time of observation	12h 39m	12h 30m
Acquired from	INPE	NASA

* The Mangueirinha area was cloud-free

A "hand templets" radial triangulation technique was used to produce a planimetric map from the aerial photographs. No control-points were used in the triangulation. The photo-interpretation was superimposed on this planimetric map. In order to aid the photo-interpretation, a Land Use and a Land Cover Classification System was adopted (Table 9). The minimum area of each mapping unit was 0.5 hectares. Using a Photo Interpreter's Scale (crown density scale) the density of Parana Pine stands was estimated from the percentage of area covered by the crowns to the nearest 25%.

Area boundaries from the photo-interpretation were drawn on stable transparency acetate sheets overlaid on alternate aerial photographs of each strip. This detail was, in turn, transferred to a 1:10,000 planimetric map using a Bausch & Lomb monoscope transfer.

Using a planvariograph, the 1:10,000 photo-interpretation map was reduced to a 1:50,000 scale. Also using the planvariograph, the corresponding area of study on the 1:100,000 topographic map (edition 1958), DSG-Sheet SG-52-H-V) was enlarged to a 1:50,000 scale. Using the river lines as the reference points, through the mono transferscope, the interpretation map was projected and copied over the enlarged 1:50,000 topographic map.

In order to gather information about the range of elevation of the different crown densities of Parana Pine stands in the Mangueirinha area, a dot-grid, with four points in each square centimeter, was laid over the 1:50,000 enlarged topographic map containing the photo-interpretation results. Each point in the dot-grid represented, on the 1:50,000 map, a ground area of 6.25 hectares. For each annotated point the information was encoded according to the formula whereby the first digit indicated the density crown of Parana Pine stands and

Table 9. Land Use and Land Cover Classification System Used for the photo-interpretation

- A. Forest
  - A.1. Only Parana Pine stands
    - A.1.1 With density of crowns more than 75%
    - A.1.2 With density of crowns between 50% and 75%
    - A.1.3 With density of crowns between 25% and 50%
    - A.1.4 With density of crowns less than 25%
  - A.2. Dense forest without Parana Pine stands
  - A.3. Forest without Parana Pine stands, less luxuriant and with less structure than the category A.2. above;may be exploited in some areas
  - A.4. Stands of bracaatinga
- B. Herbaceous vegetation
  - B.1 Agricultural areas
  - B.2 Grassland areas
- C. Non vegetated areas
  - C.1 Rock/bare soil: soil and/or rock partially exposed; may support some coverage of herbaceous vegetation
  - C.2 Water: river, lake
  - C.3 Constructed surface: road, house, etc.

the second its range of elevation (Table 10). Reference to Table 10 shows that for example, a point represented by the digits AF comprises 6.25 hectares of Parana Pine stands with crown density more than 75% and located at an elevation of between 640 and 680 meters.

Using the grid cells of the topographic map, data covering the whole study area was encoded. Each cell of information grid represented an area of 4 square kilometers (2km x 2km) or 8cm x 8cm on the 1:50,000 map. In this sense, a complete cell of the information grid had 256 points. A computer program was written in Fortran IV to read this basic information (crown density of Parana Pine stands and range of elevation) from punched cards for all the points of each cell and to display the results in tables (Appendix 3).

Table 10. Coding used to represent range of elevation for different crown density of Parana Pine stands

FIRST.DIGIT (crown density)	SECOND DIGIT (elevation in meters)
A : more than 75%	A = 441 to 480 m.
	B = 481 to 520 m.
B = between 50 - 75%	C = 521 to 560 m.
	D = 561 to 600 m.
C = between 25 - 50%	E = 601 to 640 m.
	F = 641 to 680 m.
D = less than 25%	G = 681 to 720 m.
	H = 721 to 760 m.
	I = 761 to 800 m.
	J = 801 to 840 m.
	K = 841 to 880 m.
	L = 881 to 920 m.
	M = 921 to 960 m.

Finally, from all these available data, a map and a table, respectively showing the position of the different land use/land cover classes and the quantity of the Parana Pine stands were prepared. In Figure 24 only the position of the Parana Pine stands and the forest land in the area of study have been shown, the scale of the map being too small to permit the representation of the other classes. The relationship between the distribution of the four crown density classes of Parana Pine stands and variation of elevation in the Mangueirinha area are shown in Table 11.

8.2.2 Analysis of the results

The information yielded by the photo-interpretation and particularly the resultant forest cover type map of the Mangueirinha area, provided the ground truth for the analysis of the Landsat images.

The use of 1:10,000 black and white aerial photographs made it possible to map with a reasonable degree of confidence, all the Parana Pine stands and the bracaatinga stands in the natural forest in the Mangueirinha area. Only stands of these two species of trees were spatially identified and mapped from the aerial photographs. No attention was paid to the identification of other tree species in the forest, because this was not the primary purpose of the research.

Areas with grassland appeared in medium gray tone on aerial photographs, contrasting in appearance with forest land. Areas of light grey tone on the air photos, showing sparse vegetation, were classified as being bare soil

On the forest map produced for the south west of Parana State in 1966, the Mangueirinha area was shown as supporting tropical forest and Araucaria forest. The tropical forest was located in the Iguaçú River

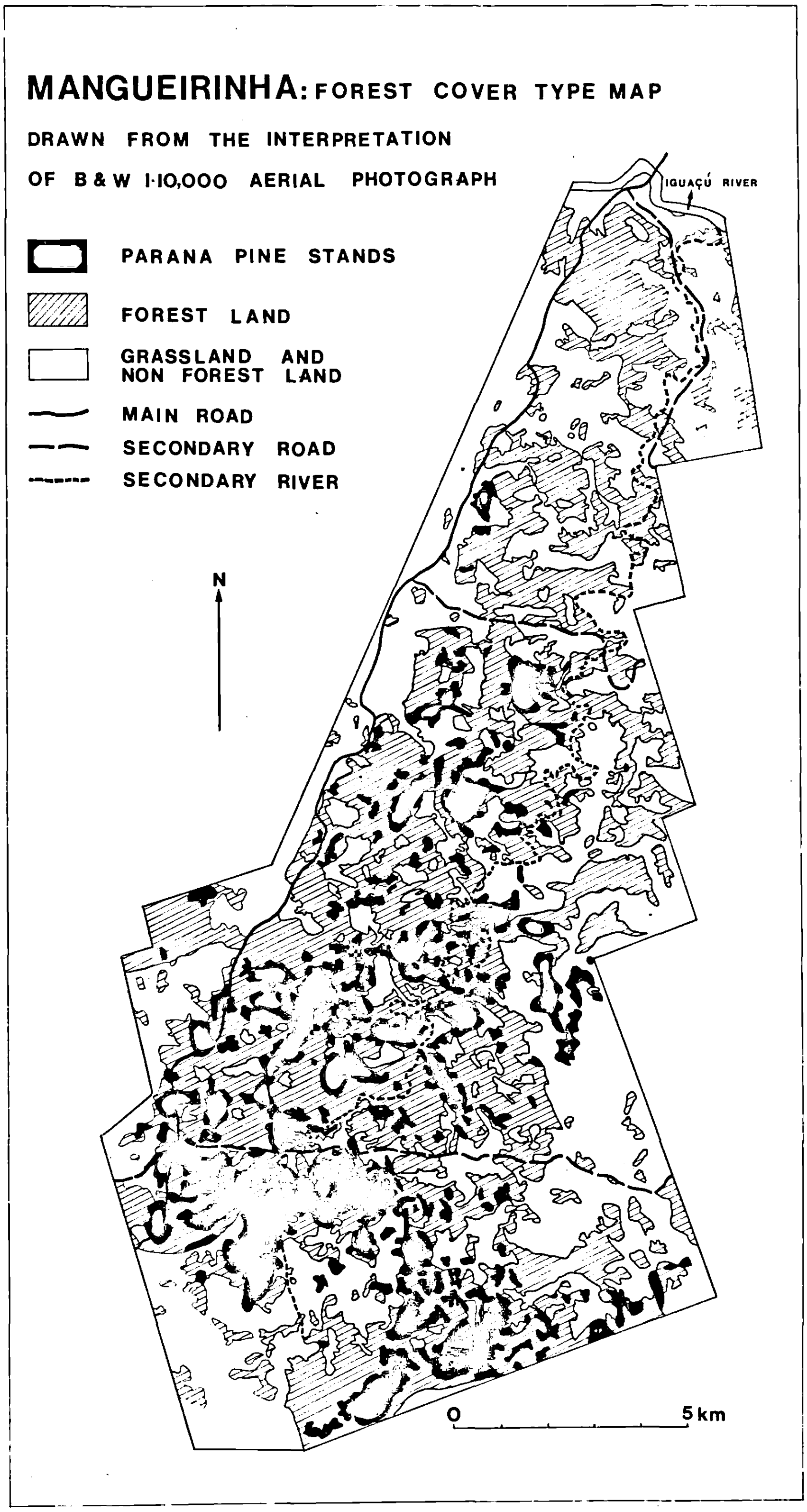


Fig 24. Forest cover type map of the Mangueirinha area

Table 11. Area distribution (in hectares) of the crown densities of Parana Pine stands in the elevation range of the Mangueirinha area.

Range of elevation (metres)	Crown Density of Parana Pine stands			
	less than 25%	between 20-25%	between 50-75%	more than 75%
440 - 480	-	-	-	-
481 - 520	-	-	-	-
521 - 560	-	6,25	-	-
561 - 600	-	6,25	-	-
601 - 640	-	-	-	-
641 - 680	-	12,5	6.25	-
681 - 720	18,75	37,5	25,0	-
721 - 760	62,5	25,0	25,0	31.25
761 - 800	137,5	156,25	137,5	56,25
801 - 840	200,0	112,5	356,25	187,5
841 - 880	387,5	218,5	518,75	237,5
881 - 920	193,75	87,5	231,25	156,5
921 - 960	118,75	125,0	56,25	37,5

valley, but the report suggested that elsewhere there was not a clear distinction between the two types of forest manifest on the aerial photography at a 1:70,000 scale. Even at the 1:10,000 scale the distinction between the different types of forest was not clear on aerial photographs.

The different levels of crown densities chosen for mapping purposes was related to the scale, type and resolution of the available aerial photographs, the knowledge of the area, the skill of the photo-interpreter and the aims of the mapping. The author believes that for analysing Landsat imagery crown densities for discriminating Parana Pine are adequate. The use of a crown density scale made the interpretation of the density of Parana Pine stands less subjective.

Classification by crown densities could not be used for mapping stands of bracaatinga because this species occurs in almost pure and dense stands. This is a characteristic of the young stage in bracaatinga stands. At the mature stage these pure stands begin to give way to those tree species which formed the major constituents of the tropical and subtropical forests.

Contrasts in the geometry of their crowns, the size and shape of the trees, the texture and tone they produced on the air photos, were the principal diagnostic features used for discriminating the stands of Parana Pine and bracaatinga. Even without stereoscopic observation both stands could be broadly mapped on the 1:10,000 aerial photograph (Figures 25 and 26), this being largely due to the dark tones produced by the Parana Pine and the light tones produced by the bracaatinga.

The data given in Table 11 confirm one fact well known regarding the ecology of Parana Pine stands: their absence from areas below 500m of elevation. Some stands occur between 520 and 680m elevation

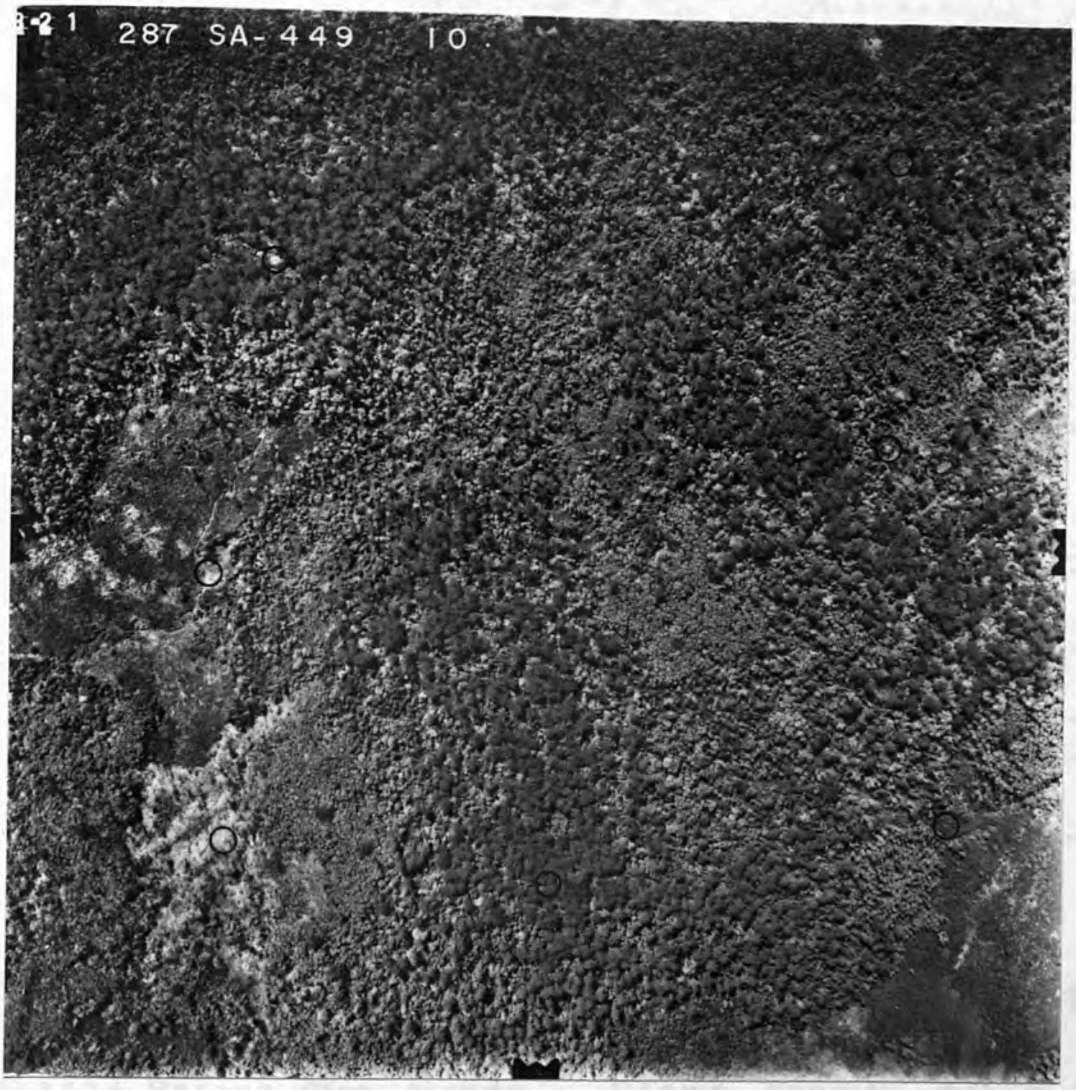
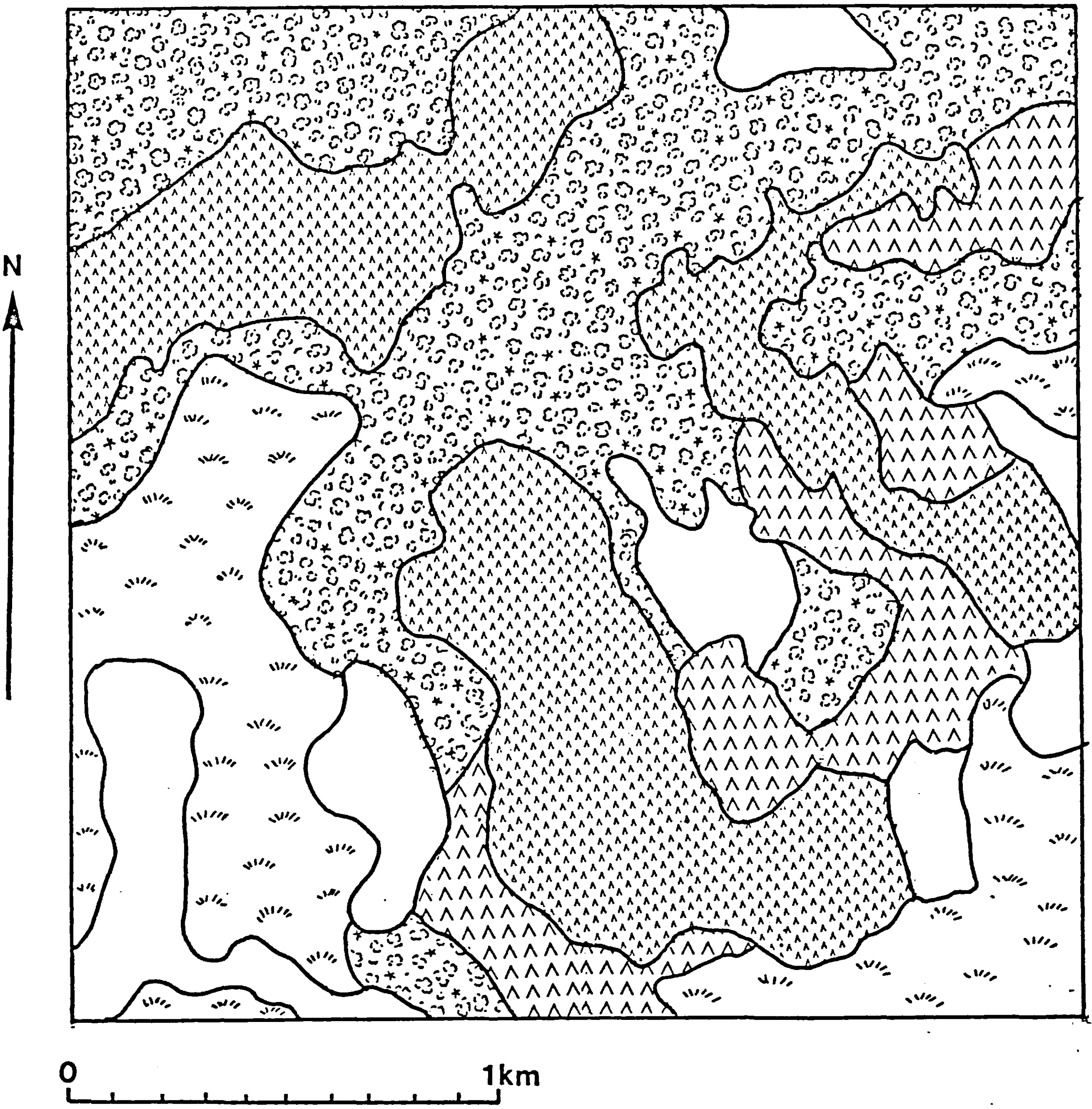


Fig 25. Aerial photograph showing Parana Pine and bracaatinga stands.



▩ Parana Pine stands - Crown density (50 - 100%)

▨ Parana Pine stands - Crown density (0 - 50%)

▦ Forest

☐ Bracaatinga stands

▤ Grassland

Fig. 26 Annotated map of the aerial photograph showing Parana Pine and Bracaatinga stands.

in the Mangueirinha area, but the main development of stands begins above 680m. Fieldwork revealed that some isolated Parana Pine trees occur close to the Iguacu River, at an elevation approximating 440m, but these do not constitute stands.

Some field checking of the photo-interpretation map was undertaken in February 1980. The checking was carried out at some points along the roads that cross the area. Additionally, using a Pentax KM camera, 35mm positive films (slides) were taken at a constant interval from a light aircraft flying along three preselected flight paths orientated in the north-south direction. The field checking and the comparison of the images on the 35mm slides with the corresponding part on the photo-interpretation map, indicated that in some few areas of the forest supporting Parana Pine stands had been exploited. Two Indian Reserves are located in the study area and mainly because of this,exploitation of the forest resources in the area had been much less than in other places in the south-west of Parana State.

8.3 Interpretation of the Landsat images

The aims of the study of the Mangueirinha area were similar to those for the Quedas do Iguaçú area (p. 82). Additionally, because aerial photographs covering the Mangueirinha area and taken three years before the earlier Landsat scenes were available, an attempt was made to map different crown densities of Parana Pine stands using classificatory programs. The mapping of bracaatinga stands was also considered an integral part of the mapping procedures.

The study was carried out using only the data from the Landsat scenes available in CCT format (Table 8). The following procedures were followed:

a) visual qualitative temporal analysis of the MSS images of the Landsat scenes covering the area of Mangueirinha;

b) computer-aided analysis, using supervised and unsupervised classifications, of a small selected area.

8.3.1 Visual qualitative temporal analysis of the Landsat scenes

As mentioned before (p.136) two Landsat scenes were available for the study of the Mangueirinha area. One scene was acquired in the winter time (01 August 1975 Landsat overpass) and another one in the spring time (24 October 1976 Landsat overpass). From each scene, a data set of 302 x 400 pixels was extracted for further analysis. These data sets were carefully chosen as representing the Mangueirinha area.

Images of the MSS bands 5 and 7 were produced, for each Landsat scene, from the corresponding data set. Each image was produced using ten levels in the density slicing and the images were subject to contrast stretching. These images were used in the additive viewer to generate colour composites at the 1:50,000 scale. The individual images of the MSS bands 5 and 7 and the colour composites were visually compared with the 1:50,000 photo-interpretation map. A series of maps, as explained on p.87-91 , was produced from the visual interpretation of the colour composites and of the images of the MSS bands.

An analysis of the images and consequently the produced maps revealed that the Landsat 01 August 1975 and 24 October 1976 overpasses scenes yielded some different information regarding the mapping of forest types.

The results obtained for the visual interpretation of the 01 August 1975 Landsat overpass, for the Mangueirinha area, revealed that:

a) Parana Pine stands could be easily detected on the image of the MSS band 5 by the fact that they produced the darkest tone in the image (Figure 27). A visual interpretation of the image is given (Figure 28). In it, is indicated the position of three cover types, namely: areas supporting the same tone on the image that Parana Pine stands, the forest land and the non-forest land which includes grassland areas.

The darkest tone of the image, however, was not exclusive for the Parana Pine stands, since small areas supporting forest land without Parana Pine stands had also the same tone (compare Figures 24 and 28). These similarities of tone were located on areas of dissected terrain, as observed from the stereoscopic analysis of the aerial photographs at 1:70,000 scale,* covering the area of study. The shadow effect of the areas with deep slope may explain 'this similarity tone.

The forest land was represented in tones, on the image, from dark to medium gray, while the grassland was represented by tones from medium to light gray. An explanation of the gray tones, as observed on the image and related to Parana Pine stands, forest land and grassland is given. The reflectance recorded by the waveband of MSS band 5 and related to vegetation is mainly due to the chlorophyll

---

* These aerial photographs were preferred to those available at the 1:10,000 scale because they provide a synoptic view of the Mangueirinha area in just two stereoscopic models at a scale near that used for the visual interpretation of the MSS image.

```
MANGUEIRINHA INPE X=(300.402) Y=(921.1320) STRIP 1 *ABUT                *SELPAR 2 4
 10 GROUPS - SLICE: PARAMETER  1            RANGE    55.00      TO    142.0

GROUP:      1       2       3       4       5       6       7       8       9      10
SIZE:   10400   22897   20821   17200   21941    8305    9649    4250    1337    4000
```

Fig 27. Mangueirinha. Output produced by density slicing and contrast stretching the data in MSS band 5 into ten groups. Output from CCT of Landsat 2. ID 75213 123955. 01 August 1975 overpass.

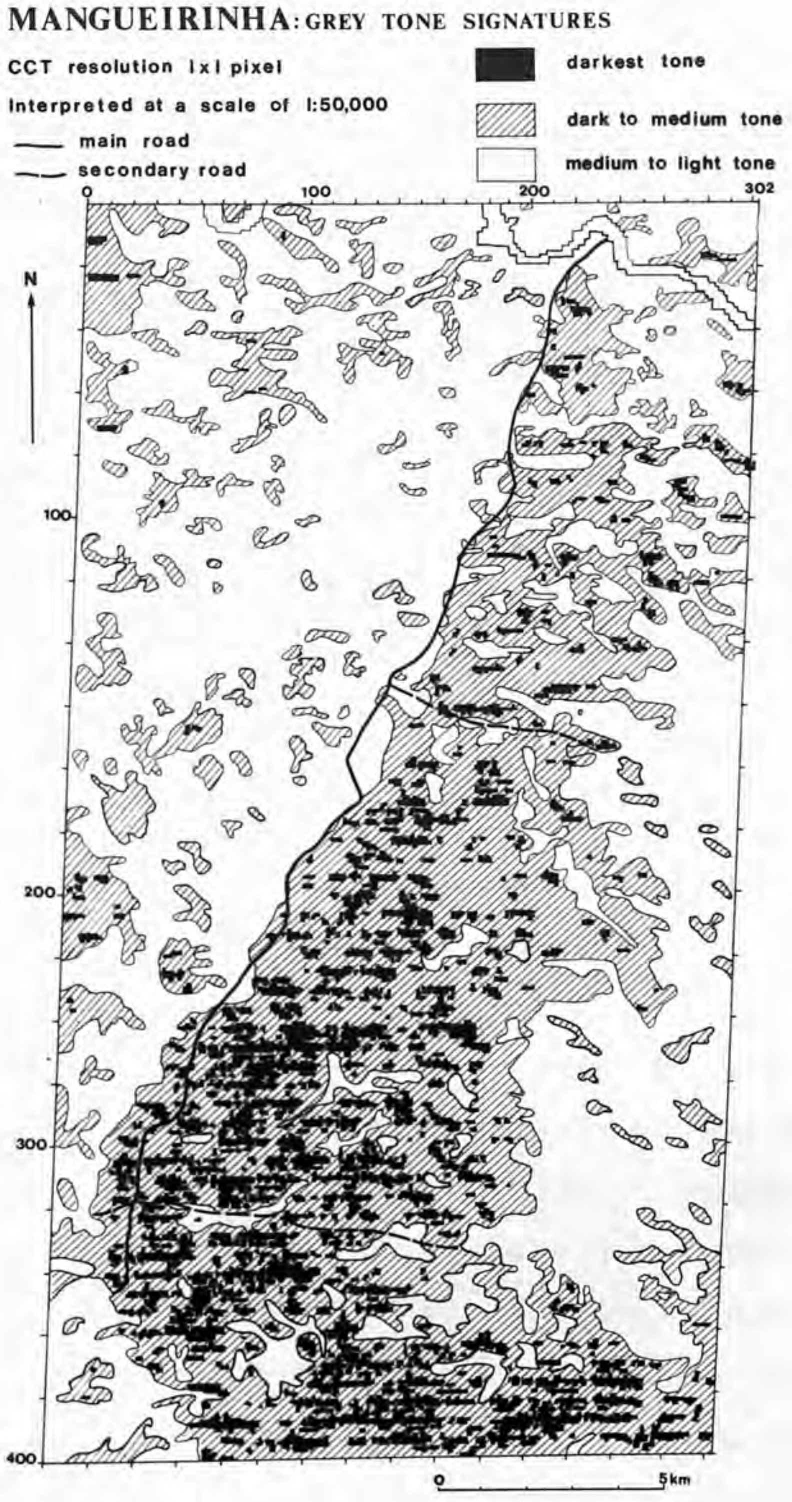


Fig 28. Mangueirinha. Visual interpretation of the grey tones signatures of the output of the MSS band 5 of Landsat scene from 01 August 1975 overpass.

of the plants. At the time that the Landsat scene was acquired, due to the adverse weather conditions in July 1975 (see p. 99) there was a maximum contrast in colour between the leaves of the Parana Pine trees, which are evergreen, and the broad-leaves of the forest trees that were severely affected by the winter time. The difference in colour, associated with size, texture, and behaviour of the leaves, resulted in different spectral reflectance for the three mentioned cover types and consequently different digital counts on the MSS band 5. Thus, the three cover types were represented in different gray tones in the image. In addition, the fact that Parana Pine stands were represented by the darkest tone on the image, indicated that the stands had the smaller mean digital counts when compared with the mean digital counts of the other vegetation and non-vegetation cover types;

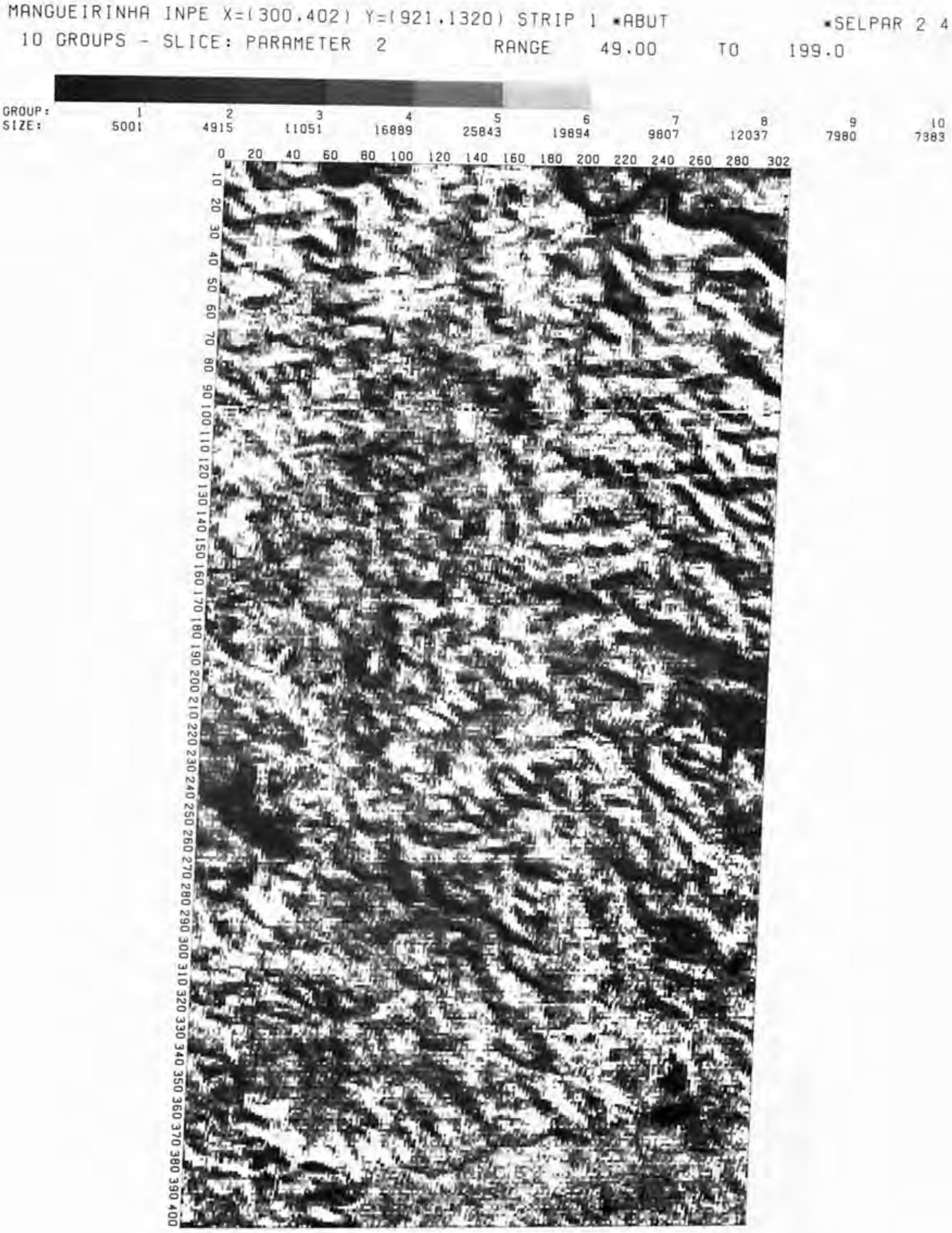
b) Parana Pine stands could be marginally detected on the image of the MSS band 7 by the fact that they produced areas with dark to medium gray tone.The stands had lower reflectance, at this waveband, than forest land which was represented by areas with tones from medium to light gray (Figure 29).

The darkest tone of the image of the MSS band 7 was represented by the Iguaçú River. It is well known in remote sensing that water bodies reflect very low infra-red wavelength. Also, a comparison of the image of the MSS band 7 with the colour composite (Figure 30) revealed that some of the darkest tones on the image, that were not water bodies, were represented in green spectral signature on the colour composite. Consequently, these areas were neither Parana Pine stands nor forest land.

The image of the MSS band 7 also shows the shadow effect* in the

---

* The shadow effect was the minimum because the scene was acquired around midday when the sun is at its peak in the sky. If the Landsat scene was acquired early in the morning, for example, around 9.30 a.m. the shadow effect would be greater than that seen on the image. The same comment applies to all the Landsat scenes used in this research because they were all acquired around midday.



```
MANGUEIRINHA INPE X=(300.402) Y=(921.1320) STRIP 1 *ABUT                *SELPAR 2 4
 10 GROUPS - SLICE: PARAMETER  2           RANGE    49.00     TO    199.0

GROUP:       1        2        3        4        5        6        7        8        9       10
SIZE:     5001     4915    11051    16889    25843    19894     9807    12037     7980     7383
```

Fig 29. Mangueirinha. Output produced by density slicing and contrast stretching the data in MSS band 7 into ten groups. Output from CCT of Landsat 2. ID 75213 123955. 01 August 1975 overpass.

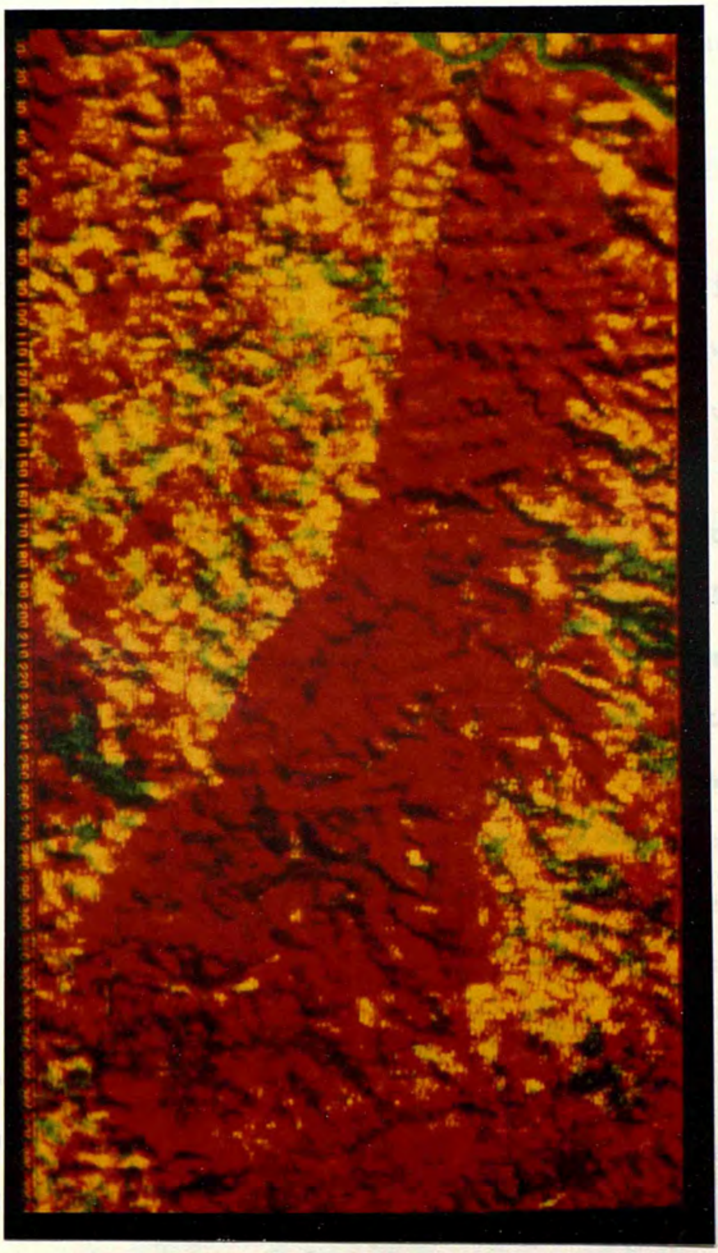


Fig 30. Mangueirinha. Colour composite generated from MSS bands 5 and 7 of Landsat 2 imagery. ID 75213/123955. 01 August 1975 overpass.

areas with dissected terrain, close to the Iguaçú River. These areas were represented on the image by areas in dark to medium gray tone. The image however did not show much tonal contrast between the land use/land cover classes in the area. In the image it was hardly possible to distinguish forest from non-forest land;

c) in the colour composite there was a clear contrast in colour spectral signature between forest land and non-forest land, the former being represented in red spectral signature and the latter in green and yellow spectral signature (Figure 30). Parana Pine stands were represented by areas in dark red spectral signature. A visual interpretation map of the colour composite is given (Figure 31). In it is shown the areas representing the same colour spectral signature as Parana Pine stands; also shown are the areas in red spectral signature representing any sort of vegetation at the time the image was acquired and finally, the other spectral signature colours, representing non-forest land. Some forest areas close to the Iguaçú River had the same spectral signature colour as Parana Pine stands due to the shadow effect. This effect is explained mainly by the low sun angle elevation, i.e. 29° when the Landsat scene was acquired in the winter time.

Analysis of the images for the Mangueirinha area from the Landsat scene acquired on 24 October 1976 indicated that:

a) Parana Pine stands were detected again relatively easily on the image of MSS band 5 because the darkest tone produced by their reflectance was on this waveband(Figure 32).Thus,Parana Pine stands continued to have the lowest reflectance at the waveband regarding all the land use/land cover classes existing in the area at the time the scene was acquired. The tropical forest situated close to the Iguaçú River however was also represented by the darkest tone on the image and this

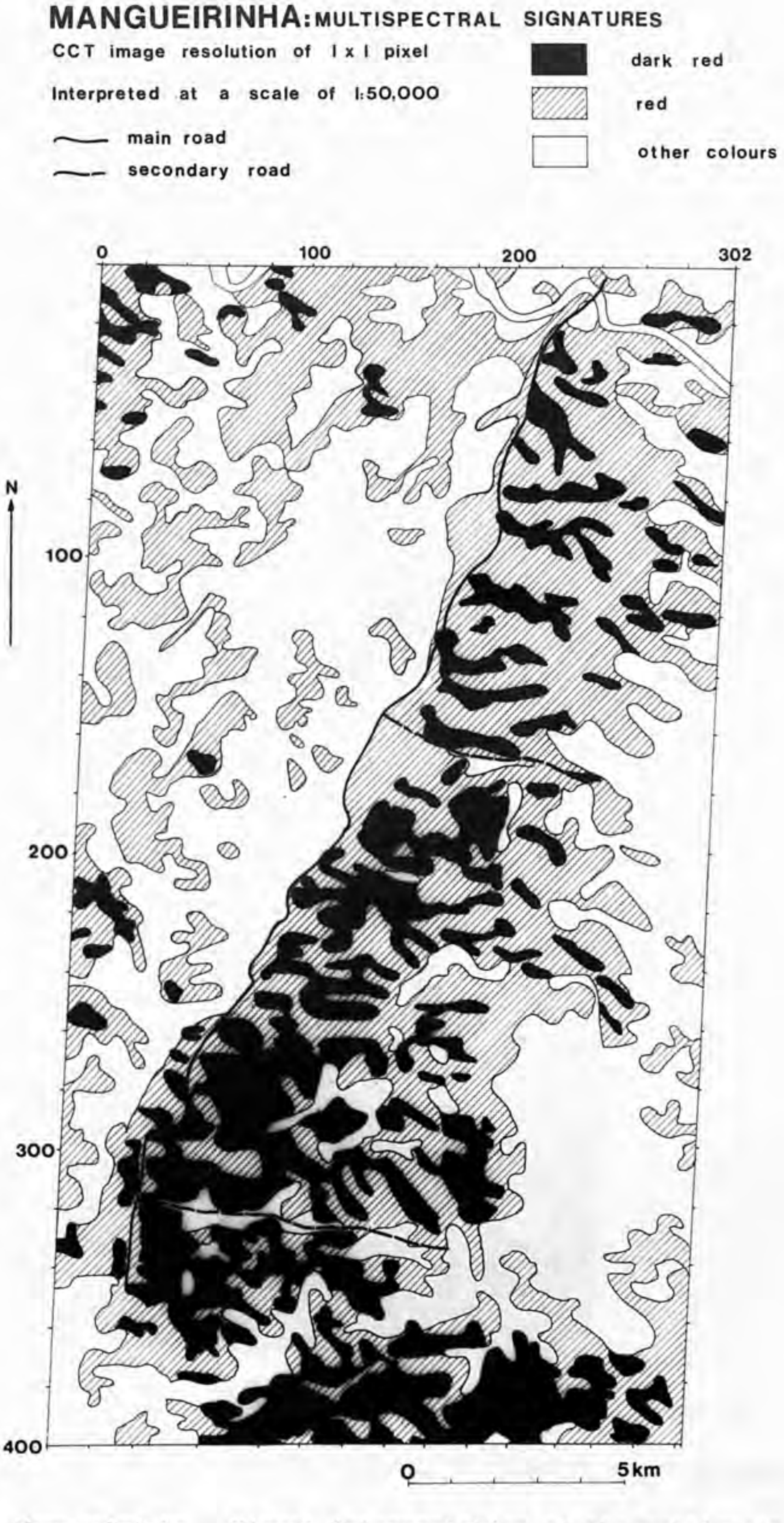


Fig 31. Mangueirinha. Visual interpretation of the multispectral colour signatures of the colour composite generated from MSS bands 5 and 7 of Landsat 2 imagery. ID 75213 123955. 01 August 1975 overpass.

```
MANGUEIRINHA AREA NASA FIRST STRIP X=(515.816) Y=(1121.1520) $L       *SELPAR 2 4
 10 GROUPS - SLICE: PARAMETER  1          RANGE    75.00     TO    248.0

GROUP:      1        2        3        4        5        6        7        8        9       10
SIZE:    6931    40572    21903    19963    13188     6702     8264     2382      730      165
```

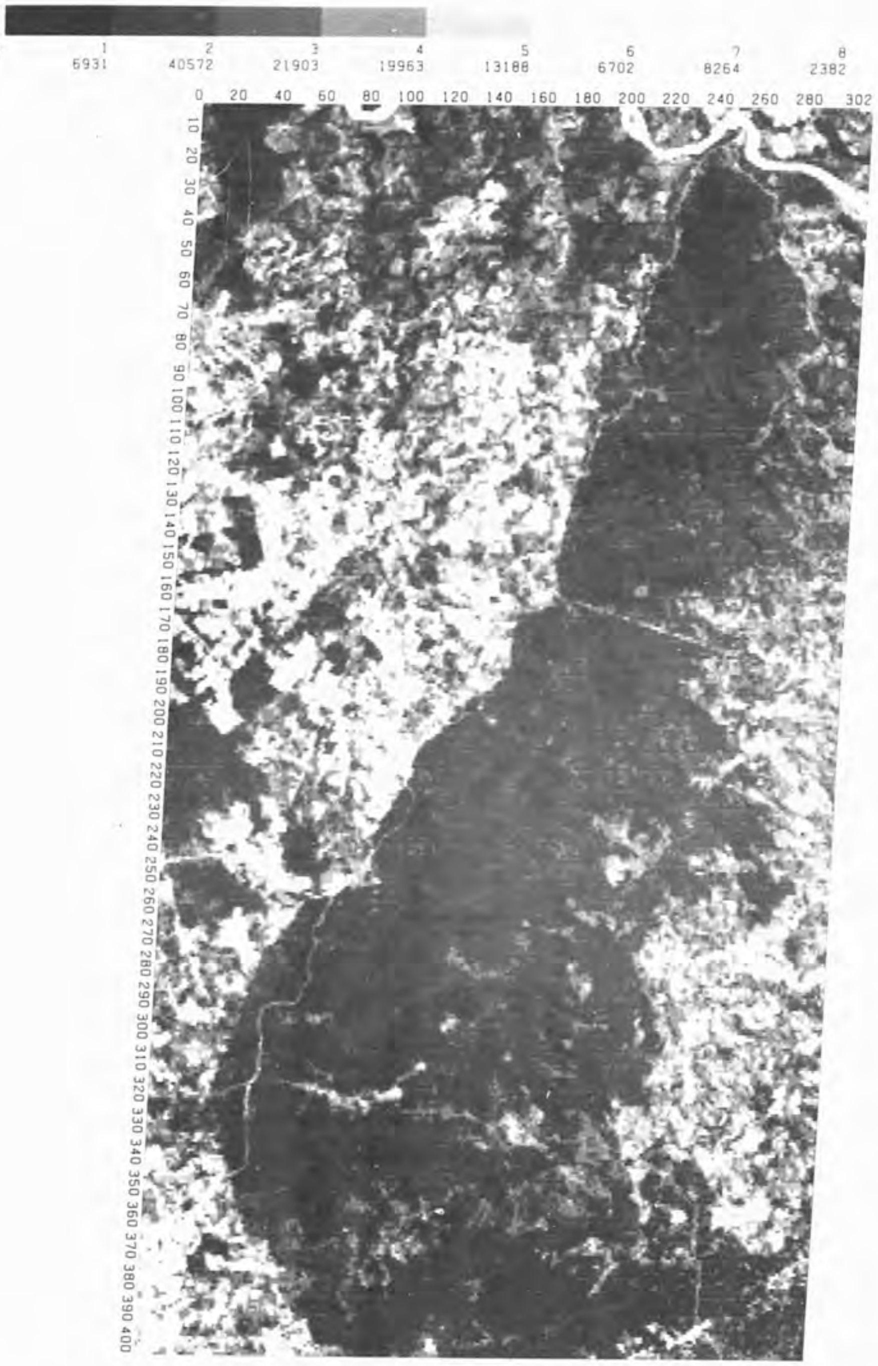


Fig 32. Mangueirinha. Output produced by density slicing and contrast stretching the data in MSS band 5 into ten groups. Output from CCT of Landsat 2. ID 8264112300500. 24 October 1976 overpass.

is shown in the visual interpretation map of the MSS band 5 (Figure 33). There was certainly slight differences in green colour between the canopies of the two forest cover types when the Landsat scene was acquired. This difference was minimized, however, by the fact that the tropical forest was located in the top parts of the areas with dissected terrain. This consequently resulted in the digital counts on the image for the tropical forest being near that for Parana Pine stands. Plate 4 is an air photo showing part of the tropical forest surrounded by deep slopes and Figure 34 is the annotated map.

The interpretation of the image of MSS band 5 indicated that there was not enough contrast in gray tone in order to distinguish forest from grassland areas in the area of Mangueirinha. This can be explained by the fact that the Landsat scene was acquired in the spring season and in one of the wettest months in the year (a shown in Figure 22). Consequently, the vegetation was everywhere in a stage of active growth period;

b) on the image of the MSS band 7, the Parana Pine stands produced a tone ranging from dark to medium gray. The tropical forest' close to the Iguacu River, on the other hand, was represented in lighter gray tone. So that these two distinctive forest types could be readily distinguished from one another on a tonal basis (Figure 35). As happened with the image of the MSS band 7 for the August 1975 scene the darkest tone of the image was represented by some non-forest areas and the Iguacu River. The image had good tonal contrast and it was much more informative regarding land use/land cover classes than the image of MSS band 7 acquired in August 1975;

c) on the colour composite, because of the difference between the reflectance of the Parana Pine stands and those of the tropical forest

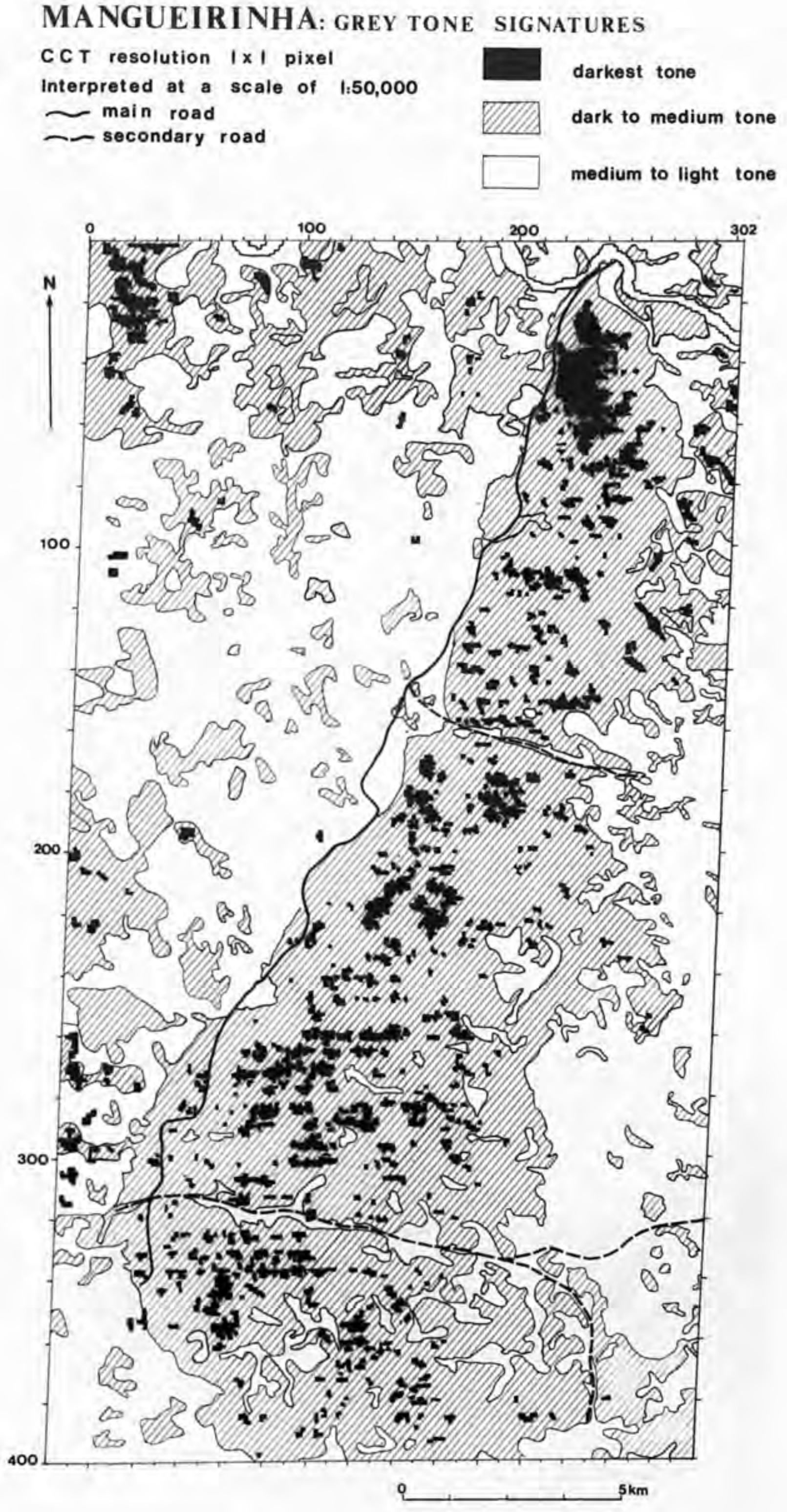


Fig 33. Mangueirinha. Visual interpretation of the grey tones signatures of the output of the MSS band 5 of Landsat scene from 24 October 1976 overpass.

Plate 4. An oblique airphoto showing the tropical forest close to the Iguaçú River. The position of the river relative to the secondary road has changed recently following the construction of an hydro electric power dam.

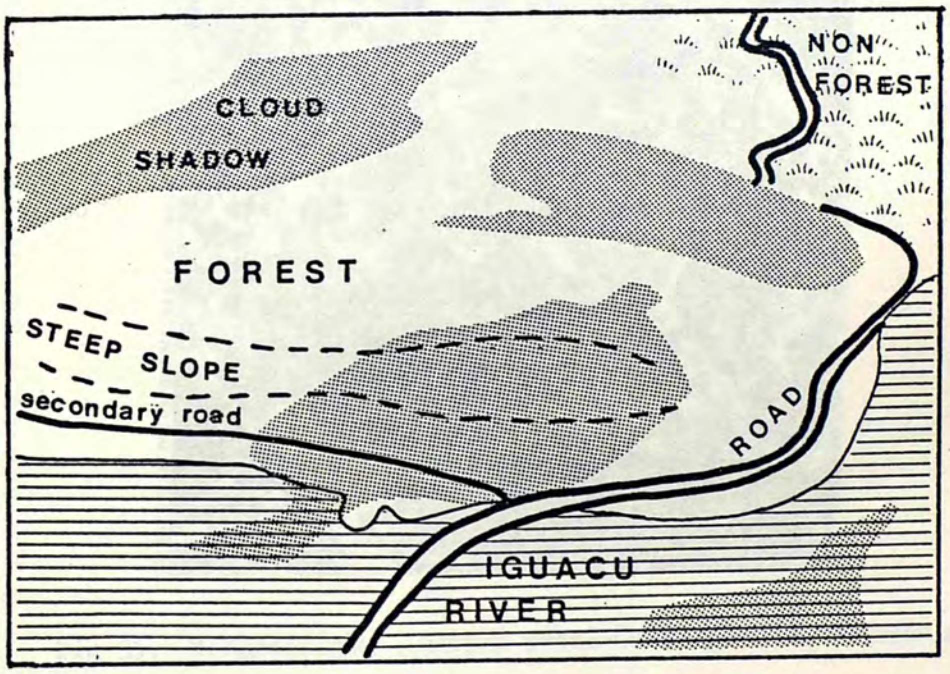
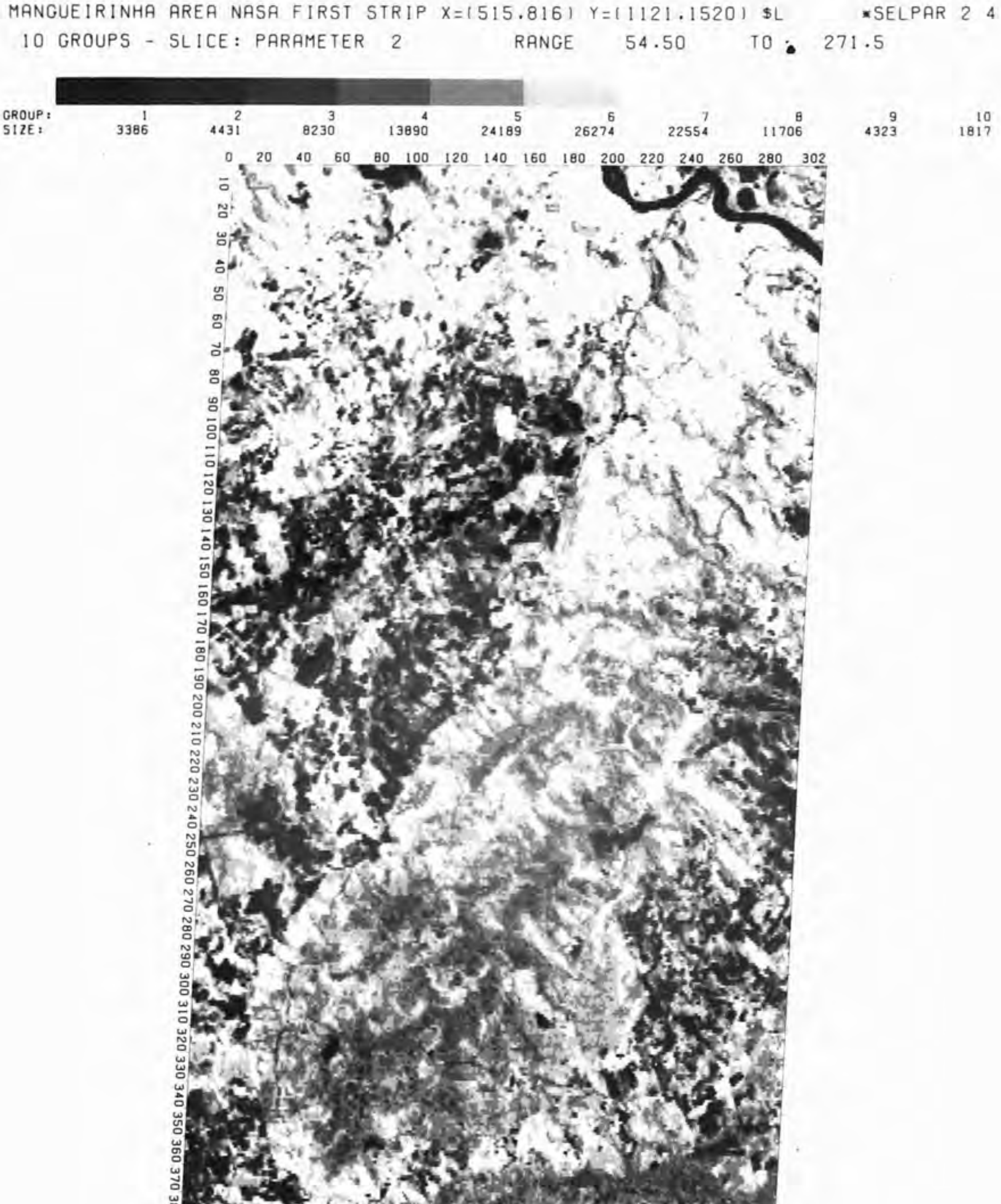


Figure 34. Annotated map of the air photo showing the tropical forest close to the Iguaçú River.



```
MANGUEIRINHA AREA NASA FIRST STRIP X=(515.816) Y=(1121.1520) $L      *SELPAR 2 4
 10 GROUPS - SLICE: PARAMETER  2          RANGE    54.50     TO   271.5

GROUP:       1       2       3       4       5       6       7       8       9      10
SIZE:     3386    4431    8230   13890   24189   26274   22554   11706    4323    1817
```

Fig 35. Mangueirinha. Output produced by density slicing and contrast stretching the data in MSS band 7 into ten groups. Output from CCT of Landsat 2. ID 8264112300500. 24 October 1976 overpass.

on the MSS band 7, the former produced a dark red spectral signature whereas the latter produced a red spectral signature (Figure 36). A visual interpretation map of the colour composite is shown (Figure 37). This map shows basically three areas. Firstly, areas with nearly the same spectral signature colour as Parana Pine stands. Secondly, areas represented by red colour spectral signature, i.e. areas representing vegetation. Thirdly, areas of non-red spectral signature that represented non-forest land.

The colour composite showed less pronounced shadow effect on the areas with dissected terrain, as that close to the Iguaçú River, than that colour composite for the Landsat August 1975 scene. This is mainly due to the high angle of sun elevation, i.e. 49°, as compared with the angle of 29° related to the Landsat scene of August 1975.

Bracaatinga stands were not visually detected on the visual analysis of the images of the MSS bands 5 and 7 and on the colour composite for the Landsat scenes acquired in August 1975 and October 1976. On these images bracaatinga stands were not distinguished from the forest land.

Regarding the mapping of Parana Pine stands, the images of Landsat scenes acquired in October 1976 were considered more effective than images for August 1975, for the following reasons:

a) on the image of MSS band 5 the boundaries of Parana Pine stands were more consistently represented;

b) the image of MSS band 7 had good tonal contrast and it was showing readily different land use/land cover classes. Parana Pine stands, however, were presented in tones ranging from dark to medium gray and in this way the stands were distinguished from the tropical forest in light gray tone;

d) in the colour composite, due to the high sun angle elevation

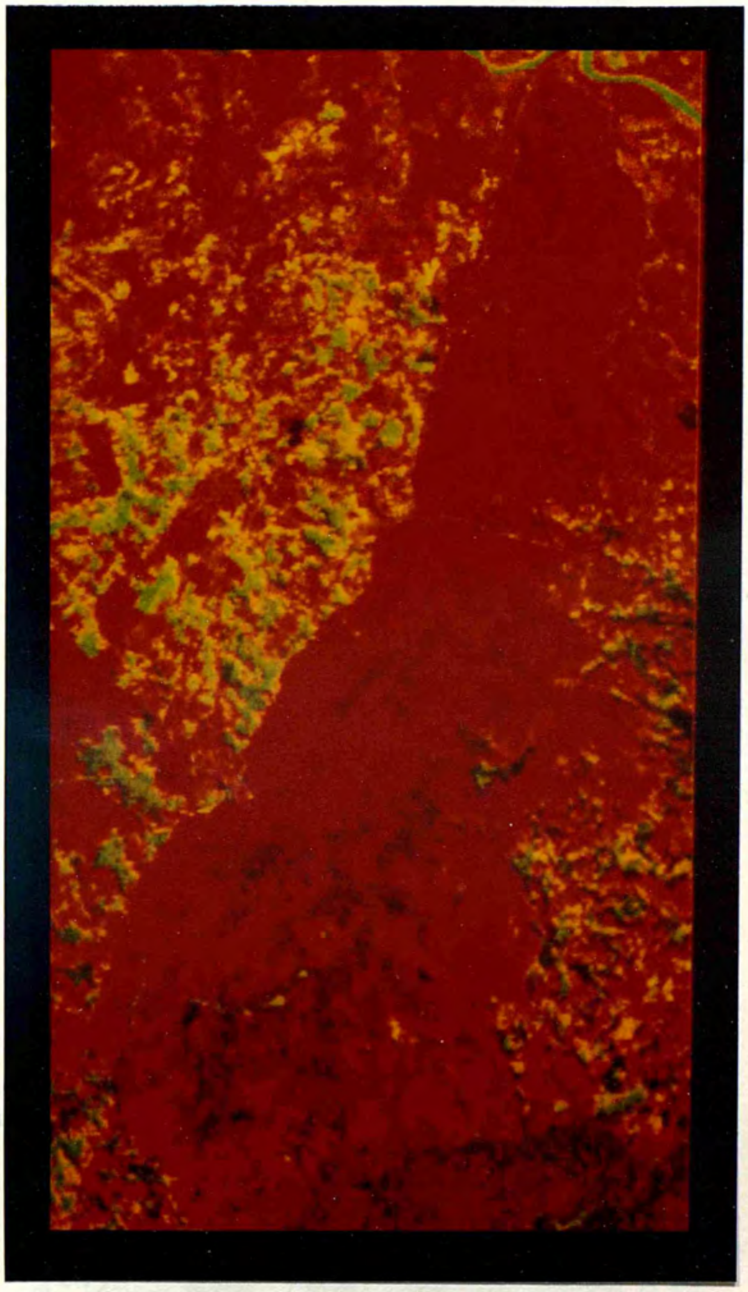


Figure 36. Mangueirinha. Colour composite generated from MSS bands 5 and 7 of Landsat 2 imagery. ID 8264112300500. 24 October 1976.

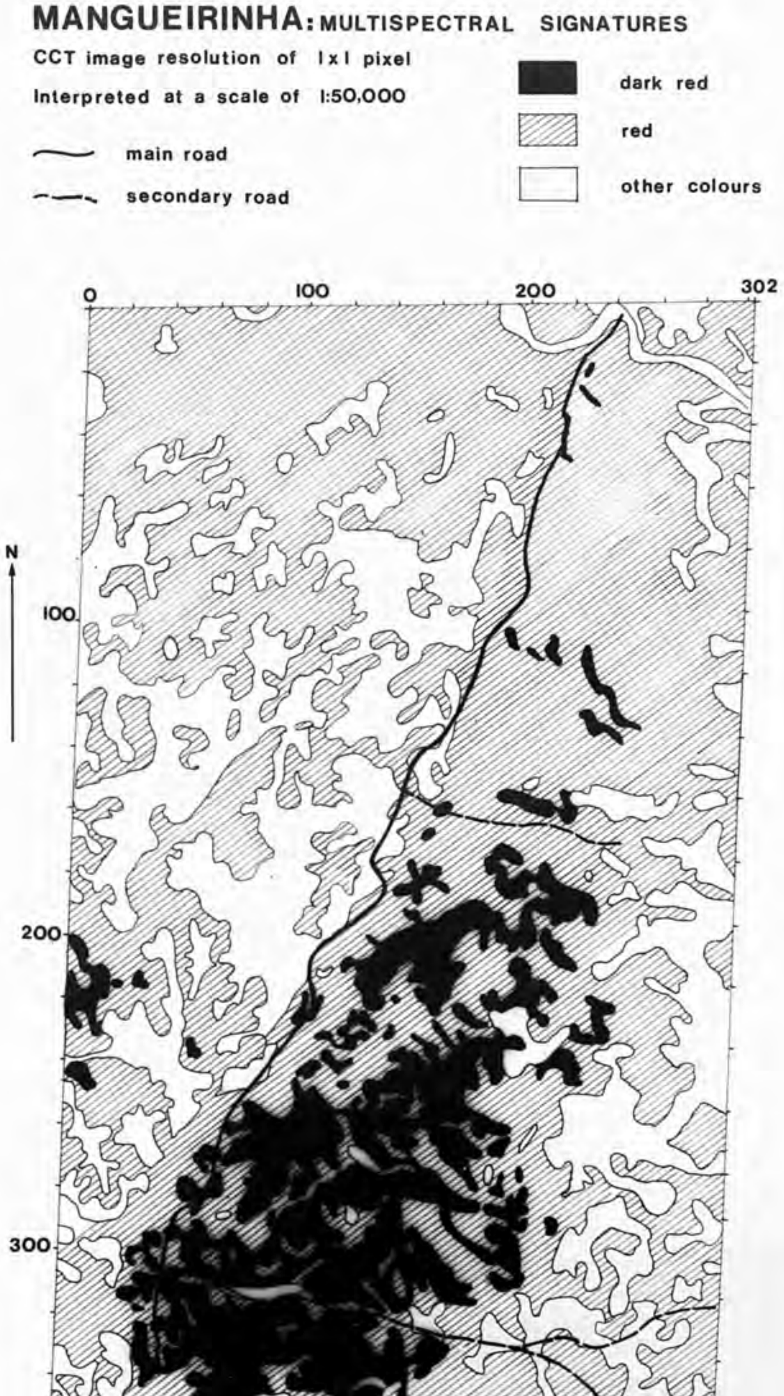


Fig 37. Mangueirinha. Visual interpretation of the multispectral colour signatures of the colour composite generated from MSS bands 5 and 7 of Landsat 2 imagery. ID 8264112300500. 24 October 1976 overpass.

when the scene was acquired, there was not much shadow effect, which avoided some areas supporting forest land being interpreted as being Parana Pine stands.

CHAPTER 9

THE ARAUCANASA AREA

9.1 Initial considerations

In order to test the feasibility of mapping Parana Pine stands of differing crown densities from the Landsat imagery by using both supervised and unsupervised classification programs available in the Bedford Remote Sensing Library, a smaller area within the Mangueirinha area was selected for study. For processing the unsupervised program the area could not exceed 30,000 pixels in the four MSS bands. Accordingly, an area measuring 100 x 71 pixels was selected.

The precise choice of area was governed by the following considerations:

a) it had to be located easily on the Landsat images and on the forest cover types;

b) the terrain should be relatively flat in order to avoid shadow effect in dissected terrain;

c) the terrain should be at an altitude between 700 and 900m, in the most favourable zone for the Parana Pine stands;

d) the chosen area should be one for which air photos, at the 1:10,000 scale were available. So a quantitative comparison between the estimated areas of Parana Pine stands from the forest map and from the computer classification could be made.

Having regard to these considerations the area chosen was that shown in Figure 38. It is clearly defined by the two roads existing in the area, and easily located in the Landsat images, in the forest

Fig. 38 Location of the test site in the Mangueirinha area

map and in the air photos. This area was named Araucanasa. It is a relatively flat terrain (Plate 5 and Figure 39) and it contains stands of Parana Pine that were easily identified on the Landsat imagery acquired in August 1975 and October 1976.

As the Araucanasa area, covered only a small ground area of $32km^2$, the mapping of Parana Pine stands of four differing crown densities using the Landsat CCT data, as had already been done with the 1:10,000 scale air photographs, was considered impracticable. The mapping of three of the crown density classes of Parana Pine stands was hampered by the problem of finding a sufficient number of training areas for the density classes for the supervised classification. Thus, it was decided to map stands within two classes of crown density, namely: those with a crown density of more than 50% (type I), those with a crown density of less than 50% (type II). There were few areas of bracaatinga stands and because of this its mapping was not taken into consideration.

A supervised and unsupervised computer classification of the Landsat digital data related to the area, was carried out using only the data set extracted from the 24 October 1976 Landsat scene overpass. This was backed by the experience acquired from the visual interpretation of the images of MSS bands 5 and 7 for the Mangueirinha area using the 01 August 1975 and 24 October 1976 Landsat overpasses scenes, which indicated that noise was present in the data set corresponding to the scene of August 1975. The strategy used in the unsupervised program considers all the data at once. Thus, if noise was present in the data set, all the results of the unsupervised classification would be affected. For this reason, the data set from August 1975 Landsat scene was not used for the computer classification.

Plate 5. An oblique airphoto showing part of the test site in the Mangueirinha area selected for the computer classification of Landsat digital data.

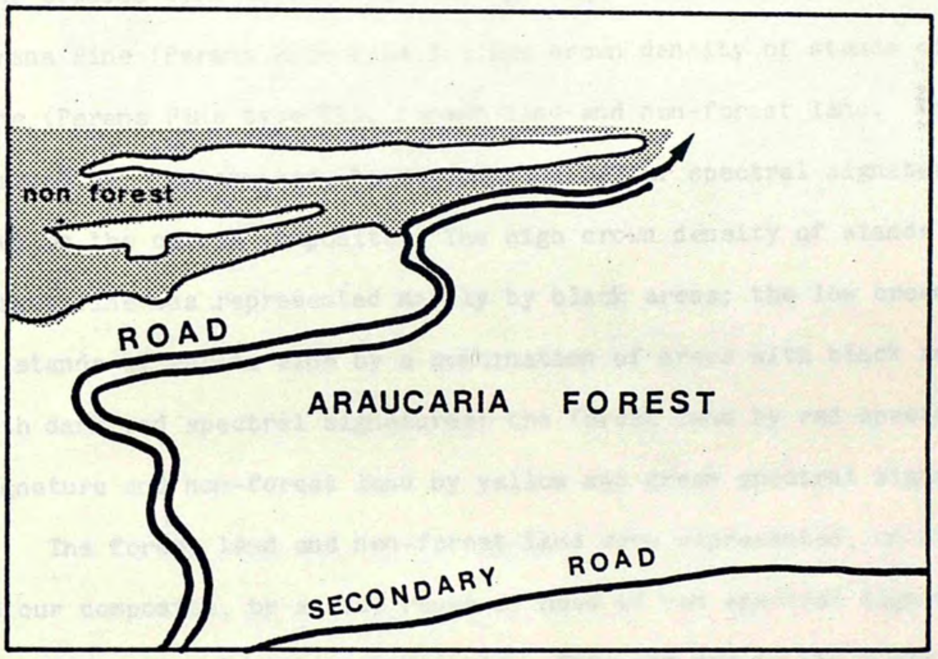


Figure 39. Annotated map of the airphoto showing the test site in the Mangueirinha area.

9.2 Selection of the training areas for the supervised classification and results of the computer-aided classification

The images of MSS bands 4, 5 and 7 corresponding to the test site of study were produced from the October 1976 Landsat scene. These images were subject to contrast stretching and density slicing into ten groups. The positive images were used in the additive viewer to generate colour composite, which was projected onto a screen at 1:15,000 scale. The colour composite is shown in Figure 40. Based upon the colour composite and the photo-interpretation map resulting from the 1:10,000 aerial photographs, an up-to-date forest map was produced for the area (Figure 41).

A visual analysis was carried out on the colour composite in order to determine the classes to be used in the computer-aided classification. Four classes were determined, namely: high crown density of stands of Parana Pine (Parana Pine type I), low crown density of stands of Parana Pine (Parana Pine type II), forest land and non-forest land. These classes were determined, based upon the colour spectral signature as seen on the colour composite. The high crown density of stands of Parana Pine was represented mainly by black areas; the low crown density of stands of Parana Pine by a combination of areas with black and areas with dark red spectral signatures; the forest land by red spectral signature and non-forest land by yellow and green spectral signatures.

The forest land and non-forest land were represented, on the colour composite, by a wide range of hues of red spectral signatures and different colours, respectively. This was due to the different environmental conditions in the forest and also different land use/land cover in the non-forest areas. In order to take this difference into

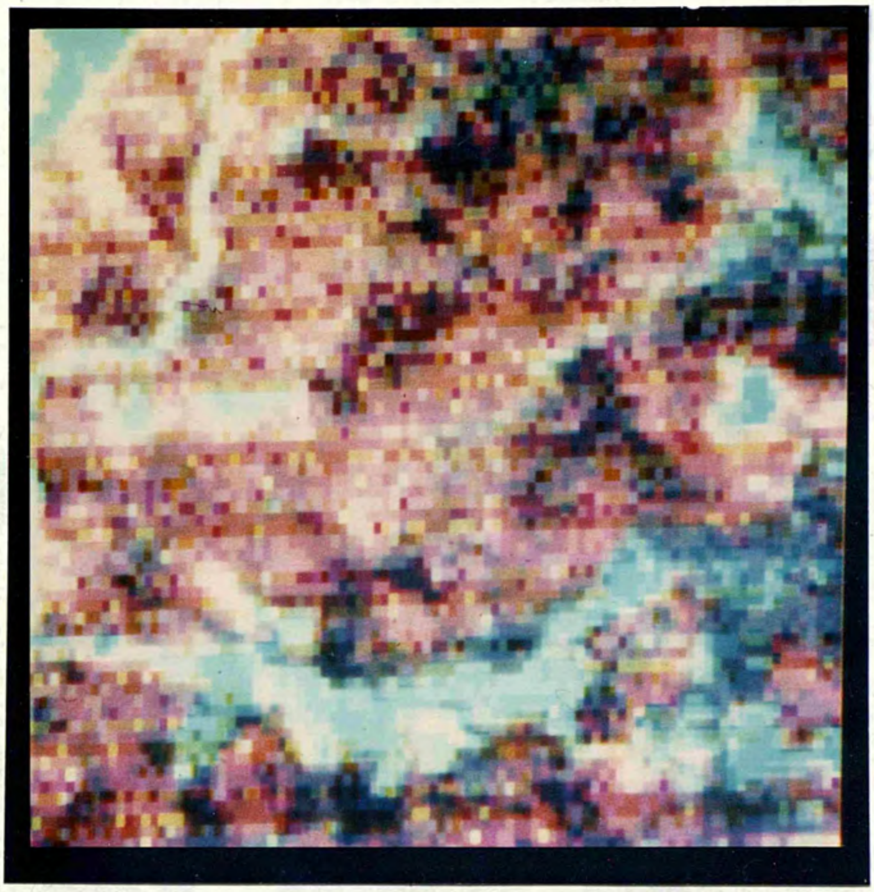


Figure 40. Landsat colour composite of the selected test site in the Mangueirinha area.

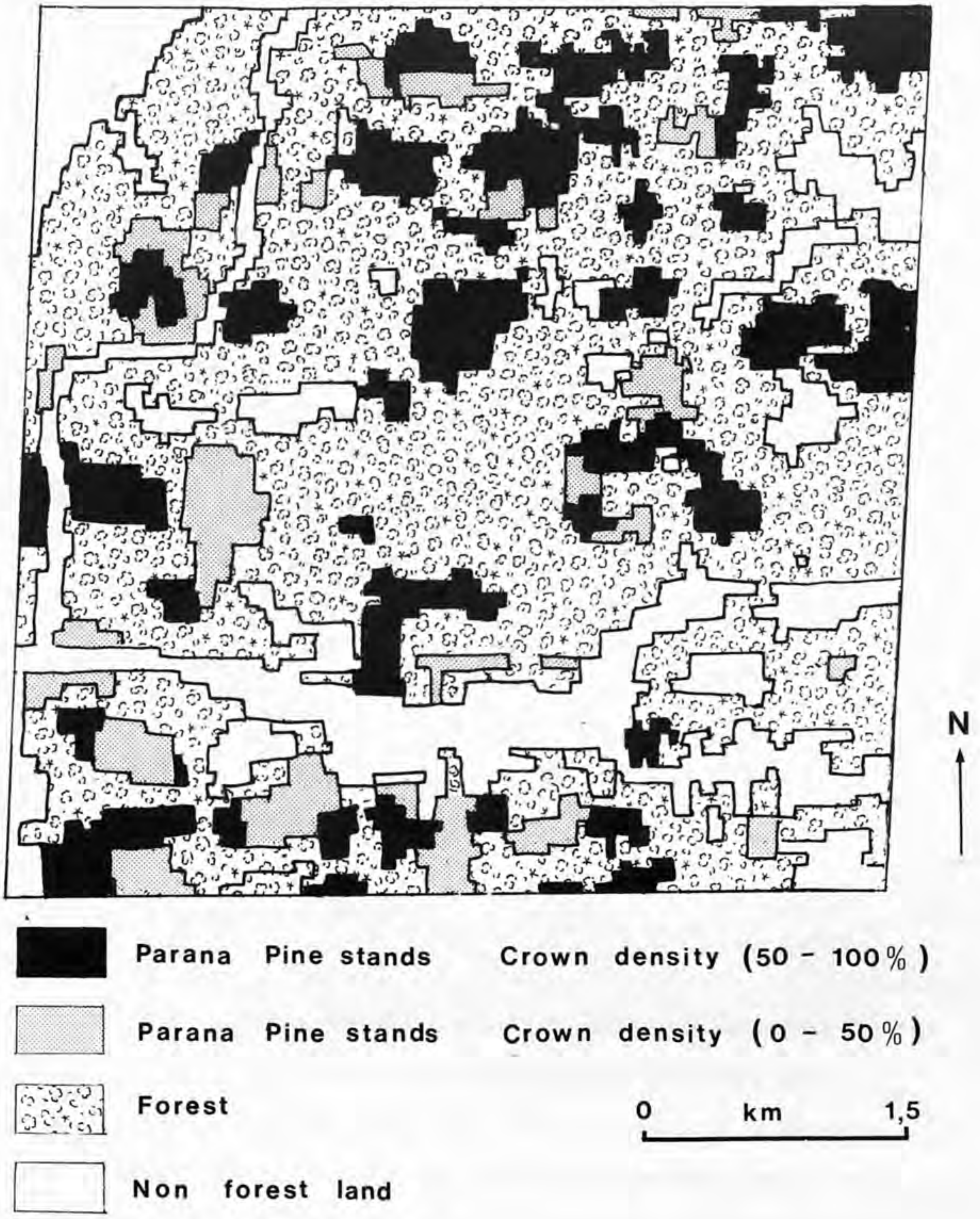


Fig 41. Forest cover type map of the selected test site in the Mangueirinha area.

account for the computer classification, three sub-classes (according to three broad densities of red spectral signature) were defined for the forest land and two sub-classes (yellow and green spectral signatures) were also defined for non-forest classes. These five sub-classes, with those two classes defined for the crown densities of Parana Pine stands, constituted the seven classes used in the computer classification. Training areas were chosen for the classes. The position of the training areas used for the classes in the supervised program is shown (Figure 42). For the evaluation of the results, the classes were grouped again into four informational classes,i.e. high crown density of stands of Parana Pine, low crown density of stands of Parana Pine, forest land and non-forest land.

The supervised and unsupervised programs were used with the following combinations of MSS bands: 4, 5, 6, 7; 4, 5, 7 and 5, 7. Table 12 reports the results of the classification accuracy using the classificatory programs and Table 13 shows the results of the estimates of areas occupied for the four classes given by the forest map and by the computer classificatory programs.

9.3 Analysis of the results

The mean digital counts and the standard deviation of the pixels defined as training areas for the various classes used in the supervised classification are listed (Table 14). From the analysis of this table an explanation of the spectral separability between the Parana Pine stands and other cover types is given. The class representing high crown density of stands of Parana Pine had the lowest mean digital counts in the MSS bands 4 and 5 from all the classes attemped in the classifi-

```
MANGUEIRINHA ARAUCARIATESTE FIRST STRIP X=(560.659) Y=(1381.1451) ARAUCAM*SELPAR
  8 GROUPS : FIELD MAP FOR TSI ARAUCARIA TESTE AREA JUNCAO DE : DATE  17/04/80

GP SHADING     POINTS          GP SHADING     POINTS
 1 0               69           5 H               33
 2 EF              52           6 EFOIJ           42
 3 H               47           7 EFOIJ           12
 4 H               32           8 -             8813
```

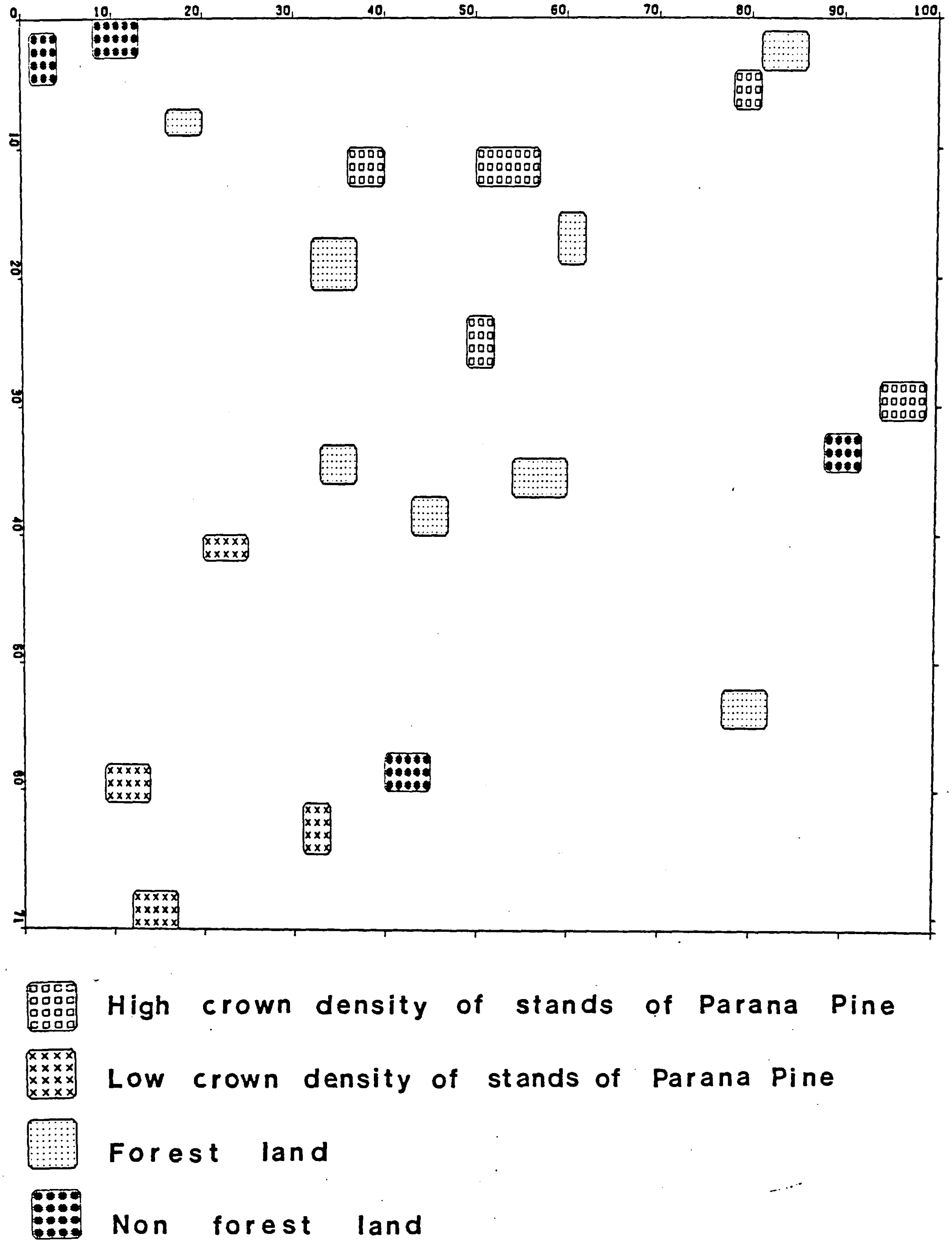


Fig 42. Position of the training areas for the classes attempted in the supervised classification of the selected test site in the Mangueirinha area.

Table 12. Results of the classification accuracy (in %) for the classes attempted in the classificatory programs of the test site in the Mangueirinha area

CLASS	Number of pixels tested	SUPERVISED CLASSIFICATION			UNSUPERVISED CLASSIFICATION		
		MSS bands 4,5, 6,7	MSS bands 4,5, 7	MSS bands 5,7,	MSS. bands 4,5, 6,7	MSS bands 4,5, 7	MSS bands 5,7
Parana Pine type I	69	94.2	92.8	92.8	94.2	69.6	97.1
Parana Pine type II	52	50.0	50.0	46.2	26.9	48.1	46.2
Forest	112	91.1	91.1	92.0	83.0	76.8	90.2
Non-forest areas	54	98.1	98.1	98.2	59.2	22.2	96.3

Table 13. Results of the estimates of the area occupied by the classes attempted in the classificatory programs of the test site in the Mangueirinha area

Number of pixels / CLASS	Forest map	SUPERVISED CLASSIFICATION			UNSUPERVISED CLASSIFICATION		
		MSS bands 4,5, 6,7	MSS bands 4,5, 7	MSS bands 5,7	MSS bands 4,5, 6,7	MSS bands 4,5, 7	MSS bands 5,7
Parana Pine type I	1047	795	812	815	1428	1295	853
Parana Pine type II	625	2048	2056	1955	1301	1524	2169
Forest	4399	3516	3476	3516	2906	2841	3241
Non-forest areas	1029	741	756	814	1465	1440	837
Total number of pixels	7100	7100	7100	7100	7100	7100	7100

Table 14. Landsat 2 MSS (bands 4, 5, 6, 7) mean digital counts ($\bar{x}$) and standard deviation ($s\bar{x}$) of the training areas of classes used in the supervised classification of the selected test site in the Mangueirinha area

CLASS	No. of pixels.	MSS 4		MSS 5		MSS 6		MSS 7	
		$\bar{x}$	$s\bar{x}$	$\bar{x}$	$s\bar{x}$	$\bar{x}$	$s\bar{x}$	$\bar{x}$	$s\bar{x}$
October 24, 1976 Landsat 2 overpass									
Parana Pine type I	69	108.6	7.1	89.7	1.4	252.5	23.3	126.0	14.5
Parana Pine type II	52	117.0	6.7	98.6	5.4	307.8	19.9	159.6	11.7
Forest	47	119.7	5.0	100.6	4.4	345.9	18.5	182.3	9.9
Forest	32	125.9	6.2	107.0	5.9	386.3	50.7	203.8	30.8
Forest	33	121.0	6.7	107.6	6.7	315.1	21.5	159.9	11.3
Non-forest	42	137.0	6.9	162.	19.5	248.0	27.9	105.4	22.1
None-forest	12	145.8	10.0	152.8	14.4	394.0	22.0	196.5	9.0

cation. Perhaps, this was not applied to the MSS bands 6 and 7. In the MSS bands 6 and 7 a class of non-forest land (i.e. representing areas of green spectral signatures on the colour composite) had the lowest mean digital counts. Consequently, it had absorbed more infrared radiation than the dense stands of Parana Pine. These two mentioned classes, according to their mean digital counts, had more spectral separability in the MSS band 7 than in the MSS band 6. Thus, the image of MSS band 7 would be more appropriate for the visual interpretation and computer classification regarding the mapping of the two classes.

The set of pixels defined as training areas for the class representing low crown density of stands of Parana Pine resulted, in the MSS bands 4 and 5, in mean digital counts nearer that for one of the forest classes. An explanation is given. The areas defined for low crown density of stands of Parana Pine was a mixed feature class, being by definition, formed by more forest land than Parana Pine stands. Consequently, there was not much contrast in colour between the canopies of the areas supporting low crown density of Parana Pine stands and the dense forest without the Parana Pine stands.

9.3.1 Supervised classification

The results yielded by the supervised classification of the area of study (Araucanasa) are evaluated. Four classes were analysed and three different combinations of MSS bands were tested using the supervised program. Study of the Table 13 indicates that the results of the classification are nearly the same for the classes in all the tested combinations of MSS bands. Because of this, only the results yielded by the supervised classification on the data contained on the MSS bands

4, 5, 7 are analysed in detail. The confusion matrix for the classification is given (Table 15).

Table 15. Confusion matrix for the test site in the Mangueirinha area classified by supervised program on the data contained on the MSS bands 4, 5, 7.

CLASS	Number of pixels tested	Accuracy in %			
		A	B	C	D
A = Parana Pine type I	69	92.8	7.2	-	-
B = Parana Pine type II	52	11.5	50.0	38.5	-
C = Forest	112	-	8.0	91.1	0.9
D = Non-forest	54	-	-	1.8	98.2

Study of Table 15 shows that using a supervised program:

a) the classification accuracy for the class representing high crown density of stands of Parana Pine (type I) was 92.8%. This indicated that the stands were accurately classified using the supervised program and that there was not spectral overlapping with the other classes. The remaining error of the classification, i.e. 7.2% was due to the misclassification of pixels as being low crown density of stands of Parana Pine;

b) the classification accuracy for the class representing low crown density of stands of Parana Pine (type II) was 50%. Thus, the other 50.0% of the pixels, in which the classification was evaluated, was wrongly classified as being high crown density of stands of Parana Pine and forest land. The percentage of pixels allocated in the mentioned classes were 11.5 and 38.5 respectively.

The low classification accuracy for the class representing low crown density of stands of Parana Pine emanated from the selection of training areas. Although careful visual analysis was carried out in the colour composite for the selection of representative training areas for the class, it was not possible to find homogeneous areas in the sense of colour spectral signature. The class was represented by a mixture of colour spectral signature, i.e. black, dark red and red. The black spectral signature was representing high crown density of stands of Parana Pine. The dark red and red spectral signatures were mainly representative of the forest land. This spatial variability in the training areas was not taken into consideration in the classificatory program that works strictly with numerical manipulation of the spectral reflectance values;

c) the classification accuracy for the class representing forest land was 91.1%. The remaining error of the computer classification was due to pixels wrongly classified as being low crown density of stands of Parana Pine and non-forest areas;

d) the classification accuracy for the class representing non-forest land was 98.2%.

The results of the supervised computer classification were also evaluated throughout the comparison of the estimates of area from the computer classification and those acquired from the updated forest map. A comparison of the results yielded by the supervised classification on the data contained in the MSS bands 4, 5, 7 and those from the forest map indicated that:

a) the estimates of area from the computer classification were 20% less than that derived from the forest map, regarding the mapping of high crown density of stands of Parana Pine. A visual comparison between the forest map (Figure 41) and the map generated by the computer classification*(Figure 43) indicated a close correspondence between the position of the stands, although some areas close to the roads were less represented in the computer map;

b) the estimates of area from the computer classification was not reliable regarding the mapping of low crown density of stands of Parana Pine. The area was over-estimated more than three times that given on the forest map. As mentioned before, the training areas defined for the class included a mixture of colour spectral signature as seen on the colour composite. Thus, the class was not homogeneous because it comprised a mixture of two forest cover types, i.e. close canopy of Parana Pine and forest land without Parana Pine trees. Consequently, an excessive number of pixels were classified in the class. This may also explain the underestimated areas found for the classes representing high crown density of stands of Parana Pine and forest land.

In summary, high crown density of stands of Parana Pine were accurately mapped in the area of study using the supervised classification with any of the tested combinations of MSS bands. Low crown density of stands of Parana Pine were not accurately mapped mainly because it was not possible to find homogeneous training areas for the class.

9.3.2 Unsupervised classification

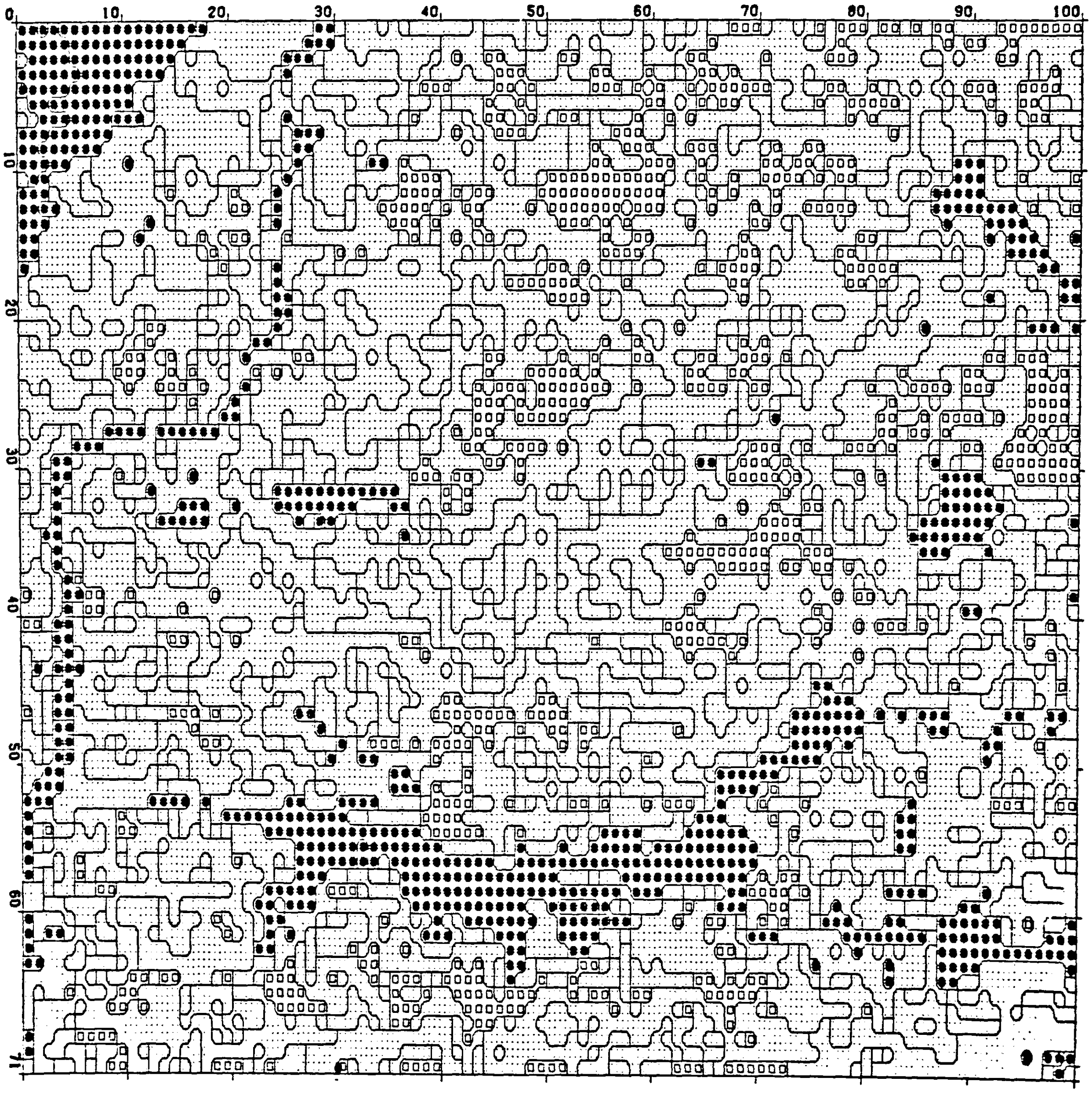
The chosen study area comprised 7100 pixels in each MSS band given a

---

* Only three classes are represented on the computer classification map. The class related to low crown density of stands of Parana Pine, due to its not reliable results, is represented in the map together with the class representing forest land.

```
MANGUEIRINHA ARAUCARIATESTE FIRST STRIP X=(560.659) Y=(1381.1451) ARAUCAM*SELPAR
  7 GROUPS-SOUPED NO BIN 22/04/80 FROM  TSI -ARAUCARIA TESTE AREA JUNCAO DE

GP SHADING     POINTS         GP SHADING     POINTS
 1 O              812          5 H             1566
 2 H             2056          6 EFOIJ          658
 3 H             1065          7 EFOIJ           98
 4 H              845
```



▦ **High crown density of stands of Parana Pine**

▒ **Forest land and low crown density of stands of Parana Pine**

● **Non forest land**

Fig 43. Computer classification map for the selected test site in the Mangueirinha area. Supervised classification using data contained on MSS bands 4,5,7.

total of 28,400 pixels on the four MSS bands. This allowed the classification with the unsupervised program. The data set corresponding to the study area was divided into twelve groups with the unsupervised program. By a rough and ready method the data set was clustered into three times as many groups as there were the cover types. Hoffer and staff (1975) used a factor of two in order to determine the number of groups for the unsupervised classification.

Following the procedure adopted by Cole _et al_ (1975) the data set was classified into a progressively larger number of groups and the output displayed on a series of microfilm plots for which maps were printed. For example, the data set was divided first into just two groups; secondly, one of the groups was subdivided so that the data set was classified into three groups. This procedure continued until the data set was divided into the required number of groups. On the series of microfilm plots (in a total of n groups less one) each group was assigned a different symbol.

The combinations of MSS bands 5 and 7 was initially used for the unsupervised classification. The resulting maps are reproduced in Figures 44 to 54.

The position of all the training areas used in the supervised classification was located on the map representing 12 groups. From the analysis of those test areas it was possible to assign each group of the classification to one of the specific classes defined in the classification scheme. The high crown density of stands of Parana Pine was represented by just one group in the unsupervised classification; the low crown density of stands of Parana Pine by two groups; the forest land by four groups and non-forest land by four groups. The dendrogram of the twelve group classification is given (Figure 55). It shows that

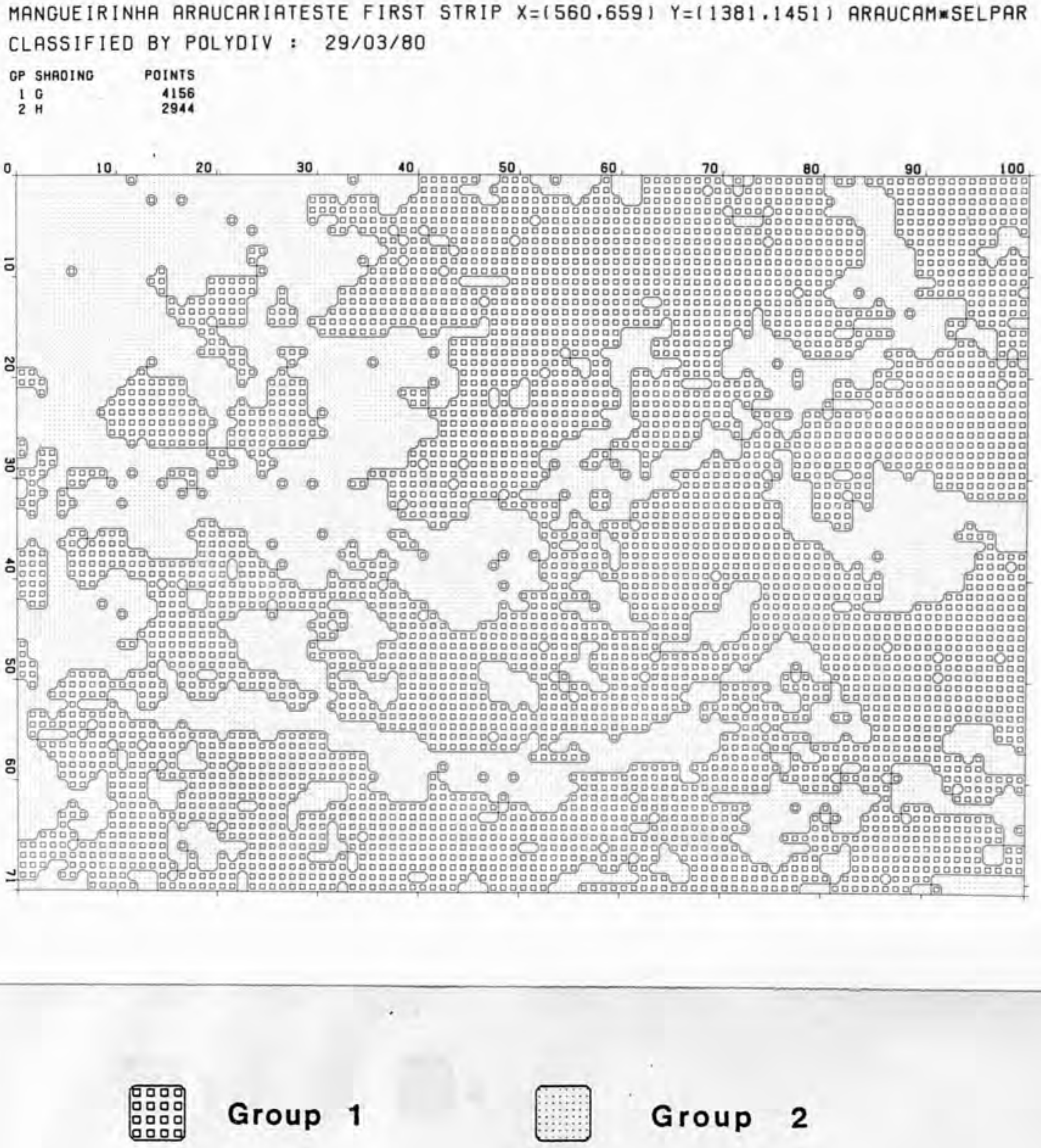
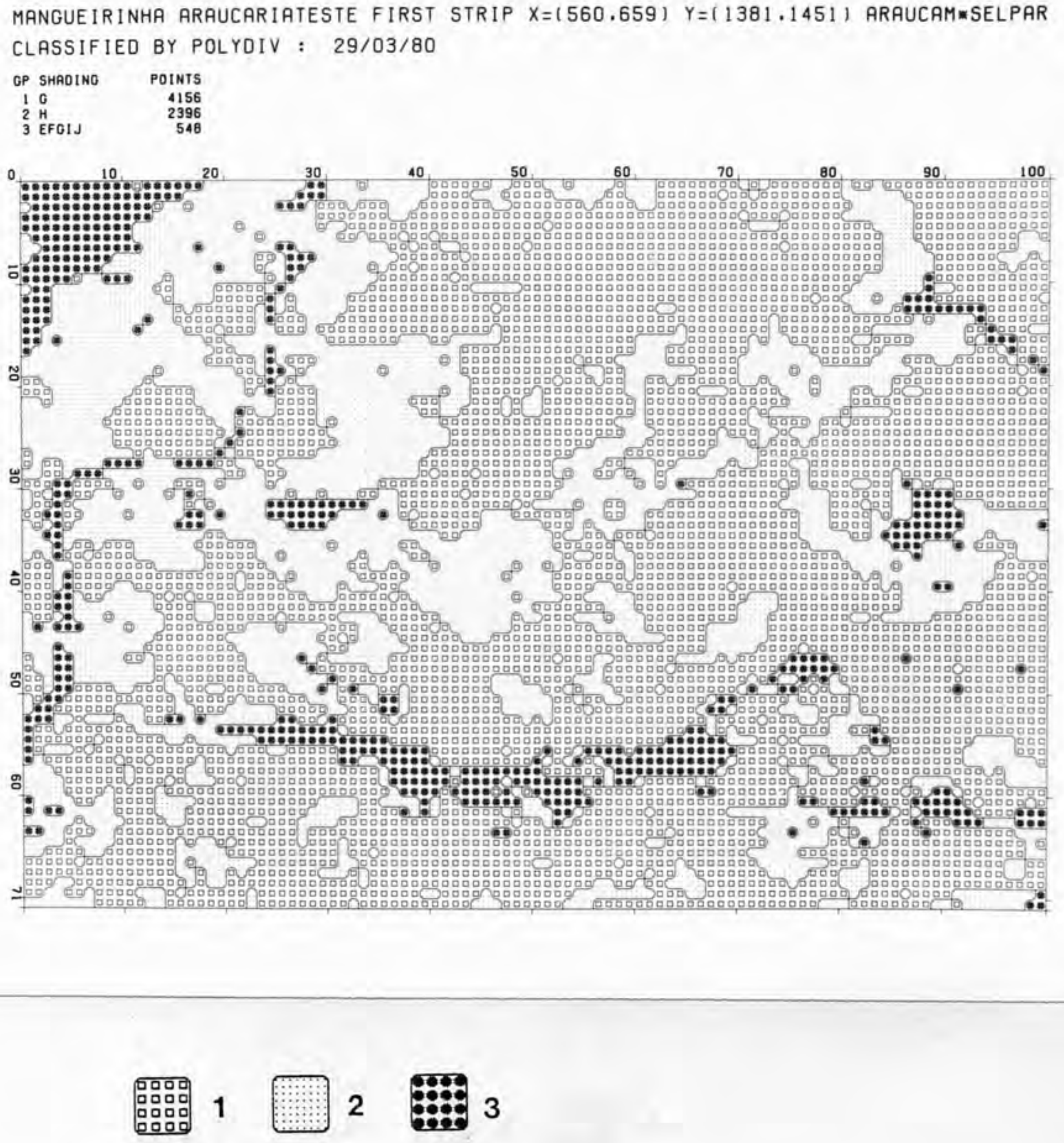


Fig 44. Computer classification map for the selected test site in the Mangueirinha area. Unsupervised classification into two groups using data contained on MSS bands 5 and 7.



```
MANGUEIRINHA ARAUCARIATESTE FIRST STRIP X=(560.659) Y=(1381.1451) ARAUCAM*SELPAR
CLASSIFIED BY POLYDIV :  29/03/80

GP SHADING        POINTS
 1 G               4156
 2 H               2396
 3 EFGIJ            548
```

Fig 45. Computer classification map for the selected test site in the Mangueirinha area. Unsupervised classification into three groups using data contained on MSS bands 5 and 7.

```
MANGUEIRINHA ARAUCARIATESTE FIRST STRIP X=(560.659) Y=(1381.1451) ARAUCAM*SELPAR
CLASSIFIED BY POLYDIV :  29/03/80

GP SHADING      POINTS
 1 G              1584
 2 H              2396
 3 EFGIJ           548
 4 E              2572
```

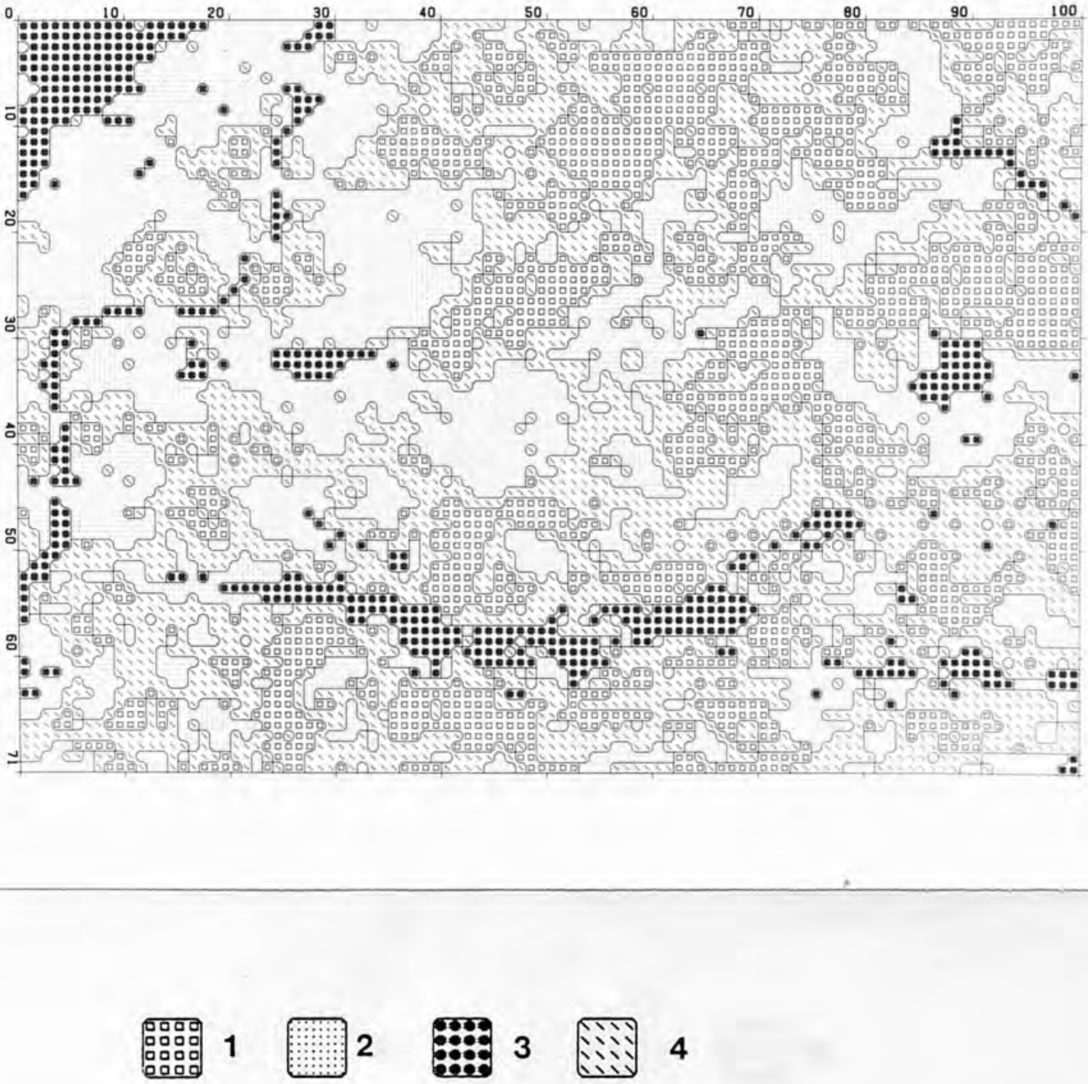


Fig 46. Computer classification map for the selected test site in the Mangueirinha area. Unsupervised classification into four groups using data contained on MSS bands 5 and 7.

```
MANGUEIRINHA ARAUCARIATESTE FIRST STRIP X=(560.659) Y=(1381.1451) ARAUCAM*SELPAR
CLASSIFIED BY POLYDIV :  29/03/80

GP SHADING        POINTS          GP SHADING       POINTS
 1 G                 853           5 F                731
 2 H                2396
 3 EFGIJ             548
 4 E                2572
```

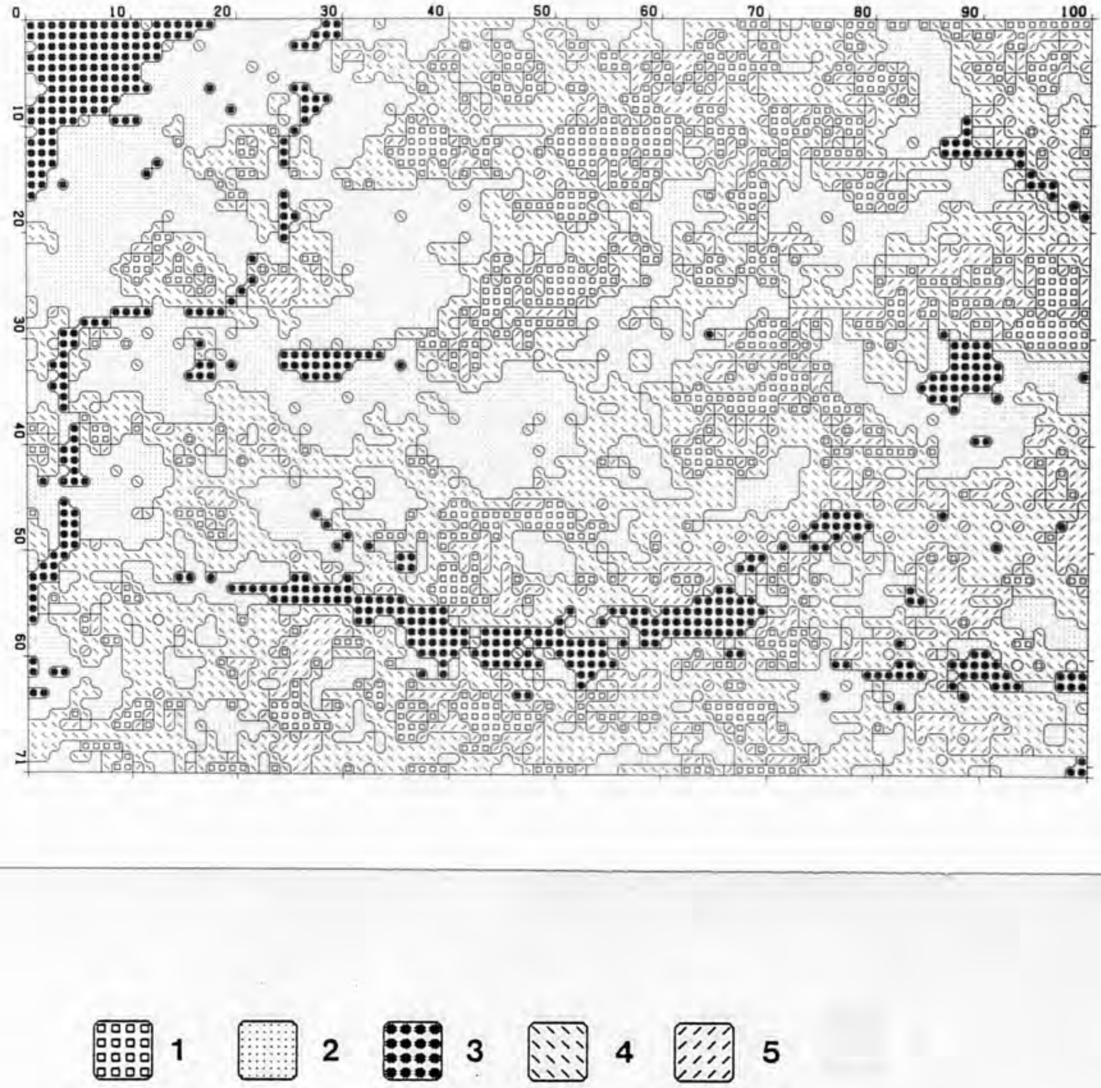


Fig 47. Computer classification map for the selected test site in the Mangueirinha area. Unsupervised classification into five groups using data contained on MSS bands 5 and 7.

```
MANGUEIRINHA ARAUCARIATESTE FIRST STRIP X=(560.659) Y=(1381.1451) ARAUCAM*SELPAR
CLASSIFIED BY POLYDIV :  29/03/80

GP SHADING      POINTS        GP SHADING      POINTS
 1 G               853         5 F               731
 2 H              2396         6 IJ             1134
 3 EFGIJ           548
 4 E              1438
```

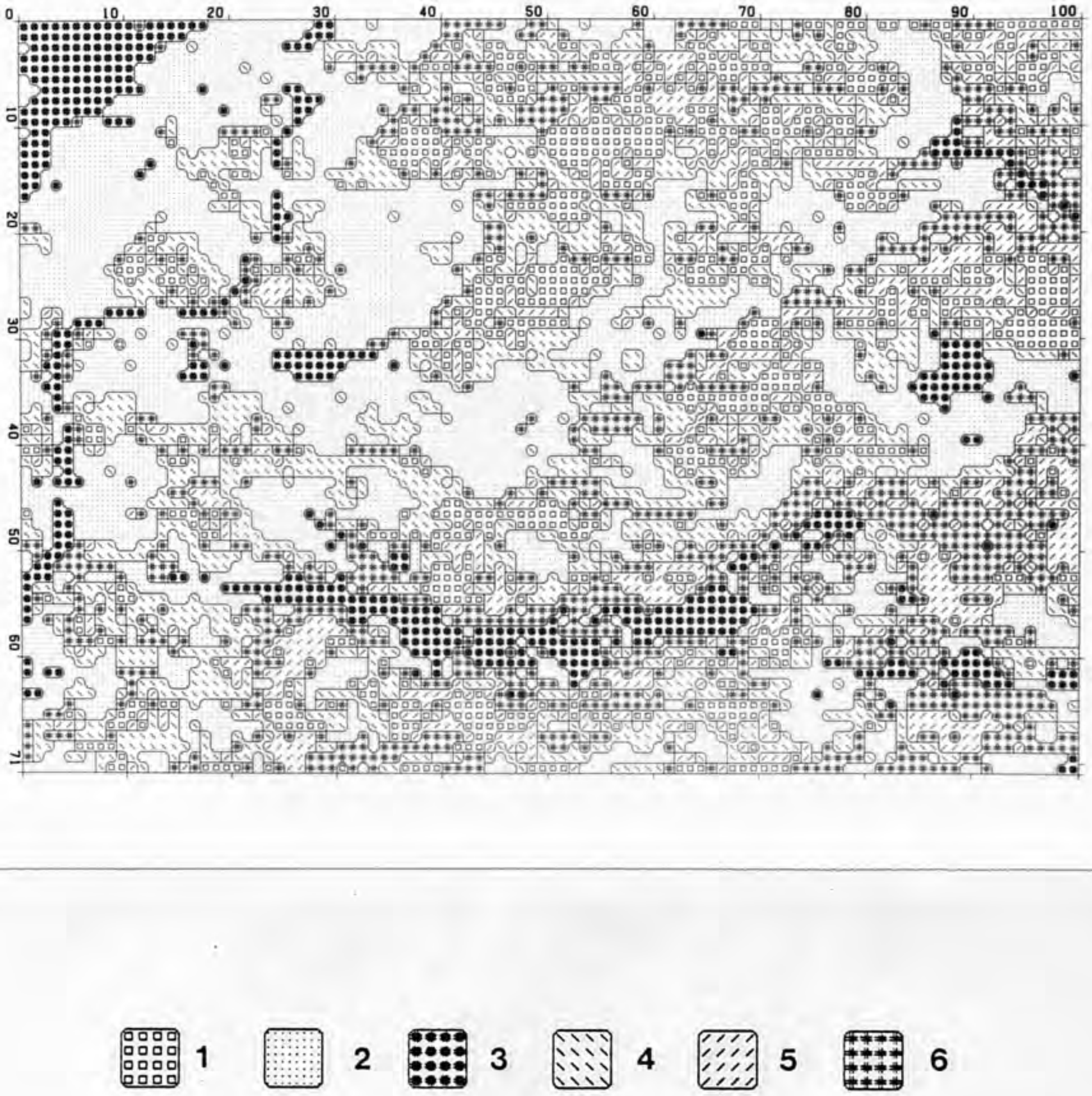
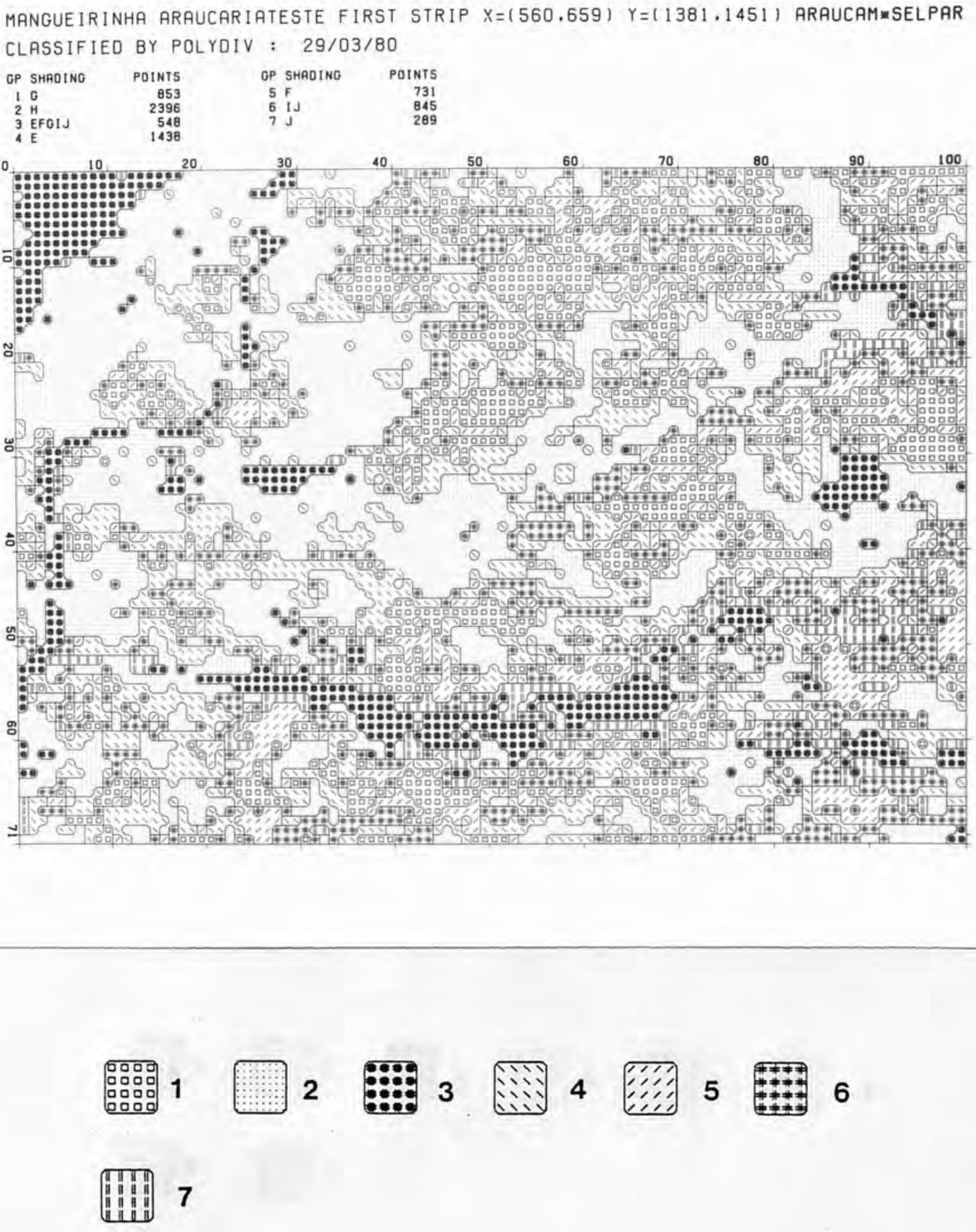


Fig 48. Computer classification map for the selected test site in the Mangueirinha area. Unsupervised classification into six groups using data contained on MSS bands 5 and 7.



```
MANGUEIRINHA ARAUCARIATESTE FIRST STRIP X=(560,659) Y=(1381,1451) ARAUCAM*SELPAR
CLASSIFIED BY POLYDIV :  29/03/80
GP SHADING        POINTS          GP SHADING        POINTS
 1 G                 853           5 F                 731
 2 H                2396           6 IJ                845
 3 EFGIJ             548           7 J                 289
 4 E                1438
```

Fig 49. Computer classification map for the selected test site in the Mangueirinha area. Unsupervised classification into seven groups using data contained on MSS bands 5 and 7.

```
MANGUEIRINHA ARAUCARIATESTE FIRST STRIP X=(560.659) Y=(1381.1451) ARAUCAM*SELPAR
CLASSIFIED BY POLYDIV :  29/03/80

GP SHADING      POINTS        GP SHADING      POINTS
 1 G               853         5 F               731
 2 H              2396         6 IJ              845
 3 EFGIJ           408         7 J               289
 4 E              1438         8 EF              140
```

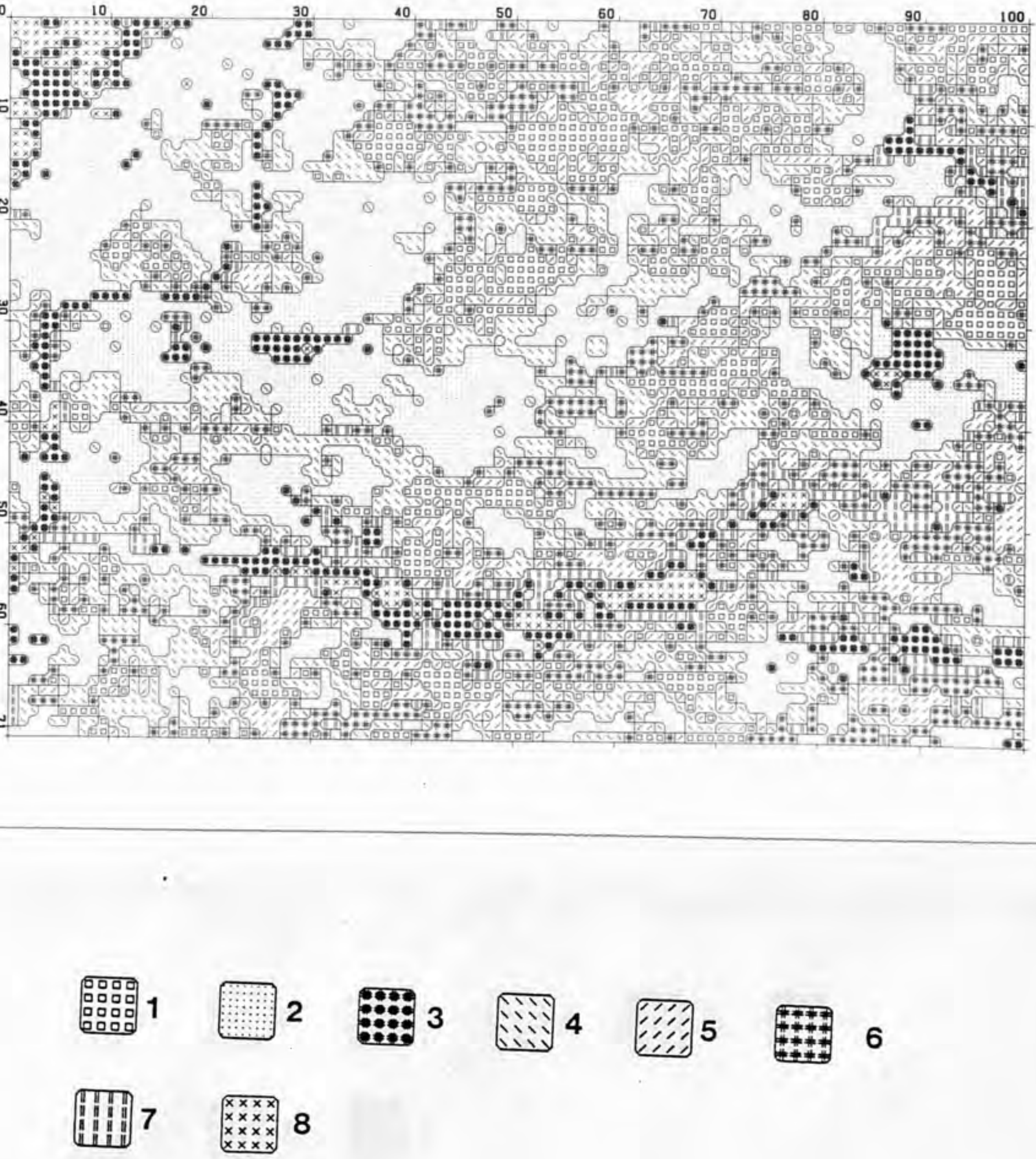
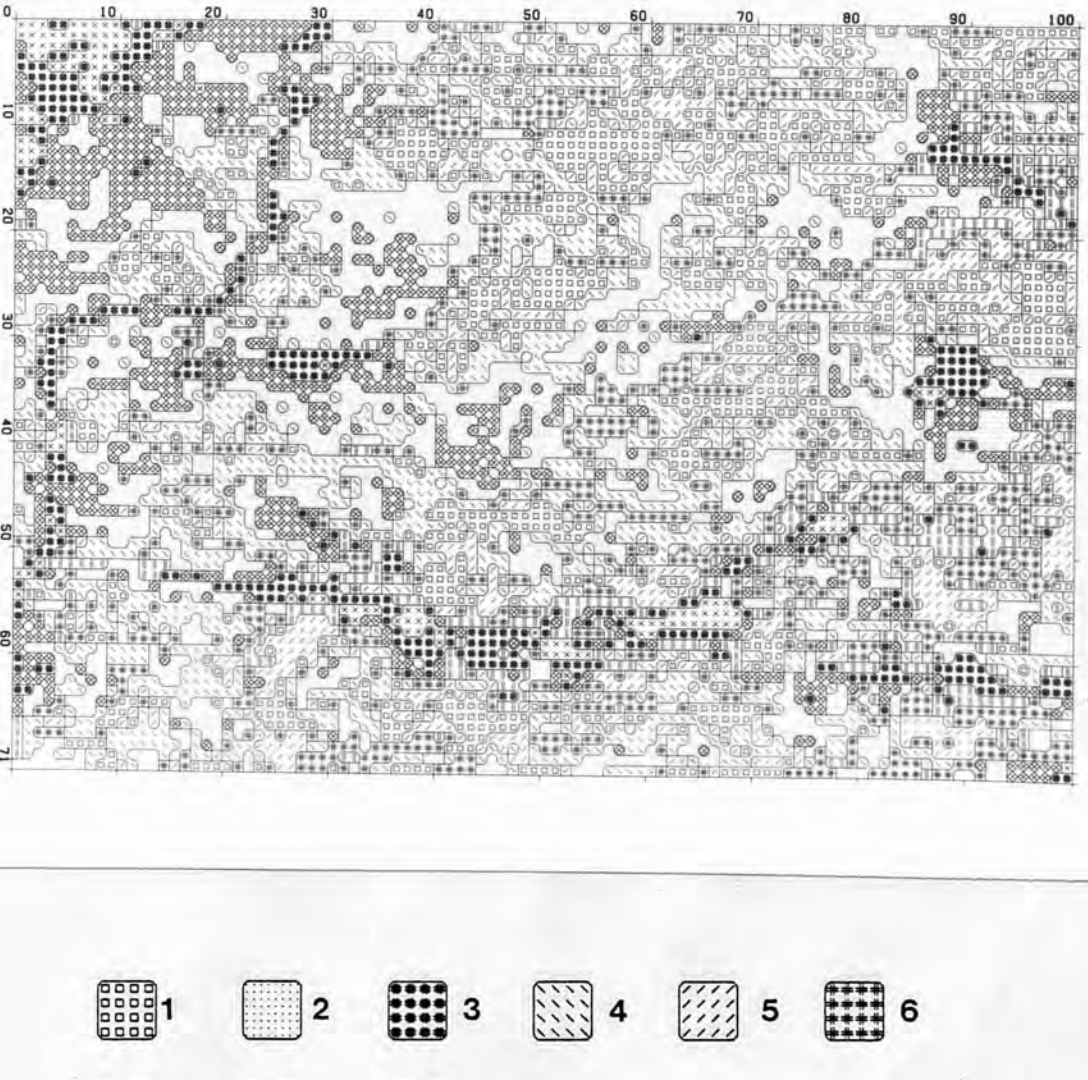


Fig 50. Computer classification map for the selected test site in the Mangueirinha area. Unsupervised classification into eight groups using data contained on MSS bands 5 and 7.

```
MANGUEIRINHA ARAUCARIATESTE FIRST STRIP X=(560,659) Y=(1381,1451) ARAUCAM*SELPAR
CLASSIFIED BY POLYDIV :  29/03/80

GP SHADING      POINTS          GP SHADING      POINTS          GP SHADING      POINTS
 1 G               853           5 F               731           9 ABEF            804
 2 H              1592           6 IJ              845
 3 EFGIJ           408           7 J               289
 4 E              1438           8 EF              140
```



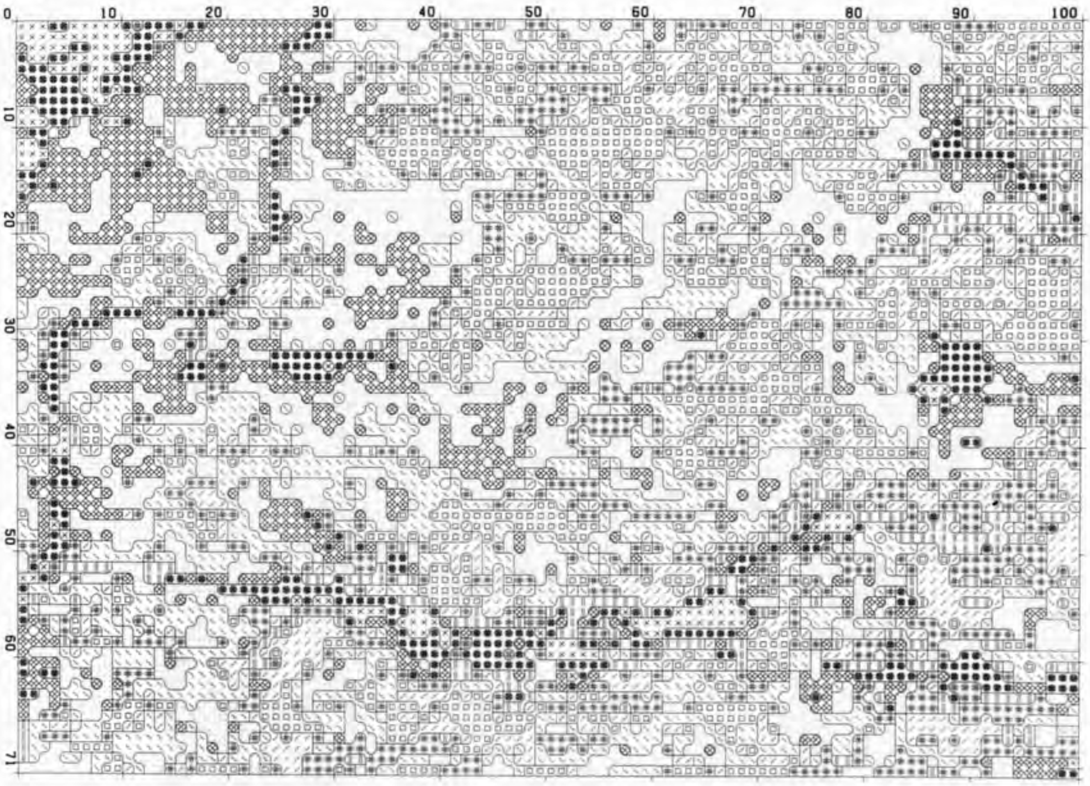
▦ 1 ░ 2 ● 3 ⧅ 4 ▨ 5 ▩ 6

▥ 7 ✕ 8 ▩ 9

Fig 51. Computer classification map for the selected test site in the Mangueirinha area. Unsupervised classification into nine groups using data contained on MSS bands 5 and 7.

```
MANGUEIRINHA ARAUCARIATESTE FIRST STRIP X=(560.659) Y=(1381.1451) ARAUCAM*SELPAR
CLASSIFIED BY POLYDIV :  29/03/80

GP SHADING     POINTS        GP SHADING     POINTS        GP SHADING     POINTS
 1 G              853         5 F              731         9 ABEF           804
 2 H             1592         6 IJ             845        10 HIJ             25
 3 EFGIJ          408         7 J              264
 4 E             1438         8 EF             140
```



▦ 1 ⬚ 2 ● 3 ▧ 4 ▨ 5 ▩ 6

▥ 7 ⊠ 8 ▩ 9 ▩ 10

Fig 52. Computer classification map for the selected test site in the Mangueirinha area. Unsupervised classification into ten groups using data contained on MSS bands 5 and 7.

```
MANGUEIRINHA ARAUCARIATESTE FIRST STRIP X=(560.659) Y=(1381.1451) ARAUCAM*SELPAR
CLASSIFIED BY POLYDIV :  29/03/80

GP SHADING        POINTS        GP SHADING       POINTS        GP SHADING       POINTS
 1 G                 853         5 F                731         9 ABEF             533
 2 H                1592         6 IJ               845        10 HIJ               25
 3 EFGIJ             408         7 J                264        11 ABCDEFGHIJK      271
 4 E                1438         8 EF               140
```

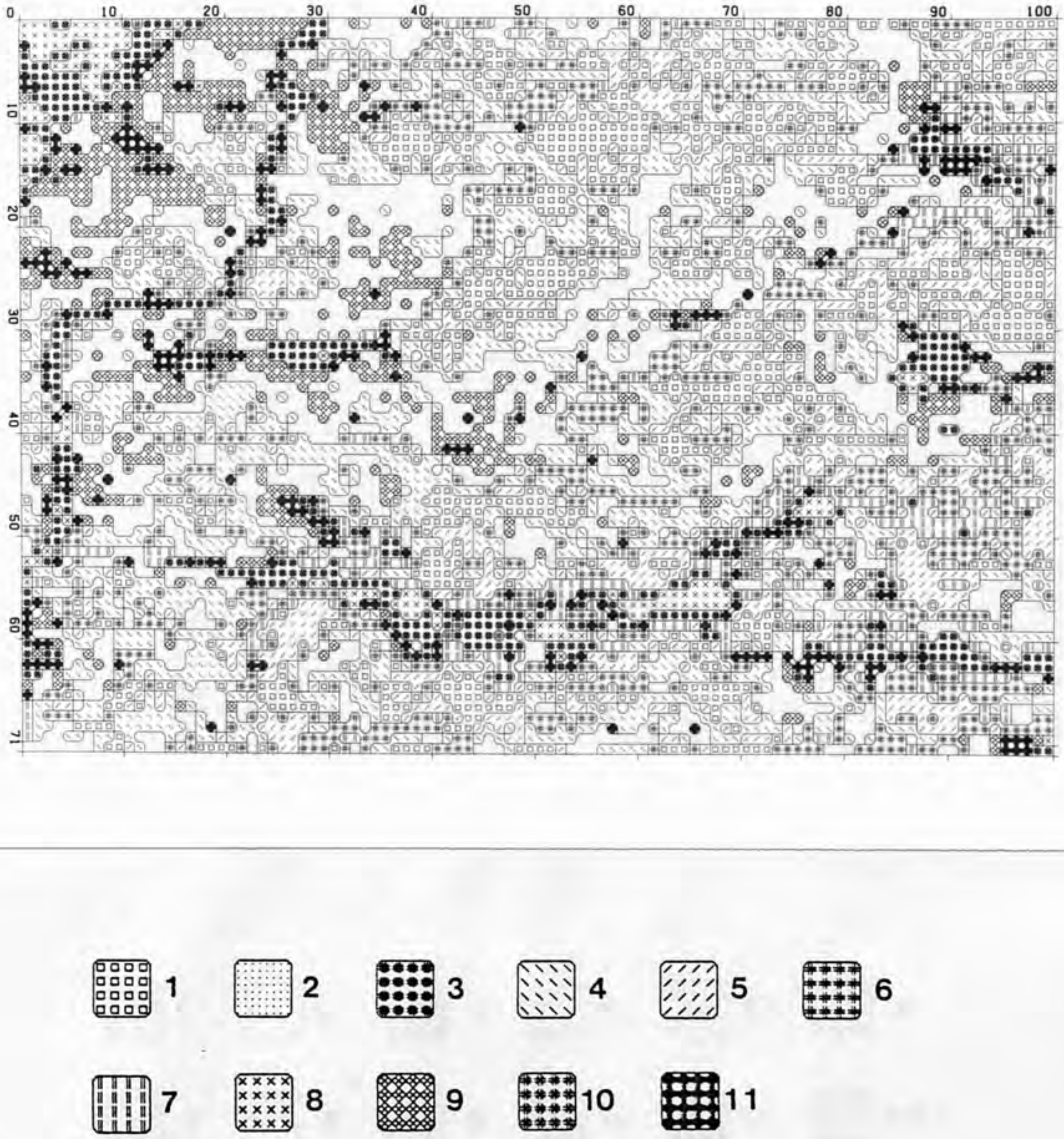
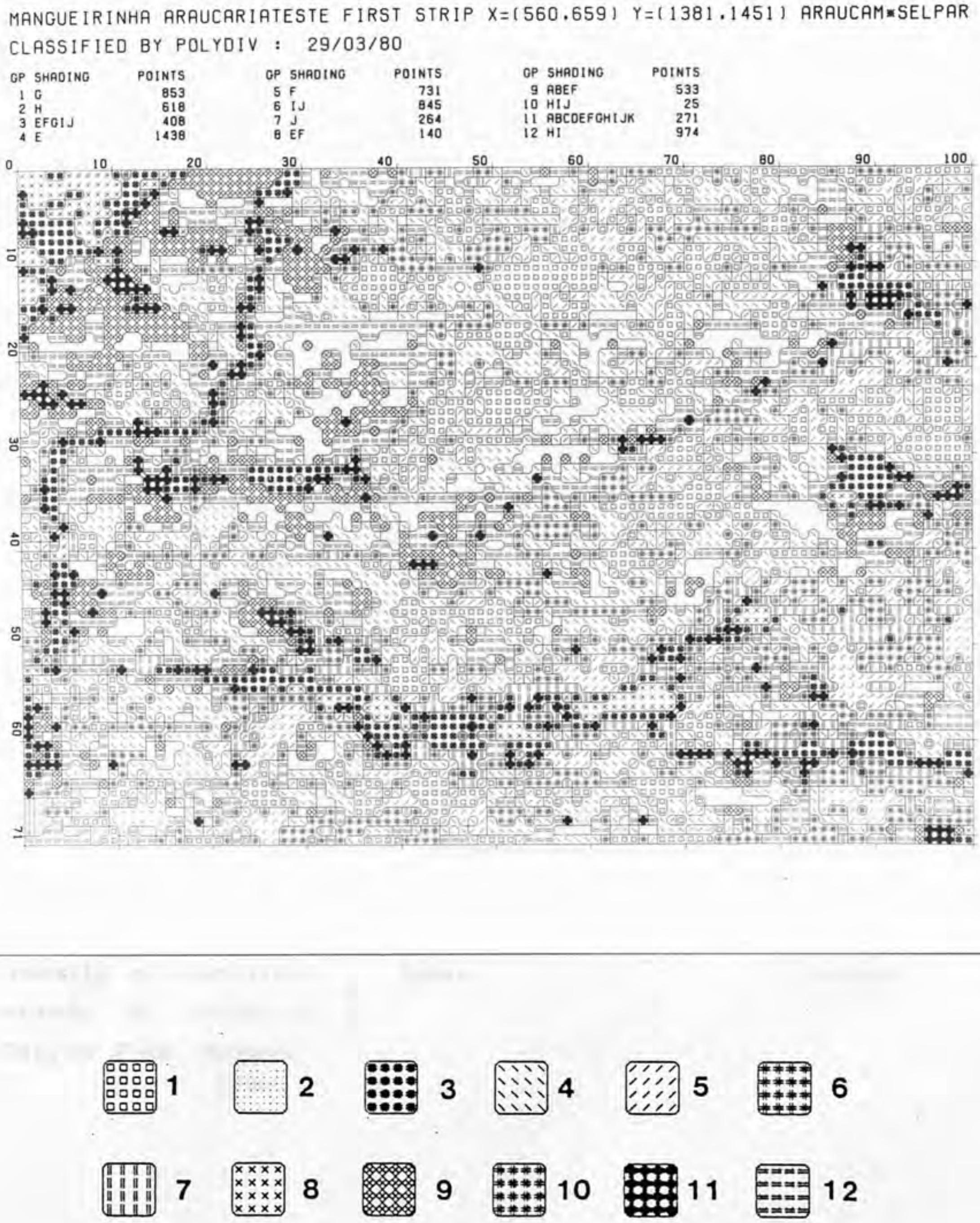


Fig 53. Computer classification map for the selected test site in the Mangueirinha area. Unsupervised classification into eleven groups using data contained on MSS bands 5 and 7.



```
MANGUEIRINHA ARAUCARIATESTE FIRST STRIP X=(560.659) Y=(1381.1451) ARAUCAM*SELPAR
CLASSIFIED BY POLYDIV :  29/03/80

GP SHADING      POINTS       GP SHADING      POINTS        GP SHADING      POINTS
 1 G               853        5 F               731         9 ABEF            533
 2 H               618        6 IJ              845        10 HIJ              25
 3 EFGIJ           408        7 J               264        11 ABCDEFGHIJK     271
 4 E              1438        8 EF              140        12 HI              974
```

Fig 54. Computer classification map for the selected test site in the Mangueirinha area. Unsupervised classification into twelve groups using data contained on MSS bands 5 and 7.

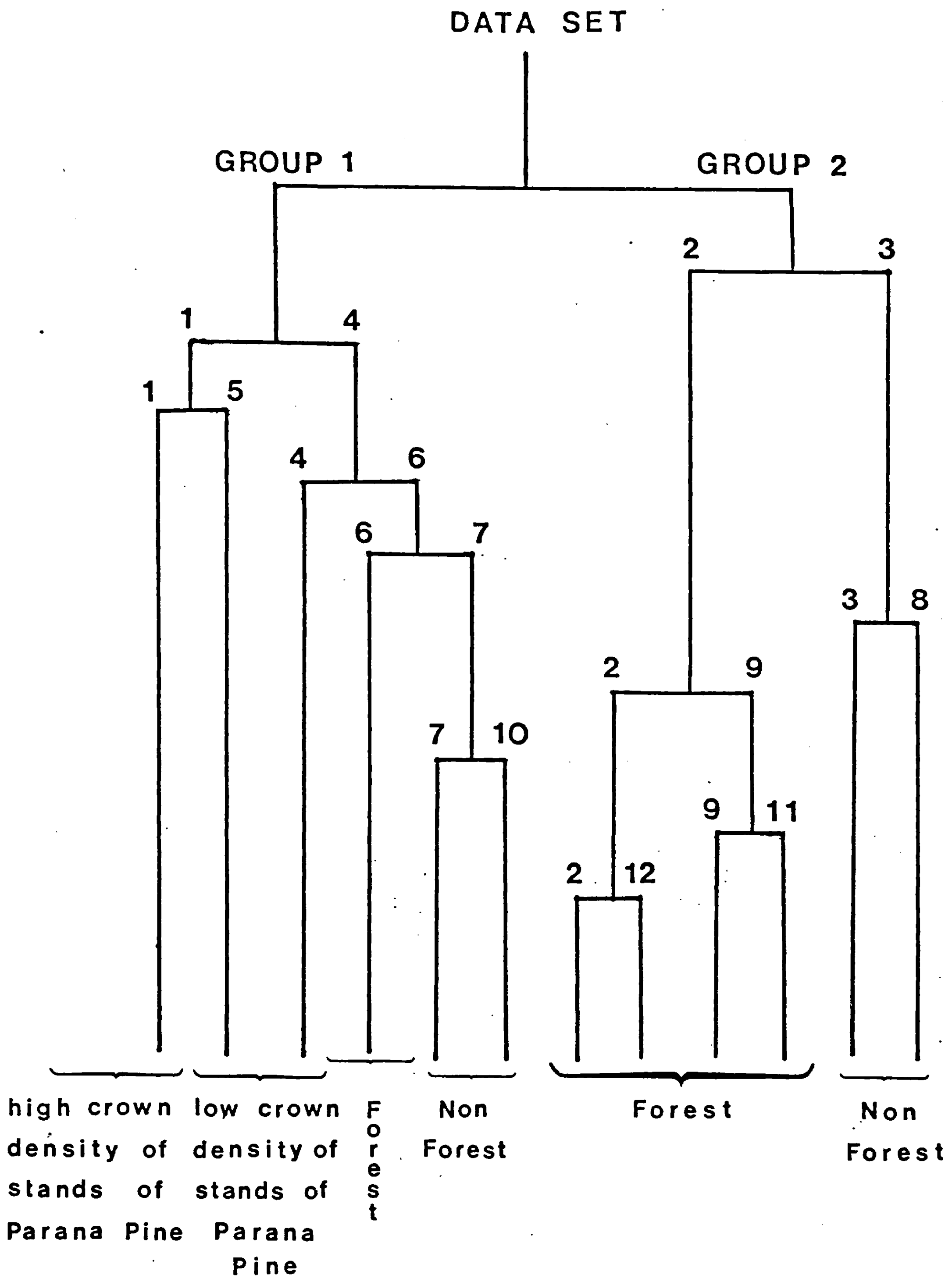


Fig. 55 Dendrogram of the unsupervised classification into twelve groups using data contained on MSS bands 5 and 7 for selected test site in the Mangueirinha area.

the last six divisions in the unsupervised classification, on the data contained on the MSS bands 5 and 7, were not related to the classes of Parana Pine stands. With this in mind a new analysis was carried out with respect to nine groups classification. This nine group classification was subjectively selected. From it the results were finally evaluated. Using basically the information in Figure 55 it became clear that high crown density of stands of Parana Pine was represented by just one group (group 1 in Figure 51), low crown density of stands of Parana Pine was represented by gwo groups (groups number 4 and 5); forest land was represented by three groups (groups 2, 6, 7) and non-forest land by three groups (groups 3, 7, 8).

An analysis of the pixels in the corresponding positions of the training areas for the high crown density of stands of Parana Pine indicated that 67 of the 69 pixels were represented by group 1 and two pixels were represented by group 4. The groups 1 and 4 had been established before as being high and low crown density of stands of Parana Pine, respectively. Following this line, all the test areas for the classes were evaluated. The results are shown in the form of a confusion matrix* for the classification (Table 16).

Table 16. Confusion matrix for the test site in the Mangueirinha area classified by the unsupervised program on the data contained on the MSS bands 5 and 7

CLASS	Number of pixels tested	% correct	No. of pixels classified as			
			A	B	C	D.
A = Parana Pine type I	69	97.1	67	2	-	-
B = Parana Pine type II	52	46.2	6	24	22	-
C = Forest	112	90.2	-	10	101	1
D = Non-forest land	54	96.3	-	-	2	52

---

* The results of analysis of the supervised and unsupervised classification are given in different form in Tables 15 and 16, but in essence they represent the same thing.

Study of Table 16 shows that, using an unsupervised classification:

a) the accuracy for mapping high crown density of stands of Parana Pine was 97.1%. From a total of 69 pixels representing the class, only two pixels were incorrectly classified as belonging to the class representing low crown density of stands of Parana Pine;

b) the accuracy for mapping low crown density of stands of Parana Pine was only 46.2% and the remaining pixels being incorrectly classified as forest land (22 in 52 pixels) and high crown density of stands of Parana Pine (6 pixels from a total of 52);

c) the accuracy for mapping forest land and non-forest land was 90.2% and 96.3% respectively.

The number of pixels allocated to each group in the unsupervised classification was also printed in the computer map. This made possible the finding of the number of pixels allocated to each class. For example, in the Figure 52, the class representing high crown density of stands of Parana Pine was represented by the group 1 which had 853 pixels. The same procedure was followed to find the number of pixels for each class. The final results were given in Table 13. The computer estimates of areas in each class in the unsupervised classification did not differ very much from the figures for the supervised classification.

In summary, the results obtained by using an unsupervised approach for classifying the data in MSS bands 5 and 7 was nearly the same as those obtained from the supervised classification, both in classification accuracy and in estimates of areal extension. For practical application, the nine group classification was used for the evaluation of the results of the unsupervised classification instead of the initial twelve groups.

The step by step procedure for the evaluation of the results of the unsupervised classification using the data on the MSS bands 4, 5, 7 was the same as that reported before using the data on the MSS bands 5 and 7. The results of the unsupervised classification were analysed using nine and twelve groups. In both group classification the results were the same and because of this the results acquired from the nine group classification are given.

There was no easy way to assign individual groups of the classification to each class, because most of the groups were representing two or three classes. This was particularly applied to the class representing high crown density of stands of Parana Pine and one of the non-forest class (i.e. areas in green spectral signature as seen on the colour composite). They were represented by the same three groups. In this sense, the allocation of just one of those groups to one of the class would affect the quantitative results of the other class. Subjective decision was taken and the class of high crown density of stands of Parana Pine was represented by two groups; the low crown density of stands of Parana Pine by one group; the forest land by five groups and the non-forest land by one group. Due to the difficulty of the characterization of the groups, the unsupervised program using the data on MSS bands 4, 5, 7 did not provide reliable results. The accuracy for mapping high crown density of stands of Parana Pine and non-forest areas were 69.6% and 22.2% respectively.

The step by step procedure for the evaluation of the results from the unsupervised classification using the data on the MSS bands 4, 5, 6, 7 was the same as that before mentioned using the other combinations of MSS bands. The results were initially acquired using the nine group classification. In the further analysis carried out using the twelve group classification, the classification accuracy for high crown density of stands of Parana Pine would be the same as that using a nine group classification, but the computer area estimates were only 160 pixels less than that reported in Table 13. In order to make the analysis homogeneous for the unsupervised classification using the different combinations of bands the nine group classification was used for the qualitative and quantitative analysis of the classification using the four MSS bands.

In order to assign each group of the classification to one specific class, there was some difficulty in defining the groups that should represent non-forest areas. Two groups were chosen as representing the non-forest areas but they were also representing the low crown density of stands of Parana Pine and forest classes. This certainly reduced the classification accuracy for the three mentioned classes. The classes representing high and low crown density of stands of Parana Pine were represented by two groups, respectively, in the unsupervised classification; the forest land by four groups. The confusion matrix of the classification is given (Table 17).

Table 17. Confusion matrix for the test site in the Mangueirinha area classified by the unsupervised program on the data contained on the MSS bands 4, 5, 6, 7.

CLASS	Number of pixels	% correct	Number of pixels classified as:			
			A	B	C	D
A = Parana Pine type I	69	97.2	65	2	-	2
B = Parana Pine type II	52	26.9	3	14	20	15
C = Forest	112	83.0	-	3	93	16
D = Non-forest land	54	59.2	-	13	9	32

Study of the Table 17 shows that:

a) the accuracy for mapping high crown density of stands of Parana Pine was 94.2%;

b) the accuracy for mapping low crown density of stands of Parana Pine and non-forest land was 26.9% and 59.2% respectively;

c) the forest land was classified with an accuracy of 83.0%. Most of the pixels incorrectly classified were allocated, in the classification, to non-forest class.

In summary, the unsupervised classification using the data on the MSS bands 4, 5, 6, 7 was successful only for mapping high crown density of stands of Parana Pine and forest land.

A comparison between the results given by the unsupervised program using the different combinations of MSS bands indicated that high crown density of stands of Parana Pine was accurately classified and mapped using combinations of MSS bands 4, 5, 6, 7 and combinations of MSS bands 5, 7. For mapping the above-mentioned class and also, forest and non-forest classes, however, the best results were acquired using the combinations of MSS bands 5, 7 only.

Two points must be considered in the analysis of the results given by the unsupervised program. The points are: the inconsistency of the results and the number of groups used for the evaluation of the results.

The first point, inconsistency of the results, is directly related to the strategy of the unsupervised program. The strategy of the program considers the data set as a single group and repeatedly subdivides the whole population. Using the combination of MSS bands 5, 7 the data set was initially split into two groups, which had 4156 and 2944 pixels, respectively. Using the combinations of MSS bands, 4, 5, 7 the first two groups of the classification had 3710 and 3390 pixels, respectively;

using the MSS bands 4, 5, 6, 7 the first two groups had 3129 and 3971 pixels. Thus, since the first split in the intial two groups, using the three different combinations of MSS bands, the results were different in quantity of pixels. Consequently, further splits gave different results for the three classifications.

A possible mathematical explanation for the different results acquired with the unsupervised programm in processing the data set from the three different combinations of MSS bands is given. Initially, the unsupervised program performs principal component analysis in the total population (data set), being in three or four dimensional spaces (i.e. using the data set from three or four MSS bands). This is carried out in order to reduce the number of variables to be considered in the classification,by transforming the original data set into an identical number of linearly independent new variables. The original data set (data matrix)

> is premultiplied by its own transport to produce a correlation matrix, the first latent vector is then extracted. The data matrix is postmultiplied by the latent vector to produce a string of scores, one for each individual, on the first principal axis. This string is ordered and divided at the point where the between group sum of squares (of deviation from the mean) is maximum. The data is dichotomized at this point, and the constitution of the two resulting sub-groups is printed-out. Each sub-group is now treated exactly as was the primary population; the process is repeated until the number of groups required has been obtained (Williams and Lance, 1975, p. 144).

According to the citation above, there are two possible explanations for the different results yielded by the unsupervised program using different combinations of MSS bands. Firstly, it may be assumed that the use of the string of scores (new variables) projected only on to the first principal axis leads to a loss of information, which originated in the different results when compared with those from processing the data set from two MSS bands. Lodwick (1979) pointed out that the use of principal component analysis is valuable with the data set, from the four MSS bands, because it can be almost described by the first two principal components. Due to the high level of correlation between the data on the four MSS bands, the first and second principal components typically account for in excess of 95% of the original variance and the remaining variance in the other two components is comparable to noise level. Secondly, the rule used as an approximate measure of the heterogeneity of the groups may not be adequate for the case in study.

The main disadvantage of the available unsupervised program is that its output does not provide any mean or covariance matrix related to the groups of each division of the data set or how much the first principal component accounts for the original variance of the data set. This certainly avoids any real analysis about the spectral separability between the groups.

The nine group classification used for the evaluation of the results from the unsupervised classification using the three different combinations of MSS bands was based on subjective and practical decision. Assuming as example, that the most important class to be mapped was that representing high crown density of stands of Parana Pine. Processing MSS bands 5, 7 the results pointed out that five groups would be enough for the accurate mapping of that class. Processing the combinations of MSS bands 4, 5, 6, 7, however, seven groups were necessary for the accurate mapping of the class. No clear indication could be given in processing the combinations of MSS bands 4, 5, 7 due to the coincidence of the defined groups for the mentioned class and one of the non-forest classes. Based mainly on this experience related to mapping the class representing high crown density stands of Parana Pine, it was subjectively selected the nine group classification for the qualitative and quantitative analysis of the unsupervised classification.

CHAPTER 10

DISCUSSION OF THE RESULTS

The remote sensing information system can be divided into three parts: the scene, the sensor and the processing system. The scene is the most dynamic and complex part of the system and basically represents the earth's surface and the atmosphere. The sensor has the purpose of gathering data to adequately characterize the variability of the factors of the scene which are important to the information desired. The processing system extracts the desired information from the data which is presented to the user using an output method (Landgrebe, 1978b).

In this research, which considers mapping of Parana Pine stands using Landsat imagery, more attention was dedicated to the processing system than to the other two parts. This is because there is no real control over the scene and over the sensor. The spatial and spectral resolution of the image is defined by the sensor. This is significant for the mapping procedure in which the level of generalization is directly related to the resolution of the image.

A study concerning forest cover type mapping using Landsat imagery should consider the spatial, spectral and temporal characteristics of the scene. The success of mapping Parana Pine stands through aerial photographs was due to the prominent position of the trees in the upper canopies of the forest. Also the shape and size of the Parana Pine crown, associated with the dense concentration of the trees in some areas, facilitated its identification and consequent mapping. The success of the mapping from Landsat imagery was because the stands had different spectral signatures from other forest cover types. The limited success in mapping bracaatinga stands was due to their low contrast and/or overlapping signature with forest land and grassland in the MSS spectral bands.

From the interpretation point of view, spatial features such as size, shape and texture are vitally important to the achieving of correct identification of the object, and this was particularly so in the mapping of Parana Pine stands using aerial photographs. On the Landsat images, the mapping of the stands was more dependent on tone variations (spectral response) and on very gross spatial features. Say-Wittgenstein and Kalensky (1974) suggest the following reasons why spatial signatures are less useful in Landsat image interpretation than are spectral signatures:

a) Landsat was designated as an experiment in multispectral sensing;

b) the concept of spectral signatures is more readily understood than mathematical approaches to the definition of such terms as "irregular", "smooth", or "wavy" on which the concept of spatial signatures is based;

c) multispectral analysis can be done on a one pixel basis while spatial analysis requires several terms or even hundreds of suitably distributed pixels in every class to obtain statistically significant spatial patterns;

d) analysis of spatial patterns requires the use of computers while there are several optical and photographic methods for multispectral image analysis.

The spectral reflectance values (digital counts) considered in this research were those provided by the Landsat scenes and they were relative rather than absolute ones. Among the forest and non-forest cover types considered in the supervised program, Parana Pine stands had the lowest digital counts on the MSS bands 4 and 5. The same was applied to the MSS bands 6 and 7 when only forest cover types were considered.

The amount of energy reflected by a tree depends on the characteristics of the tree species and of the environmental factors. The characteristics of the tree species relevant for remote sensing are: amount of biomass per ground picture element and its chemical composition, texture and colour of exposed leaves and their spatial arrangement, crown morphology and canopy closure of the stands. These characteristics and their seasonal changes define the species spectral reflectance. The environmental factors affecting species reflectance are:

a) tree's irradiation, especially, spectral composition and intensity of daylight and direction of sunlight;

b) atmosphere conditions, especially transmittance and scattering;

c) site conditions, especially soil type, moisture content, drainage, terrain relief and slope aspect;

d) weather conditions, especially type and percentage of clouds and wind.

In addition, daylight radiation reflected from trees is strongly dependent on the direction of observation (Kalensky and Wilson, 1975).

The tone and colour of the image is influenced by other factors including atmospheric conditions, film-filters and less quality in the case of aerial photographs, processing and enhancement techniques and geographic location expressed in terms of aspect and slope (Howard, 1970).

The temporal analysis of the Landsat scenes is related to the availability of the scenes. Statistics for the potential scenes (with less than 30% of cloud cover and MSS band quality above 5 in the scale

0 to 9) for acquisition from INPE and the U.S. Geological Survey/Eros Data Center indicated that by December 1979 there were 41 and 21 scenes for the Quedas do Iguacu and Mangueirinha areas, respectively (Table 18).

Table 18. Statistics of the Landsat scenes (1972-1979) available for the areas of study.

MONTH AREA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Quedas do Iguaçú	1	3	3	4	1	4	6	3	3	4	5	4	41
Mangueirinha	-	1	1	-	2	3	3	3	4	2	2	-	21

YEAR AREA	1972	1973	1974	1975	1976	1977	1978	1979	TOTAL
Quedas do Iguaçú	1	3	2	8	8	8	8	3	41
Mangueirinha	1	1	2	5	2	5	3	2	21

Study of Table 18 shows that more scenes are available for the winter and spring seasons(from June to November) than for summer and autumn. For the 16 potential cloud free scenes for the Quedas do Iguaçú area 11 scenes were acquired between June and November, and for the Mangueirinha area all the five cloud free scenes were from June to September. Thus, availability, quality and cloud cover of the scenes is not a problem only for the Quedas do Iguaçú area.

The single data computer classifications for the two areas of study used Landsat CCTs from different rows and paths. Study of the six scenes used in the Quedas do Iguacu area showed that in five scenes the two areas appeared together. This certainly gives considerable flexibility in terms of selection of Landsat scenes for future studies of the Mangueirinha area in all seasons of the year. This flexibility does not extend far beyond the Mangueirinha area, however much less choice of scenes is available for forest areas only 50 to 100km to the east.

Multitemporal classification (i.e. two or three Landsat scenes are merged and classified as having eight or 12 bands) was not attempted in this research. As there is no restriction of the time of the year to map Parana Pine stands, in theory any two scenes could be merged for multitemporal classification. Practical experience from the visual analysis of the single-data Landsat scenes of the Quedas do Iguaçú area suggests that a good combination for multitemporal classification would be the summer scene for 30 January 1974 and the winter scene for 02 August 1975. No advantage will be gained in using two multi-temporal classification scenes from the same season because the information they contain is very much the same.

The following two aspects related with processing techniques of the Landsat scenes will be discussed in detail: visual interpretation and computer-aided classification.

10.1 Visual interpretation

The visual analysis of the Landsat scenes was one of the most important techniques used in the research and, by itself, indicated that Parana Pine stands showed different spectral signature from the other forest types.

Visual analysis for the delineation of the boundaries of the Parana Pine stands was carried out using Landsat scenes derived either from transparency or from CCT formats. From the resulting interpretations, it appeared that the image generated from the CCTs was superior to that from the transparency although no direct quantitative comparison was carried out. This difference was because the inherent resolution of system correct CCT data is better than that of standard photographic image products since it is not degraded in any way by the image generation and photographic process. This loss of detail may explain the failure to detect Parana Pine stands in the image of MSS band 5 of the Landsat scenes for August 1977, April 1978 and November 1978 overpasses related to the Quedas do Iguaçú area. The Landsat positive transparencies used were fourth generation copies. The same loss of vegetative and forestry detail on Landsat transparencies was also mentioned by Heller (1973).

Even though imagery may be degraded in successive copying, the value of Landsat scenes as transparency copies can not be underestimated for future use in the Parana Pine stands mapping and forestry studies. This is supported by Jones (1976) who states that because the establishment of adequate computer facilities is an expensive operation, much work with images from Landsat has been done by conventional "eye-ball" methods with single band images and colour composites. The point is further demonstrated by statistics given by NASA (1980a). Between July 1973 and March 1980, 1,175,001 Landsat photographic scenes were sold against 13,800 Landsat digital scenes.

Parana Pine stands could be detected in the image of the MSS bands, since the images were produced using the Landsat digital data from the CCTs. The MSS band 4 produced less information, than the MSS band 5 regarding the mapping of Parana Pine stands. It also added little information in the colour composite generated from the MSS bands, 4, 5 and 7. The MSS band 4 is strongly affected by haze, this being the reason for low information. The MSS band 5 was the best individual image for mapping Parana Pine stands because the stands appeared in darkest tones on the image, and forest land was easily distinguished from the non-forest land. MSS band 6 was little used but an analysis of the mean digital counts of the various classes used in the computer classification using digital data from the Landsat scene of October 1976 overpass indicated that the image would report less information than MSS band 7 in separating Parana Pine stands and one of the classes representing non-forest land. The MSS band 7 was another useful image in order to distinguish between Parana Pine stands and other forest cover types. In the image Parana Pine stands were not represented by the darkest tone. The visual interpretation of the image of MSS band 7, without the use of the image of MSS band 4 or 5 and/or forest cover type map, would be hampered by the problem that our eyes are not suitable for the detection and identification of objects in the infra-red waveband. Even with the image of the MSS band 7 for the complete Landsat scene it was very difficult to separate forest land from non-forest land; it was easy only to identify rivers because their darkest tone and their spatial characteristics.

The additive viewer, composed of three projectors, was an important tool in the visual interpretation of Landsat scenes. It not only avoided the acquisition of the print colour composite but also gave more flexibility in terms of the scale of interpretation. Since enlargement of a portion of the third generation 70mm MSS Landsat transparency negative bands was made, visual interpretation and visual analysis could be carried out at any scale smaller than 1:50,000. Conversely, analysis could be carried out at any scale with the images of the MSS bands produced from the computer processing of Landsat digital data. Images were interpreted and analysed at a 1:50,000 and 1:15,000 scales. The main constraint on the use of the additive viewer was the eye fatigue after a period of visual interpretation of black and white images or colour composites in a dark room.

The images of the MSS bands originated from the computer processing of Landsat digital data which were digitally enhanced. The enhancement technique (density slicing and contrast stretching) distorts the original digital counts and because of this, after enhancement techniques, the data set corresponding to the area of study was not suitable for computer processing.

Contrast stretching was used with density slicing in all the production of all images. Contrast stretching was used because noise was present in the data set and the image lacked tonal contrast. The parameters selected for contrast stretching were subjective and carefully selected. Practical experience indicated that the best approach was:

a) the production of a histogram showing the total range of digital counts of the data set, for each MSS band, in 20 equal slices;

b) then to find out the mean digital counts for the classes of interest for use in the computer classification. For this it was necessary to carry out visual interpretation in the colour composite in order to find some representative training areas for the classes;

c) after this, the information from the first and second step was combined in order to select the best parameters for contrast stretching of the MSS bands. Since the mapping of Parana Pine stands was the main goal of the research, the selection of the parameters for contrast stretching were easily defined for the MSS bands 4 and 5. This was due to the fact that Parana Pine stands generally were represented by the lowest digital count in relation to the other classes attempted in the computer classification. The lower and upper levels for the contrast stretching were selected in order to impose the condition that the first slice, of the ten levels defined for the density slicing, was containing the digital counts representing the Parana Pine stands. In this way, the Parana Pine stands would appear in the darkest tone on the images of the mentioned bands. In the visual interpretation of the images of the MSS bands 4 and 5 it was much more easy to delineate the boundaries of the darkest tone areas (black areas on the image) than those two or three levels of gray tone (depending on the characteristics of the area of study these could include the darkest tone) representing the stands on the image of the MSS band 7. If the parameters were not correctly selected, however, the Parana Pine stands would not be evident on the image of MSS bands 4 and 5. Since the Parana Pine stands were not represented by the lowest digital counts on MSS bands 6 and 7, the parameters for contrast stretching related to these bands were arbitrarily selected in the histogram.

10.2 Computer-aided classification

The following three stages of the computer-aided classification scheme will be discussed: training, classification and output. In practice these three stages were not separate, but they are discussed in this way for easier presentation.

The success of the classification stage relied directly on the quality of the training phase. The training phase comprised the selection of the training areas for the classes used in the classification, a graphical analysis of the spectral separability between the classes, and the evaluation of the results.

The selection of the training areas for the classes was greatly facilitated by the optical formation of the colour composite and its projection on to forest maps. Meisner and Illesand (1979) pointed out that no matter how sophisticated one statistical classifier might be, the success of a spectral pattern classification effort is fundamentally limited by the degree to which the user can relate existing spectral classes to useful information classes. In both study areas, it was easy to select representative training areas for Parana Pine stands, using digital data from the CCTs. This was also the case for reforestation areas in the Quedas do Iguaçú area. However this would not be less likely to occur for bracaatinga stands, because the stands were not successfully separated from the forest land and grassland in the visual analysis of the colour composites.

In order for the training areas to be representative of all the variation within each cover type throughout the area of the test site, small training areas were defined in different locations on the image rather than one larger sized training area for each class. The size of the training areas were strongly influenced by the area of occurrence of the class itself in the reported test site. In the test site selected in the Quedas do Iguaçú area, the size of the training areas for Parana Pine stands were between 74 and 96 pixels, while for the reforestation areas they were between 16 and 24 pixels. Due to the small size of the test site in the Mangueirinha area, however, the size of the training areas was between 9 and 21 pixels for the high crown density of stands of Parana Pine and between 10 and 15 pixels for the low crown density stands of Parana Pine.

During the selection of the training areas no effort was made to evaluate the effect of the quantity and the size of the training areas on the classification accuracy. Kumar _et al_ (1979) pointed out that the percentage of correctly classified pixels decreases as the number of the training areas decreases but on the other hand the cost of classifying the data increases with an increase of the number of training areas. In this research, the number of the training areas were subjectively selected according to the test site.

There is a common belief in remote sensing literature that several iterations, with continuous modifications of the training areas and variations of the classification scheme, are needed to develop an accurate and satisfactory classification. Thie (1976) reported the use of 15 iterations of training, displaying, classifying and analysing training statistics before a final training set was evolved during a computer-aided classification carried out in Manitoba, Canada. The size of the area however, was 13,000 km^2. With the test site in the Mangueirinha area (32 km^2) a selection of the training areas was made twice because:

a) the visual selection of the training areas was made in the colour composite projected on to a screen at 1:15,000 scale;

b) it was intended to map only two crown densities of Parana Pine stands;

c) the darkest tone in the image of the MSS bands 4 and 5 was representing Parana Pine stands exclusively.

Due also to the broad classification scheme used for the test site in the Quedas do Iguaçú area the training areas were selected twice. With the two data sets created throughout the microdensitometer scanning of the transparency scenes for the Quedas do Iguacu area, no greater number of iterations was carried out. For the computer classification of the data set from August 1975 Landsat scene the position of the training areas was imposed by the previous analysis using digital data from the CCT. For the data set from September 1976

Landsat scene due to the exploitation of the forest, to the small size of the reforestation areas and to the size of pixel representing 202 m on the ground, there was a limited option of selecting a greater variety of training areas. Thus, only three iterations were made until the final results were acquired.

Quantitative measures of separability between classes are reported in the remote sensing literature (for example, Marill and Green, 1963; Swain and King, 1973) but this technique is not available at the present time in the bulk of the package programs at the Bedford Remote Sensing Library. Shimabukuro *et al* (1980) used one quantitative measure in order to group in four different spectral classes, for a *posteriori* computer classification, the initial ten reforestation cover types of concern in the study. However, Todd *et al* (1980) found the concept of separability very complex due to the use of large numbers of clusters in the unsupervised classification and the detail of the classification scheme. Lillesand and Kieffer (1979) pointed out that the graphical representation of the spectral response pattern, self-classification of training sets and large area accuracy analysis may be involved in the evaluation of separability between classes. In this research, the graphical representation of the spectral response pattern (and table containing the mean digital counts for the classes) and self-classification were used in the evaluation of the separability between classes. Conclusive analysis was made during the course of the analysis.

A trial was made to determine the optimal spectral bands of maximum separability for cover types. This problem is known in pattern recognition as feature selection and is solved through mathematical quantitative techniques. However, the technique was not available in the Bedford Remote Sensing Library. A simple approach of comparison of the quantitative results of processing three combinations of MSS bands was considered.

With data set from the test site of the Mangueirinha area, the three combinations of MSS bands processed through the supervised program resulted in practically the same results, while this did not happen using the unsupervised program. It cannot be said that the supervised method was better than the unsupervised one. It can be concluded that the specific supervised program used gave better results than the specific unsupervised program. There are a considerable number of algorithms, for the supervised and unsupervised methods, available in the specialized literature of remote sensing and pattern recognition (see, for example, Su _et al_ (1972); Bond and Atkinson (1972); Beers and Van Kuilenburg (1974); Narendra and Goldberg (1977); Kumar _et al_ (1979)). In addition, Hoffer and staff (1975) used a hybrid method of supervised and unsupervised methods for the analysis of spectrally complex areas. In general, the researcher is limited by the programs available in the place that the research is being carried out, unless the researcher is prepared to develop and test a new algorithm. This was certainly not the intention of this research. It is essential to know the degree of reliability of the available classificatory programs. In future studies the maximum size area for study using the available unsupervised program in the Bedford College Remote Sensing Library can be extended to 150 x 100 pixels using only two MSS bands.

The performance of the classificatory programs used can also be compared through the computer processing time (CPU) required for the classification.

The CPU* for processing the unsupervised program using combinations

---

* There was no way to compare the required CPU for processing supervised and unsupervised programs, because there was no compatibility between the output of the programs. The CPU for the unsupervised program included the time required to read the

/continued

of MSS bands 4, 5, 7 and MSS bands 4,5,6,7 was practically the same. Perhaps, 20% less time was needed for processing MSS bands 5,7. Thus, the results for processing two MSS bands were better than processing four MSS bands not only through quantitative and qualitative analysis, but also through the amount of CPU required for the classification.

For processing supervised programs using combinations of MSS bands 4,5,7 and MSS bands 4,5,6,7, 20% and 5% more CPU was needed respectively, compared with processing MSS bands 5,7. Thus, data sets can be processed, giving nearly the same results and using nearly the same CPU, using combinations of MSS bands 5,7 or MSS bands 4,5,6,7. These comparative figures mentioned above were from processing a small test site in the Mangueirinha area, but if the study areas were bigger in size, these differences could be more weighted. Thus the processing of the two MSS bands would be more effective. Kalensky and Scherk (1975) and Kan and Dillman (1975) also found that two spectral MSS bands would be most effective for Landsat computer analysis of forest cover type mapping.

The available unsupervised program to be processed needs a large store of computer space because in the initial stage of the classification, the total population of pixels (data set) is analysed for *a posteriori* split into two groups. For processing combinations of two, three and four MSS bands through unsupervised programs in the test site of the

---

* cont.
data set from a file, classify the data in 12 spectral groups, print the results (number of pixels allocated in each group), and produce a series of 11 microfilms. The CPU for the supervised program included the time required to read the data set from a file, calculate the covariance matrix for each class, classify the data according to the number of classes defined through training areas, print the results and the computer map using the printer-line, and calculate the classification accuracy related to the classes.

Mangueirinha area, the computer needed to allocate respectively 50, 57 and 65 times more space (counting in K units in the computer) than processing the same combinations of MSS bands through supervised classification. The considered aspect, together with the limited restriction in size of area to be processed by the unsupervised program, enhance the technical advantage of the available supervised program against the available unsupervised program for classifying Parana Pine stands using Landsat digital data. Lee (1977), Carneiro (1978) and King and Kikula (1979) found that supervised classification method of automatic classification was more accurate than unsupervised classification for mapping forest types.

After the test site had been submitted to the computer classification, the next step was the evaluation of the results using quantitative and qualitative techniques. Classification accuracy is not easily defined and even interpretation results derived from aerial photographs are often difficult to evaluate. In the context of this research, the results derived from the visual interpretation of the Landsat scenes, and from the computer classification were compared with the results derived from the conventional interpretation of aerial photographs. There were problems with such comparisons, however, because the photo-interpretation map should not be considered as absolute ground truth. Variables always were involved due to interpreter fatigue, his ability to detect gradual changes and to make consistent decisions. In addition, differences may occur due to the Landsat averaging conditions over 0.4 hectare samples versus high resolution photographs where individual tree crowns were observable.

The quantitative analysis of the computer classification was made through self-classification accuracy and areal comparison. If a realistic view is taken, both mentioned ways presented some limitations. Lillesand and Kieffer (1979) pointed out that it should avoid considering the confusion matrix based on the self-classification as a measure of classification accuracy, because this confusion matrix simply tells us how well the classifier can classify the training areas and nothing more. In addition, the ground estimates of the area of the classes was not made on the topographic map; also the Landsat CCT data had not been geometrically corrected.

The problem concerned with the classification accuracy could be solved through the use of test areas, which should be selected using a statistical sampling design. The author decided to use the self-classification as a measure of classification accuracy, mainly due to the small size of the test sites. If the entire area of study, i.e. the Mangueirinha or Quedas do Iguacu area, was computer classified, certainly the classification accuracy should be evaluated through test areas. An important consideration would be the size of the test areas. An analysis of the size of the training areas for the computer classification of the test site in the Mangueirinha area and the images of MSS bands and colour composites for the area of Mangueirinha suggest test areas with a size of 3 x 3 pixels. If the size of 5 x 5 pixels were used it would have few potential test areas representing just one cover type for high and low crown density of stands of Parana Pine, respectively. For the Quedas do Iguacu area the size of the test areas might be 5 x 5 pixels due to the large extension of land occupied by Parana Pine stands.

The results of the computer classification for the test site in the Mangueirinha area indicated that high crown density of stands of Parana Pine can be accurately mapped using Landsat digital data. The same conclusion was backed by the visual interpretation of the images of the

MSS bands and colour composites for the entire area of Mangueirinha. The results given by the computer classificatory programs were not reliable for the mapping of low crown density stands of Parana Pine. This was because of the spectral overlap with the classes defined for high crown density of stands of Parana Pine and forest land. Consequently, its areal estimates were over-estimated when compared with the value from the forest map. The problem related to mapping mixed features has been encountered as one main limitation of the standard statistical pattern recognition technique (Kan, 1976).

All the maps produced from the computer classification had the salt-and-pepper appearance. This can be cleaned by a pre-processing technique, which is based mainly on the comparison of the pixel in the center of a block of nine pixels with its neighbouring pixels. The degree of detail given by the computer classification maps may be certainly distracting to the timber manager who would prefer some hectare areas (as for example, four hectares) to be the minimum mapping unit . The interpreter, during the visual interpretation of remote sensor imagery, produces smooth maps. This was not made during the interpretation of the image of MSS band 5 for the Mangueirinha area using the Landsat scenes of August 1975 and October 1976. This was because the intention was to produce a visual interpretation map showing the unbiased position of all the areas with the same spectral response (tone) as Parana Pine stands, being either the stands or not.

With the exception of the classification of the test site of the Quedas do Iguaçú area that was carried out using the Image 100, the analysis and classification of the Landsat digital data was carried out using the Bedford Remote Sensing Library and the main computers, CDC 6600 and C.DC 7600, of the University of London Computer

Center. The time waited to receive the results from one computer program submitted was some hours (from two to 24 hours) according to the requested computer time for processing the program. However , when microfilm plots were required from the program, it was necessary to wait one or two days to receive the microfilm. Thus, nearly all the Landsat data analysis was made using a processing batch, over which the author had no control in the processing and results were available only after the processing was completed.

This research can be considered as a second step forward in the realistic approach to the assessment of the Landsat MSS imagery for the mapping of the Parana Pine stands in Parana State. The first step was undertaken during the mapping of the stands in the south of Brazil for which visual interpretation of stretched colour composites generated from digital data of MSS bands from CCTs (Instituto Brasileiro de Desenvolvimento Florestal, 1978; Keech et al, 1979; Gantzel, 1979) was carried out. Thus, future studies will continue in the same and in new areas, regarding other aspects of mapping procedures that were not considered in this research (for example, cost-benefit analysis of the interpretation of Landsat scenes in different format, an assessment of other enhancement techniques, computer classification of extensive areas). In addition, in the future,certainly other remote sensing data will be available and all of them must be evaluated in the way of the mapping of Parana Pine stands and other forest cover types. Also, latter investigations will be set up related to the mapping of bracaatinga stands, which were not successfully mapped through visual analysis of Landsat images for the Mangueirinha area. One best approach will be the mapping of different reforestation cover types, one of them being bracaatinga.

CONCLUSIONS

With reference to the visual interpretation of the Landsat MSS images and the results of the computer-aided analysis of the Landsat MSS data the following conclusions can be derived:

FROM THE STUDY OF THE QUEDAS DO IGUAÇÚ AREA

a) there appears not to be restriction with regard to the season of the year for mapping Parana Pine stands. The stands were detected in all the images of MSS bands 6 and 7 and in the colour composites generated from the MSS bands 4, 5, 7 for the six Landsat scenes available in transparency format;

b) Parana Pine stands and reforestation areas were correctly mapped using a supervised classification program with digital data derived from the Landsat scene (in computer compatible tape format) acquired in the winter time. The individual classification accuracy achieved was greater than 90% for the two forest cover types. The estimates of the area occupied by the reforestation areas given by the classification programs over-estimated the real ground value as ascertained from the forest cover type map;

c) Parana Pine stands were also successfully classified processing supervised classification programs in digital data from the microdensitometer. In the same classification, reforestation areas were not successfully classified.

FROM THE STUDY OF THE MANGUEIRINHA AREA

a) Parana Pine stands were detected in the visual interpretation of the images of MSS band 5 and of the colour composites generated from the MSS bands 5 and 7 using digital data from two different Landsat scenes in computer compatible tape format. Bracaatinga stands were not visually detected on the above MSS images and colour composites;

b) the spring scene yielded better discrimination regarding the mapping of Parana Pine stands and other land use/land cover classes than the winter acquired scene;

c) the parameters for contrast stretching must be carefully selected in order to enhance the stands of Parana Pine in the images of MSS bands 4 and 5;

d) a combination of MSS bands 4,5,6,7; 4,5,7; 5,7 input to the supervised classification program yielded approximately the same results (classification accuracy and estimates of the area occupied by each class) when mapping two crown density of Parana Pine stands, forest land and non-forest land;

e) a combination of MSS bands 5,7 input to the unsupervised classification program yielded better results than processing the combinations of MSS bands 4,5,6,7 and 4,5,7 when mapping the four classes above mentioned;

f) the supervised classification program is more effective than the unsupervised program for the mapping of Parana Pine stands;

g) computer classification program of Landsat data is most effective for mapping high crown density stands of Parana Pine.

REFERENCES

1 AGGERS, L.W. and KELLEY, E.B. (1976). Douglas County Forest cover condition mapping and forest volume inventory. In Proceedings of the American Society of Photogrammetry, Fall Convention, Seattle, Washington, September 28-October 1, pp. 218-229.

2 ALDRICH, R.C. (1975). Detecting disturbances in a forest environment. Photogrammetric Engineering and Remote Sensing, 41(1), pp.39-48.

3 ANDERSON, J.R. et al (1976). A land-use and land cover classification system for use with remote-sensor data. U.S. Geological Survey, Reston, Va., Professional Paper 964.

4 ASHLEY, M.D. and REA, J. (1974). Densitometry of ERTS-1 imagery to access vegetation change. In Remote Sensing of Earth Resources, Vol. III, edited by F. Shahrokhi, The University of Tennessee, Tullahoma, pp. 297-318.

5 AUBREVILLE, A. (1949). A floresta do pinho do Brasil. Anuário Brasileiro de Economia Florestal, 2, pp. 21-46.

6 AVERY, T.E. (1967). Forest Measurements. New York, McGraw-Hill.

7 ----- (1977). Interpretation of Aerial Photographs. Minneapolis, Minnesota, Burgess Publishing Company. Third edition.

8 BEAUBIEN, J. (1979). Forest type mapping from Landsat digital data. Photogrammetric Engineering and Remote Sensing, 45(8), pp. 1135-1144.

9 BEERS, J.M.P. and KUILENBURG, J.V. (1974). Automatic classification methods applied to multispectral photography. In Remote Sensing of Earth Resources, Vol. III, edited by F. Shahrokhi, The University of Tennessee, Tullahoma, pp. 207-222.

10 BEST, R.G. and SMITH, J.R. (1978). Photographic contrast enhancement of Landsat imagery. Photogrammetric Engineering and Remote Sensing, 44(8), pp. 1023-1026.

11 BOND, A.D. and ATKINSON, R.J. (1972). An integrated feature selection and supervised learning scheme for fast computer classification of multi-spectral data. In Remote Sensing of Earth Resources, Vol. I, edited by F. Shahrokhi, The University of Tennessee, Tullahoma, pp. 645-672.

12 CARNEGIE,D.M. and De GLORIA, S.D. (1973). Monitoring California's Forage using ERTS-1 and supporting aircraft data. In Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1. March 5-9, Vol. I: Technical Presentations. NASA Goddard Space Flight Center, Maryland, pp. 91-95.

13 CARNEIRO, C.M.R (1978). Forest cover mapping from Landsat-MSS data by analogue and computer assisted techniques in the Federal Republic of Germany - A feasibility study. Faculty of Forestry of the Albert-Ludwigs-University at Freiburg in Bresgau - Germany. Doctoral dissertation.

14 CARNEIRO , C.M.R. and HILDEBRANDT, G. (1978). Qualitative and quantitative interpretations of Landsat MSS data to forest cover mapping in Germany. In Proceedings of Symposium on Remote Sensing for Observation and Inventory for Earth Resources and Inventory for Earth Resources and the Endangered Environment. July 2-8, Freiburg, Federal Republic of Germany,edited by G. Hildebrandt and H.J.Boehnel, Vol. III, pp. 1791-1807.

15 CARNEIRO, C.M.R. (1980). The Brazilian Forest Cover Monitoring Programme. In International Archives of Photogrammetry. International Society for Photogrammetry, XIV Congress, Hamburg, Vol. XXIII, Part B7, Commission VII, pp. 132-141.

16 CENTRO DE PESQUISAS FLORESTAIS (1974). Estudo das alternativas técnicas, economicas e sociais do setor florestal do Paraná Subprograma "materia prima". Convenio SUDESUL - Governo do Estado do Paraná. Universidade Federal do Paraná. Curitiba,Brasil.

17 COMISSÃO DE ESTUDOS DOS RECURSOS NATURAIS RENOVÁVEIS DO ESTADO DO PARANÁ (CERENA) (1966). Inventario de reconhecimento do pinheiro no sudoeste do Paraná. Curitiba, Brazil, Companhia de Desenvolvimento Economico do Paraná.

18 CHANDLER, B. (1977). Some basic programs for imagery processing. Physics Department, Bedford College, University of London.

19 CLEUSTERS, A. et al (1978). Application of computer aided analysis of Landsat data to land use studies in Belgium. In Proceedings of Symposium on Remote Sensing for Observation and Inventory for Earth Resources and the Endangered Environment. July 2-8. Freiburg, Federal Republic of Germany, edited by G. Hildebrandt and H.J.Boehnel, Vol. III, pp. 1497-1514.

20 COLE, M.M. et al (1975). An evaluation of visual and semi-automated approaches to the recognition of spectral signatures in air survey and satellite imagery of mineralized natural terrain. Convegno Internazionale Sullo Spazio, Rome.

21 COLE, M.M. and OWEN-JONES, E.S. (1977). The use of Landsat imagery in relation to air survey imagery for terrain analysis in Northwest Queensland, Australia. ERTS follow-on programme study No 2632 (29650). Final Report. Supported by the U.K. Department of Industry, London.

22 COLWELL, R.N. (1975). Introduction. In Manual of Remote Sensing, edited by R.G.Reeves, American Society of Photogrammetry, Chapter 1, pp. 1-26.

23 COMMISSION OF THE EUROPEAN COMMUNITIES (1978). Agreste Project. Agricultural resources investigations in Northern Italy and Southern France. NASA Landsat satellites investigations Nr 28790. Final Report, June.

24 DALLIMORE, W. and JACKSON, A.B. (1966). A handbook of coniferae and ginkgoaceae. London, Edward Arnold. Fourth edition.

25 DA SILVA, L.B.X. (1978). Avaliação do comportamento inicial de diversas essencias nativas e exóticas. Curitiba, Brazil, Setor de Editoração da Fundação Cultural de Curitiba.

26 DA SILVA, L.B.X., HUMPHREYS, R., and TUDOR, J. (1975). Personal communication. Setor de Ciencas Agrarias, Curitiba, Brazil.

27 DE SELM, H.R. and TAYLOR, T.W. (1973). Vegetation boundaries on ERTS-1 imagery. In Remote Sensing of Earth Resources, Vol. III, edited by F. Shahrokhi, The University of Tennessee, Tullahoma, pp. 925-933.

28 DE STEIGUER, J.E. (1975). Forest type mapping at the Atchafalaya River Basin from satellite and aircraft imagery. In The Fifth Biennial Workshop on Color aerial photography in the plant sciences and related fields. August 19-21, American Society of Photogrammetry, pp. 129-141.

29 DIETRICH, D.L. and LACHOWSKI, H.M. (1977). Landsat forest inventory of the Philippines. In Proceedings of the American Society of Photogrammetry - Fall, Technical Meeting, October 18-21, pp. 137-144.

30 DISPERATI, A.A., KEECH, M.A. and GANTZEL, O.L. (1979). Algumas considerações sobre o mapeamento de Araucaria angustifolia (Bent.).O. Ktze em florestas nativas através de fotografias aéreas e imagens Landsat. IUFRO Meeting: a Problemática das Araucarias. Curitiba, Brazil, 21-28 Outubro.

31 DODGE, A.G. and BRYANT, E.S. (1975). Forest mapping with satellite data. Journal of Forestry, 74(8), pp. 526-531.

32 DÖRFEL,H.J. (1978). Phänologische aspekte bei der fernerkundung von vegetationsflächen. In Proceedings of Symposium on Remote Sensing for Observations and Inventory for Earth Resources and The Endangered Environment. July 2-8. Freiburg, Federal Republic of Germany, edited by G.Hildebrandt and H.J.Boehnel, Vol. III, pp. 1611-1624.

33 EMPRESA BRASILEIRA DE PESQUISA AGROPECUARIA(EMBRAPA) (1975). Levantamento de Reconhecimento dos solos do sudoeste do Estado do Paraná (informe preliminar). Rio de Janeiro, Centro de Pesquisas Biológicas, Embrapa.

34 ERB, R.B. (1973). The utility of ERTS-1 data for applications in agriculture and forestry. In Third Earth Resources Technology Satellite Symposium. NASA SP-3517, Goddard Space Flight Center, Washington, D.C., Vol. I, pp. 75-85.

35 ESTES, J.E. and SIMONETT,D.S. (1975). Fundamentals of image interpretation. In Manual of Remote Sensing (edited by R.G. Reeves), American Society of Photogrammetry, Falls Church, Chapter 14, 1, pp. 869-1076.

36 EVERITT, B. (1974). Cluster Analysis. London, Heinemann Educational Books.

37 FLEMING, M.D. et al (1975). Computer-aided analysis of Landsat-1 MSS data: A comparison of three approaches, including a "modified clustering" approach. LARS Information Note 072475. Laboratory for Applications of Remote Sensing and the Agricultural Experiment Station, Purdue University, Indiana.

38 FLEMING, M.D. and HOFFER, R.M. (1979). Machine processing of Landsat MSS data and DMA topographic data for forest cover type mapping. In Proceedings of Symposium on Machine Processing of Remotely Sensed Data. Purdue University, Laboratory for Applications of Remote Sensing, June 27-29, pp. 377-391.

39 FLOUZAT, G. and MONCHANT, M. (1978). Identification and inventory of fir forests with Landsat data. In Agreste Project: Agricultural Resources investigations in northern Italy and southern France. Commission of the European Communities, Final Report, June, Chapter 7.

40 FONTANEL, A. *et al* (1975). Enhancement of Landsat-1 by combination of multispectral classification and principal component analysis. In *NASA Earth Resources Survey Symposium*, Houston, Texas, June, Vol. 1-B, pp. 991-1012.

41 FUNDACAO NACIONAL DO INDIO (FUNAI). (1973). *Inventario florestal dos postos Indigenas dos estados do Parana, Santa Catarina e Rio Grande do Sul.* Centro de Pesquisas Florestais da Universidade Federal do Parana.

42 GANTZEL, O.L. (1979). *Avaliação das florestas de Araucaria angustifolia (Bent.) O.Ktze do sul do Brazil atraves de imagens do satelite Landsat 2*. Curitiba, Brazil, Setor de Ciencias Agrarias, M.Sc.Thesis.

43 GREGORY, A.F. (1973). Preliminary assessment of geological applications of ERTS-1 imagery from selected areas of the Canadian Arctic. In *Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1*, NASA Sp-327, Goddard Space Flight Center, Maryland, Vol. I, pp. 329-343.

44 GROOTENBOER, J. (1973). The influence of seasonal factors on the recognition of surface lithologies from ERTS imagery of the western transvaal. In *Third Earth Resources Technology Satellite Symposium*, Goddard Space Flight Center, Washington D.C., December 10-14, Vol. I, pp. 643-655.

45 HARRIS, L.F. (1973). The use of photographic methods in contrast enhancement of ERTS-1 imagery. In *Symposium on Significant Results Obtained from the Earth Resources Technologic Satellite-1*, NASA SP-327, Goddard Space Flight Center, New Carrollton, Maryland, 1, pp.1649-1655.

46 HARTIGAN, J.A. (1975). *Clustering Algorithms*. New York, John Witery & Sons.

47 HEATH, G.R. (1974). ERTS data tested for forestry applications. Photogrammetric Engineering, 40(3), pp. 1087-1091.

48 HELLER, R.C. (1973). Analysis of ERTS Imagery - Problems and promises for foresters. In Application of Remote Sensors Forestry, Joint report by working group "Application of Remote Sensors in Forestry", edited by G. Hildebrandt, Freiburg, Germany, pp. 373-394.

49 ----- (1975a). Remote Sensors for Airborne and Spaceborne Imagery. in Remote Sensing in Forestry, Proceedings of the Symposium held during the IUFRO World Congress , Oslo 21-26 June, edited by G. Hildebrandt, University of Freiburg, Germany, pp. 37-52.

50 ----- (1975b). Evaluation of ERTS-1 data for forest and rangeland surveys. U.S.D.A. Forest Service Research Paper PSW-112.

51 HERTEL, R.J.G. (1962). Estudos sobre a Araucaria angustifolia. 1. Descricao morfologica do fruto; a germinação. Curitiba, Brazil, Sociedade Paranaense Ciencas Naturais, Coletanea 1.

52 HILDEBRANDT, G. (editor) (1971). Application of Remote Sensors in Forestry. Joint Report by Working Group "Applications of Remote Sensors in Forestry". Freiburg, Germany.

53 ----- (1973). Proceedings Symposium IUFRO Subject Group S 6.05 Remote Sensing including Aerial Photography. Freiburg 17-21 September, Germany.

54 ----- (1976). Remote Sensing in Forestry. Proceedings of the Symposium held during the XVI IUFRO World Congress, Oslo 21-26 June.

55 HOFFER, R.M. and staff (1975). Natural Resource Mapping in Mountainous Terrain by Computer Analysis of ERTS-1 Satellite Data. Research Bulletin 919 (LARS Information Note 061575). Laboratory for Applications of Remote Sensing and Agricultural Experiment Station, Purdue University, West Lafayette, Indiana.

56 HOFFER, R.M. (1976). Techniques and Applications for Computer Aided Analysis of Multispectral Scanner Data. In *Remote Sensing in Forestry*. Proceedings of the Symposium held during the XVI IUFRO World Congress, Oslo 21-26 June, pp. 103-113.

57 ----- (1978). Biological and physical considerations in applying computer-aided analysis techniques to remote sensor data. In *Remote Sensing: The Quantitative Approach*, edited by Philip H. Swain and Shirley M. Davis. McGraw-Hill International Book Company, Chapter 5, pp. 227-289.

58 HOWARD, J.A. (1970). *Aerial Photo-Ecology*. London, Faber.

59 HUECK, K. (1972). *As florestas da America do Sul*. Sao Paulo, Brazil, Poligono.

60 INSTITUTO AGRONOMICO DO PARANA (IAPAR) (1976). Clima do Parana. In *Manual Agropecuario para o Parana*. Londrina, Brazil.

61 INSTITUTO BRASILEIRO DE DESENVOLVIMENTO FLORESTAL (IBDF) (1978). *Inventario florestal do pinheiro no sul do Brasil*. Fundação de Pesquisas Florestais da Universidade Federal do Parana. Relatorio final, Curitiba, Brazil.

62 JANKAUSKIS,J. (1973). Inventario florestal: Companhia de Papel e Celulose Iguacu. In *Anais do Secondo Congresso Florestal Brasileiro*, Curitiba, Parana, pp. 228-235.

63 JONES, A.D. (1976). Photographic data extraction from Landsat images. *Photogrammetric Engineering and Remote Sensing*, 42(11), pp. 1423-1425.

64 JOYCE, A.T. and PENDLETON, T.W. (1973). Computer implemented land use classification with pattern recognition software and ERTS digital data. In *Third Earth Resources Technology Satellite Symposium*. NASA SP-3517, Goddard Space Flight Center, Washington, D.C., March 5-9, Vol. I, pp. 331-338.

65 KALENSKY, Z. and SCHERK, L.R. (1975). Accuracy of forest mapping from Landsat computer compatible tapes. In Proceedings of the Tenth International Symposium on Remote Sensing of Environment. Ann Arbor, Michigan, October 6-10, pp. 1159-1167.

66 KALENSKY, Z. and WILSON, D.A. (1975). Spectral signatures of forest trees. In Proceedings of the Third Canadian Symposium on Remote Sensing. Alberta, Canada. September 22-24, pp. 155-171.

67 KAMAT, D.S. et al (1977). Mapping of forest regions from Landsat imagery for computer processing: A case study of east Bastar region. In Remote Sensing of Earth Resources, Vol. IV, edited by F. Shakaokhi, The University of Tennessee, Tullahoma, pp. 357-364.

68 KAN,E.P. (1976). A new computer approach to map mixed forest features and postprocess multispectral data. In Proceedings of the American Society of Photogrammetry, Fall Convention, Seattle, Washington, September 28-October 1, pp. 386-402.

69 KAN, P.E. and DILLMAN, R.D. (1975). Timber type separability in Southeastern United States on Landsat-1 MSS data. In Proceedings of the NASA Earth Resources Survey Symposium, Houston, Texas, Vol. 1A, pp. 135-157.

70. KEECH, M.A., DISPERATI, A.A. and GANTZEL, O.L. (1978). The delineation of Araucaria angustifolia in the forests of southern Brazil using satellite imagery. In Proceedings of the International Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment, Freiburg, Germany, edited by G. Hildebrandt and H.J.Boehnel, July 2-8, Vol. III, pp. 1805-1811.

71 KING, R. B. and KIKULA, I.S. (1978). Assessment of computer processed Landsat data in areas of subsistence or no cultivation. In Remote Sensing and National Mapping. Proceedings of the

Fifth Annual Conference of the Remote Sensing Society, Durham, England, December 18-20, pp. 123-146.

72 KIRBY, C.L. (1973). Forest and land inventory using ERTS Imagery and aerial photography in the boreal forest region of Alberta, Canada. In Third Earth Resources Technology Satellite-1 Symposium, Goddard Space Flight Center, Washington, D.C., December 10-14, Vol. I, pp. 127-136.

73 KIRVIDA, L. and JOHNSON, G.R. (1973). Automatic interpretation of ERTS data for forest management. In Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1. March 5-9, Vol. I: Technical Presentations, Section B, pp. 1075-1082.

74 KLAMKANSORN, B. (1976). Landsat 1 imagery application in forestry. In Remote Sensing in Forestry. Proceedings of the Symposium held during the XVI IUFRO World Congress. Oslo 21-26 June, edited by G. Hildebrandt, University of Freiburg, Germany, pp. 227-233.

75 KLEIN, R.M. (1960). O aspecto dinamico do pinheiro brasileiro. Sellowia, 12, pp. 17-44.

76 KRUMPE, P.F. (1973). The use of high altitude and earth orbital ERTS-1 in an analysis of Northern California Wildland environments. In Remote Sensing of Earth Resources, Vol. II, edited by F. Shahrokhi, The University of Tennessee, Tullahoma, pp. 1029-1048.

77 KUMAR, R. et al (1979). Classification of areas using pixel-by-pixel and sample classifiers. In Proceedings of Symposium Machine Processing of Remotely Sensed Data. June 27-29. Purdue University, Laboratory for Application of Remote Sensing, pp. 420-428.

78 LANDGREBE, D.A. (1978a). The quantitative approach: concept and rationale. In Remote Sensing: The quantitative approach. McGraw-Hill International Book Company. Chapter 1, pp.1-20.

79 ----- (1978b). Useful information from multispectral image data. Another look. In Remote Sensing: The quantitative approach. McGraw-Hill International Book Company, Chapter 7, pp.336-374.

80 LAUBENFELDS, D.J.de (1957). The status of conifers in vegetation classifications. In Annals of Association of American Geographers, 47, pp. 145-149.

81 LAUER, D.T. (1971). Multiband photography for forestry purposes. In Application of Remote Sensors in Forestry. Joint Report by Working Group "Application of Remote Sensors in Forestry", Freiburg, Germany, pp. 21-36.

82 LAWRENCE, R.D. and HERZOG, J.H. (1975). Geology and Forestry Classification from ERTS 1 Digital Data. Photogrammetric Engineering and Remote Sensing, 41(10), pp. 1241-1251.

83 LEE, Y.J. (1976). Computer-assisted forest land classification in British Columbia and the Yukon-Territory: A case study. In Proceedings of the American Society of Photogrammetry - Fall Convention, Seattle, Washington, September 28-October 1, pp.240-250.

84 LILLESAND, T.M. and KIEFER, R.W. (1979). Remote Sensing and Image Interpretation. John Wiley & Sons. Inc.

85 LODWICK, G.D. (1979). Measuring ecological changes in multispectral Landsat data using principal components. In Proceedings of the Thirteenth International Symposium on Remote Sensing of Environment, Environmental Research Institute of Michigan, Ann Arbor, 2, pp. 1131-1142.

86 LOETSCH, F. and HALLER, K.E. (1964). Forest Inventory. Munchen Bayerischer/Landwirtschaftsverlag GmbH, Vol. I.

87 LONGHI, S.J. and FAHSER, L.E.H. (1979). A estrutura de uma floresta natural de Araucaria angustifolia (Bert.). O. Ktze. no sul do Brasil. IUFRO Meeting: A Problematica das Araucarias. Curitiba, Brasil, 21-28 October.

88 MAACK, R. (1931). Urwald und Savanne im Landschaftsbild des Staates Parana. Zeitschrift der Gesellschaft für Erd Kunde zu Berlin, No. 3/4, pp. 95-116, Berlin.

89 ----- (1949). Notas complementares à apresentação preliminar do mapa fitogeografico do Estado do Paraná (Brasil).Arquivos do Museu Paranaense, vol. VII, Curitiba, pp. 351-362.

90 ----- (1968). Geografia fisica do Estado do Parana. Curitiba, Brazil, Codepar.

91 MACHADO, S.A. and SIQUEIRA, J.D.P.(1979). Distribuição natural da Araucaria angustifolia (Bert.) O.Ktze. IUFRO Meeting: A problemática das Araucarias, Curitiba, Brazil.

92 MAGNANINI, R.L.C. (1963). Mapa climatico In BRASIL. Conselho Nacional de Geografia. Geografia do Brasil: grande Região sul. Rio de Janeiro.

93 MAIZELS, J.K. (1977). Digital processing of Landsat imagery. A User's guide to the Bedford College Image processing program library. Geography Department, Bedford College, University of London.

94 MARILL, T. and GREEN, D.M. (1963). On the effectiveness of receptor in recognition systems. IEEE Transactions on Information Theory, Vol. IT-9, p. 11.

95 MA TOS, J.R. (1972).O pinheiro brasileiro. Sao Paulo, Gremio Politecnica.

96 MEISNER, D. and LILLESAND, T.A. (1979). An alternative approach to training analysis. In Proceedings of Symposium Machine Processing of Remotely Sensed Data. June 27-29. Purdue University, Laboratory for Application of Remote Sensing, p.354.

97 MESSMORE, J., COPELAND, G.E. and LEVY, G.F. (1975). Mapping forest Vegetation with ERTS-1 MSS data and automatic data processing techniques. In Remote Sensing of Earth Resources, Vol. IV, edited by F. Shahrokhi, The University of Tennesse, pp. 327-344.

98 MILLER, B. *et al* (1972). ERTS Two-Inch RBV Cameras Performance Characteristics. In Remote Sensing of Earth Resources, Vol.I, edited by F. Shahrokhi, The University of Tennessee, Tullahoma, pp. 408-437.

99 MORAIN, S.A. (1971). Interpretation and mapping of natural vegetation. In Remote Sensing Techniques for Environmental Analysis, edited by J. Estes and L. Senger, pp. 127-165.

100 MOREIRA, J.C. (1980). Personal communication. Instituto de Pesquisas Espaciais, São Paulo,Brazil.

101 NARENDRA, P.M. and GOLDBERG, M. (1977). A non-parametric clustering scheme for Landsat. Pattern Recognition, 9(4), pp. 207-215.

102 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) (1976). Landsat Data Users Handbook. Doc. No 76 SDS 4258. Goddard Sapce Flight Center, Greenbelt.

103 ----- (1980a). Landsat Data Users Notes, Issue 12, May. U.S. Geological Survey, EROS Data Center, Sioux Falls.

104 ----- (1980b). Landsat Data Users Notes, Issue 13, July. U.S. Geological Survey, EROS Data Center, Sioux Falls.

105 ----- (1980c). Landsat Data Users Notes, Issue 14, September. U.S. Geological Survey, EROS Data Center, Sioux Falls.

106 NIELSEN, V. and WIGHTMAN, J.M. (1974). An attempted forest classification at the regional level using ERTS-1 MSS imagery. In Proceedings of Symposium on Remote Sensing and Photo-Interpretation. October 7-11, Banff, Alberta, Canada. Commission VII of International Society of Photogrammetry, Vol. I, pp. 113-124.

107 NOSSEIR, M.K., PALESTINO, C.V.B, and BATISTA, G.T. (1975). Mapeamento de Vegetação Natural dos Estados de Minas Gerais e do Espirito Santo (Regiao Leste do Brasil) atraves de Imagens MSS do ERTS-1. Instituto de Pesquisas Espaciais, INPE-617-LAFE, São Jose dos Campos-Sao Paulo, Brasil.

108 OLIVEIRA, B. (1948). As Regiõesde occorencia normal da Araucaria. Anuario Brasileiro de Economia Florestal, 1, pp. 185-199.

109 OSWALD, E.T. (1974). Evaluation of ERTS imagery for vegetation interpretation in British Columbia. Canadian Surveyor, 28(2), pp. 147-154.

110 PALESTINO, C.V.B (1976). Formatação das fitas CCT exemplo de Montagem de arquivos em disco para sua utilizacao. Sao Jose dos Campos, Instituto de Pesquisas Espacias.

111 PATRICK, E.A. (1972). Fundamentals of Pattern Recognition. New Jersey, Prentice-Hall Inc.

112 PRESTON, E.J. (1932). A vegetation map of Parana. The Geographical Review, October, pp. 676-677.

113 PROSPEC A/A (1974). Foto interpretação e mapeamento das Reservas de Araucaria angustifolia (Bert.) O. Ktze. Rio de Janeiro. Convenio Instituto Brasileiro de Desenvolvimento Florestal/FINPE/Ministerio do Planejamento.

114 REITZ, R. and KLEIN, R.M. (1966). Araucariaceas. Flora Ilustrada catarinense. Itajai. Herbario Barbosa Rodrigues.

115 RENNIE, J.C. and BIRTH, E.E. (1974). Use of ERTS-1 imagery in Forest Inventory. In Remote Sensing of Earth Resources, Vol. III, edited by F. Shahrokhi, The University of Tennesse, Tullahoma, pp. 671-684.

116 ROGERS, R.L. (1953). Problemas silviculturais da Araucaria angustifolia. Anuario Brasileiro de Economia Florestal. 6, pp. 308-359.

117 ROMARIZ, D.A. (1974). *Aspectos da vegetação do Brasil.* Fundação Instituto Brasileiro de Geografia e Estatistica. Diretoria Tecnica. Rio de Janeiro, Brasil.

118 SABINS, F.F. Jr. (1978). *Remote Sensing. Principles and Interpretations.* Freeman, San Francisco.

119 SALAS, F. *et al* (1973). Photo interpretation of ERTS-A multispectral images analysis of vegetation and land use for Valencia Lake Basin Region. In *Third Earth Resources Technology Satellite-1 Symposium*, Goddard Space Flight Center, Washington, D.C. December 10-14, Vol. I: Technical Presentations, Section A, pp. 585-593.

120 SAYN-WITTGENSTEIN, L. (1960). *Recognition of tree species on air photographs by crown characteristics.* Forest Research Branch Canadian Department of Forestry, Tech. Note No. 95.

121 ----- (1977). Remote sensing and today's forestry issues. In *Proceedings of the Eleventh International Symposium on Remote Sensing of Environment*, Environmental Research Institute of Michigan, Ann Arbor, pp. 267-276.

122 ----- (1978). *Recognition of tree species on aerial photographs*. Forest Management Institute, Ottawa, Ontario. Information Report FMR-X-118. Canadian Forestry Service. Department of the Environment.

123 SAY-WITTEGENSTEIN, L. and KALENSKY, Z. (1974). Interpretation of forest patterns on computer compatible tpaes. In *Proceedings of Second Canadian Symposium on Remote Sensing*, 29 April - 1 May. University of Guelph, Guelph, Ontario, Canada, Vol. I, pp. 268-276.

124 SIEGAL, B.A. and ABRAMS,M.J. (1976). Geologic mapping using Landsat data. *Photogrammetric Engineering and Remote Sensing*, 42(3), pp. 325-337.

125 SHEDA, M.D. (1978). Remote sensing application in tropical dry deciduous forests. In Proceedings of Symposium on Remote Sensing for Observation and Inventory of Earth Resources and the Endangered Environment. July 2-8, Freiburg, Federal Republic of Germany, edited by G. Hildebrandt and H.J. Boehnel, Vol. III, pp. 1893-1901.

126 SHIMABUKURO, Y.E. et al (1980). Automatic classification of reforested Pine and Eucalyptus using Landsat data. Photogrammetric Engineering and Remote Sensing, 46(2), pp. 201-219.

127 SIQUEIRA, J.D.P. (1977). Tabelas de volume para povoamentos nativos de Araucaria angustifolia (Bert.) O. Ktze no sul do Brasil. Curitiba, Brazil, Setor de Ciencias Agrarias, M.Sc. Thesis.

128 ----- (1980). Personal communication. Curitiba, Setor de Ciencias Agrarias.

129 SILVA, J.A. (1977). Estimativa do diametro da copa e idade do pinheiro brasileiro (Araucaria angustifolia (Bert.) O.Ktze). em ambiente natural. Brasil Florestal, 8 (31), pp. 24-29.

130 ----- (1978). O comprimento do tronco, relação altura -diâmetro e altura-idade do pinheiro brasileiro (Araucaria angustifolia (Bert.) O.Ktze) e folhosas associadas em ambiente natural. Brasil Florestal, 9 (34), pp. 43-50.

131 SUPERINTENDENCIA DO DESENVOLVIMENTO DA REGIAO SUL (SUDESUL). (1978). Vegetação atual da Regiao sul. Porto Alegre, Brazil, Ministerio do Interior, Sudesul, Serie Planejamento e Estudos Regionais, No. 2.

132 SU, M.Y., JAYROE, R.R. and CUMMINGS, R.E. (1972). Unsupervised classification of Earth Resources data. In Remote Sensing of Earth Resources, Vol. I, edited by F. Shahrokhi, The University of Tennessee, Tullahoma, pp. 673-693.

133 SWAIN, P.H. and KING, R.C. (1973). Two effective feature selection criteria for multispectral remote sensing. LARS Information Note 042674. Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette.

134 THIE, J. (1976). An evaluation of remote sensing techniques for ecological land classification. In Proceedings of the Second Annual William T. Pecora Symposium. Mapping with Remote Sensing Data. Sponsored by The American Society of Photogrammetry and The United States Geological Survey. Sioux Falls, 25-29 October,pp. 362-381.

135 THORLEY, G.A. (1975). Forest lands: Inventory and Assessment. In Manual of Remote Sensing, edited by R. G. Reeves, American Society of Photogrammetry, Chapter L7, Vol. II, pp. 1353-1426.

136 TODD, W.J., GEHRING, D.G. and HAMAN, J.F. (1980). Landsat wildland mapping accuracy. Photogrammetric Engineering and Remote Sensing, 46(4), pp. 509-520.

137 TUELLER, P.T. (1975). Mapping Vegetation in the Great Basin from ERTS-1 Imagery. In Proceedings of the American Society of Photogrammetry, 41st Annual Meeting, March 9-14, Washington, D.C., pp. 338-370.

138 VELASCO, F.R.D. et al (1978). Sistema MAXVER: Manual do usuario, INPE 1315-NT1/110, Instituto de Pesquisas Especiais (INPE/CNPq) São José dos Campos, Sao Paulo, Brazil.

139 VLCEK, J. (1974). Difficulties in determining meaningful spectral signatures of forest tree canopies. In Proceedings of Symposium on Remote Sensing and Photo Interpretation. Comission VII, International Society of Photogrammetry, Banff, Alberta, Canada, 2, pp. 805-812.

140 VOLKART, C.M. (1963). Determinacion de la relacion diametro copa: diametro tronco en Araucaria angustifolia y Pinus elliottii

en la Provincia de Missiones. In Actas del Congresso Forestal Argentino, 1, Buenos Aires. Servicio Nacional Forestal, pp. 231-237.

141 WATANABE, S. (editor) (1969). Methodologies of Pattern Recognition The Proceedings of the International Conference on Methodologies of Pattern Recognition, Honolulu, Hawaii, January 1968, pp.24-26.

142 WATKINS, A.H. (1978). The EROS Data Center. U.S. Department of the Interior/Geological Survey.

143 WILLIAM, W.T. and LANCE, G.N. (1975). POLYDIV: a divisive classificatory program for all-numeric data. The Australian Computer Journal, Vol. 7, No 3, p. 144.

144 YASSOUGLOU, N.J. (1973). Application of ERTS-1 imagery to land-use, forest density and soil investigations in Greece. In Third Earth Resources Technology Satellite-1 Symposium, Goddard Space Flight Center, Washington, D.C., December 10-14, Vol. I: Technical Presentation, Section, pp. 159-182.

145 YOUNG, T.Y. and CALVERT, F.W. (1974). Classification, Estimation and Pattern Recognition. New York, American Elsevier Publishing Company Inc.

Appendix 1. Computer program to extend the range of digital counts of the Landsat CCT produced at Instituto de Pesquisas Espaciais from 0 to 999.

```
JOB(UAFA017BRZ,J6,T60,M6600,NT1)  DISPERATI
REQUEST(DATA,*PF)
FTN.
ATTACH,ADLIB,ID=LIBBED.
ATTACH,BRILIB,LIB,ID=UAAP046.
REQUEST(ERTS,PE,S,VSN=N6204F,INHIBIT,NOLABEL)
LIBRARY,ADLIB,BRILIB.
LGO.
CATALOG(DATA,MANG)
SYS,EXIT.
EXIT.
REWIND,DATA.
PRINTBF,DATA,1000,0,1.

      PROGRAM BRAZIL (ERTS,DATA,INPUT,OUTPUT,TAPE7=ERTS,
     1                TAPE8=DATA,TAPE5=INPUT,TAPE6=OUTPUT)
C     PROGRAM TO CONVERT SECTION OF BRAZILIAN ERTS FILE TO LONDON
C     FORMAT
      IMPLICIT INTEGER (A-Z)
      REAL EOF
      COMMON/RANGES/MAXXIN,XINSTT,XINEND,XINLEN,XOUTLEN,XREDUC,
     1              MAXYIN,YINSTT,YINEND,YINLEN,YOUTLEN,YREDUC
      COMMON/DIRECTS/ KARD(10)
      COMMON/TITLES/ TITLE (8)
C                              WRITE PROGRAM TITLE
      WRITE(6,9000)
C                                READ RUN NAME CARD
      READ (5,9300) TITLE
      IF(EOF(5).NE.0.0) GO TO 5000
      WRITE(6,9400) TITLE
C                                READ FILE NUMBER CARD
      READ (5,9100) KARD
      IF(EOF(5).NE.0.0) GO TO 5200
      WRITE(6,9200) KARD
C                                CHECK VALID FILE NUMBER
      IFAIL=1
      NFILE=INTIFY(KARD(1),IFAIL)
      IF(IFAIL.NE.0 .OR. NFILE.LE.0 .OR. NFILE.GT.8) GO TO 5100
C                                FIND REQUIRED FILE ON TAPE
      CALL GETFILE (NFILE)
C                                READ X RANGE CARD
      READ (5,9100) KARD
      IF(EOF(5).NE.0.0) GO TO 5200
      WRITE(6,9200) KARD
C                                CHECK VALID X RANGES
      CALL CHKRNGE (1HX,MAXXIN,XINSTT,XINEND,XINLEN,XOUTLEN,XREDUC)
C                                READ Y RANGE CARD
      READ (5,9100) KARD
      IF(EOF(5).NE.0.0) GO TO 5200
      WRITE(6,9200) KARD
C                                CHECK VALID Y RANGES
      CALL CHKRNGE (1HY,MAXYIN,YINSTT,YINEND,YINLEN,YOUTLEN,YREDUC)
C                                SKIP BLOCKS TO START OF REQUIRED RANGE
      CALL SKIPBLK (YINSTT)
C                                REFORMAT REQUIRED RANGE
      CALL REFORM
```

```
      STOP
C
 5000 WRITE(6,8000)
      CALL NOTIFY ("NO DIRECTIVES FOUND",3HABT)
C
 5100 WRITE(6,8100) KARD(1)
      CALL NOTIFY ("DIRECTIVE ERRORS",3HABT)
C
 5200 WRITE(6,8200)
      CALL NOTIFY ("PREMATURE EOF IN DIRECTIVES",3HABT)
C
 8000 FORMAT("0***ERROR*** NO DIRECTIVE CARDS FOUND")
 8100 FORMAT("0***ERROR*** INVALID FILE NUMBER = ",A4)
 8200 FORMAT("0***ERROR*** PREMATURE END OF FILE ENCOUNTERED WHEN READIN
     1G DIRECTIVES")
C
 9000 FORMAT(40X,"BRAZIL V1.0"/40X,"------------"///
     1          " DIRECTIVES"/" ------------"/)
 9100 FORMAT(3A4,A8,6A10)
 9200 FORMAT(1X,3A4,A8,6A10)
 9300 FORMAT(8A10)
 9400 FORMAT(1X,8A10)
      END
      SUBROUTINE GETFILE (NFILE)
C     ROUTINE POSITIONS TAPE AT IDENTIFICATION BLOCK OF FILE NTAPE
C     ON TAPE
      IMPLICIT INTEGER (A-Z)
      REAL UNIT
      COMMON/RANGES/MAXXIN,XINSTT,XINEND,XINLEN,XOUTLEN,XREDUC,
     1                  MAXYIN,YINSTT,YINEND,YINLEN,YOUTLEN,YREDUC
      DIMENSION BUFF(6),CHARS(16),BINS(20)
C                                      WRITE SEARCHING MESSAGE
      WRITE(6,9000) NFILE
C                                      ENSURE SEARCH FROM BEGINNING
      REWIND 7
C                                      READ IN AN IDENTIFICATION BLOCK
  200 BUFFER IN (7,1)(BUFF(1),BUFF(6))
      IF(UNIT(7).EQ.0.0) GO TO 5000
C                                      UNPACK CHARACTER INFO
      CALL GUNPACK (CHARS,BUFF,8,16,0)
C                                      CONVERT CHARS TO ASCII
      DO 400 I=1,16
      CHARS(I)=ASCII(CHARS(I))
  400 CONTINUE
C                                       CHECK IF REQUIRED FILE
      IFAIL=1
      FILENO=INTIFY(SHIFT(CHARS(13),6).OR.CHARS(14),IFAIL)
      IF(IFAIL.NE.0) GO TO 5100
      IF(FILENO.EQ.NFILE) GO TO 1000
C                                       NOT REQUESTED FILE - SKIP TO EOF
      WRITE(6,9100) FILENO
  700 BUFFER IN (7,1)(BUFF(1),BUFF(6))
      IF(UNIT(7).NE.0.0) GO TO 700
      GO TO 200
C                                  WRITE TAPE IDENTIFICATION CHAR INFO
 1000 WRITE(6,9200) CHARS
C                                  UNPACK BINARY INFO
```

```
      CALL GUNPACK (BINS,BUFF,16,20,0)
      WRITE(6,9300) BINS(9),
     1                     SHIFT(BINS(10),-5),
     2                     (SHIFT(BINS(10),-1).AND..NOT.MASK(56)),
     3                     BINS(11),
     4                     (BINS(I),I=12,16),
     5                     BINS(19),BINS(20)
C                                      SET DIMENSIONS OF DATA ON TAPE
      MAXXIN=BINS(15)
      MAXYIN=BINS(19)
      RETURN
C
 5000 WRITE(6,8000)
      CALL NOTIFY ("DESIRED FILE NOT ON TAPE",3HABT)
C
 5100 WRITE(6,8100)
      CALL NOTIFY ("TAPE POSITIONING ERROR - CONSULT ANALYST",3HABT)
C
 8000 FORMAT("0***ERROR*** DESIRED FILE NUMBER WAS NOT FOUND - CHECK COR
     1RECT TAPE HAS BEEN CORRECTLY REQUESTED")
 8100 FORMAT("0***ERROR*** TAPE POSITIONING ERROR - FILE NUMBER INVALID
     1- CONSULT ANALYST")
C
 9000 FORMAT(/40X,"SEARCHING FOR FILE",I2," .....")
 9100 FORMAT(/40X,".....SKIPPING FILE",I2," .....")
 9200 FORMAT(/40X,"FILE IDENTIFICATION                 = ",12R1/
     1          40X,"FILE NUMBER                         = ",10X,2R1/
     2          40X,"NO. FILES IN SET                    = ",10X,2R1)
 9300 FORMAT(/40X,"DATA BLOCK LENGTH                   = ",I12/
     1         /40X,"SATELLITE NUMBER                    = ",I12/
     2         /40X,"YEAR OF IMAGE                       = ",I12/
     3          40X,"DAY                                 = ",I12/
     4          40X,"HOURS                               = ",I12/
     5          40X,"MINUTES                             = ",I12/
     6          40X,"SECONDS                             = ",I12/
     7         /40X,"WIDTH OF STRIP                      = ",I12/
     8          40X,"OVERLAP WITH ADJ STRIPS             = ",I12/
     9          40X,"NO. OF STRIPS                       = ",I12/
     A          40X,"FIRST DATA ELEMENT ORDINAL          = ",I12)
      END
      INTEGER FUNCTION ASCII (N)
      INTEGER ASCTAB(256)
      DATA ASCTAB/32*1R?,
     2 1R ,1R ,1R",1R£,1R$,1R:,1R&,1R',1R(,1R),1R*,1R+,1R,,1R-,1R.,1R/,
     3 1R0,1R1,1R2,1R3,1R4,1R5,1R6,1R7,1R8,1R9,1R:,1R;,1R ,1R=,1R>,1R?,
     4 1R@,1RA,1RB,1RC,1RD,1RE,1RF,1RG,1RH,1RI,1RJ,1RK,1RL,1RM,1RN,1RO,
     5 1RP,1RQ,1RR,1RS,1RT,1RU,1RV,1RW,1RX,1RY,1RZ,1R[,1R\,1R],1R↑,1R_,
     6 1R?,1RA,1RB,1RC,1RD,1RE,1RF,1RG,1RH,1RI,1RJ,1RK,1RL,1RM,1RN,1RO,
     7 1RP,1RQ,1RR,1RS,1RT,1RU,1RV,1RW,1RX,1RY,1RZ,1R[,1R\,1R],1R↑,1R?,
     F 128*1R?/
C                                              CHECK VALID CHAR NUMBER
      IF(N.LT.0 .OR. N.GT.225) N=127
C                                              LOOK UP DISPLAY CODE GRAPHIC
      ASCII=ASCTAB(N+1)
      RETURN
      END
      SUBROUTINE SKIPBLK (N)
```

```
C     ROUTINE SKIPS N BLOCKS ON TAPE
      IMPLICIT INTEGER (A-Z)
      REAL UNIT
      DIMENSION DUMBUFF(2)
C                                         SKIP N BLOCKS
      DO 500 I=1,N
      BUFFER IN (7,1)(DUMBUFF(1),DUMBUFF(2))
      IF(UNIT(7).EQ.0.0) GO TO 5000
  500 CONTINUE
      RETURN
C                                         ERROR - EOF DETECTED
 5000 WRITE(6,8000) N
      CALL NOTIFY ("PREMATURE EOF ON TAPE",3HABT)
 8000 FORMAT("0***ERROR*** PREMATURE EOF ON TAPE AFTER SKIPPING",I10,
     1          " BLOCKS - CONSULT ANALYST")
      END
      SUBROUTINE CHKRNGE (RNGNM,MAXRNG,STT,END,INSIZE,OUTSIZE,REDUC)
C     ROUTINE CHECKS RANGE AND SCALING SPECIFICATIONS
      IMPLICIT INTEGER (A-Z)
      COMMON/DIRECTS/ KARD(10)
C                                         CHECK VALID START
      IFAIL=1
      STT  =INTIFY(KARD(1),IFAIL)
      IF(IFAIL.EQ.0 .AND. STT.GT.0) GO TO 300
      WRITE(6,8000) RNGNM,KARD(1)
      GO TO 5000
C                                         CHECK VALID END
  300 IFAIL=1
      END  =INTIFY(KARD(2),IFAIL)
      IF(IFAIL.EQ.0 .AND. END.LE.MAXRNG) GO TO 500
      WRITE(6,8100) RNGNM,KARD(2)
      GO TO 5000
C                                         CHECK START .LT. END
  500 IF(STT.LT.END) GO TO 700
      WRITE(6,8200) RNGNM
      GO TO 5000
C                                         CHECK VALID REDUCTION FACTOR
  700 IFAIL=1
      REDUC=INTIFY(KARD(3),IFAIL)
      IF(IFAIL.EQ.0 .AND. REDUC.GE.0) GO TO 900
      WRITE(6,8300) RNGNM,KARD(3)
      GO TO 5000
C                                         DEFAULT REDUCTION IS 1
  900 IF(REDUC.EQ.0) REDUC=1
C                                         CALC NO. INPUT PIXELS
      INSIZE=(END-STT)+1
C                                         CALC NO. OUTPUT PIXELS
      OUTSIZE=INSIZE/REDUC
C                                         CHECK NO PIXELS LOST
      IF(INSIZE.NE.(OUTSIZE*REDUC)) WRITE(6,8400) RNGNM
      RETURN
C
 5000 CALL NOTIFY ("DIRECTIVE ERRORS",3HABT)
C
 8000 FORMAT("0***ERROR*** INVALID START OF RANGE IN ",A1,
     1          " DIRECTION - ",A4)
 8100 FORMAT("0***ERROR*** INVALID END OF RANGE IN ",A1,
```

```
     1       " DIRECTION = ",A4)
 8200 FORMAT("0***ERROR*** START OF ",A1," RANGE GREATER THAN END")
 8300 FORMAT("0***ERROR*** INVALID REDUCTION FACTOR IN ",A1,
     1       " DIRECTION = ",A4)
 8400 FORMAT("0***NOTE*** ODD PIXELS WITH HIGHEST ",A1," LOST"/)
      END
      SUBROUTINE REFORM
C     ROUTINE CONTROLS REFORMATING OF DATA
      IMPLICIT INTEGER (A-Z)
      COMMON/RANGES/MAXXIN,XINSTT,XINEND,XINLEN,XOUTLEN,XREDUC,
     1              MAXYIN,YINSTT,YINEND,YINLEN,YOUTLEN,YREDUC
      COMMON/LINES /LINE(1736)
      COMMON/OUT   /VAL(50),FMT(2),PARAMS,CPL,VPL,PRIV(60)
      COMMON/TITLES/ TITLE(8)
      DIMENSION ROW (4,432)
      REAL SCALE
C                                SET UP OUT FOR BRIAN"S I-O PACKAGE
      DATA FMT/10H(6(4I3,1X),    1H)/
      DATA PARAMS,CPL,VPL/4,6,24/
C                                 WRITE OUTPUT DATA-SET HEADER
      WRITE(8,9000) TITLE,XOUTLEN,YOUTLEN,PARAMS
C                                CALC SCALING FOR RANGE 0-999
      SCALE=3.9/FLOAT(XREDUC*YREDUC)
C                                INITIATE BRIAN"S I-O SYSTEM
      CALL INITOUT (8)
C                                 GENERATE OUTPUT LINES LOOP
      DO 2000 OUTY=1,YOUTLEN
C                                 INITIALISE BAND TOTALS
      DO 200 OUTX=1,XOUTLEN
      DO 200 BAND=1,4
      ROW(BAND,OUTX)=0
  200 CONTINUE
C                                 GET INPUT LINES REDUCED TO ONE OUTPUT
C                                 LINE LOOP
      DO 800 PARTY=1,YREDUC
      CALL GETLINE
C
      INX4=(XINSTT-1)*4
      DO 600 OUTX=1,XOUTLEN
C                                SUM INPUT VALS REDUCED TO ONE TOTAL
      DO 400 PARTX=1,XREDUC
      DO 300 BAND =1,4
      INX4=INX4+1
      ROW(BAND,OUTX)=LINE(INX4) + ROW(BAND,OUTX)
  300 CONTINUE
  400 CONTINUE
  600 CONTINUE
  800 CONTINUE
C                                 SCALE VALUE IN RANGE 0-999
      DO 1300 OUTX=1,XOUTLEN
      DO 1100 BAND=1,4
      VAL(BAND)=FLOAT(ROW(BAND,OUTX))*SCALE + 0.5
 1100 CONTINUE
C                                OUTPUT PIXEL
      CALL OUTDATA
 1300 CONTINUE
 2000 CONTINUE
```

```
C                                 TERMINATE OUTPUT
      CALL ENDOUT
      REWIND 8
      RETURN
 9000 FORMAT(8A10/3(I4,2X),"F")
      END
      SUBROUTINE GETLINE
C     ROUTINE UNTWISTS REQUIRED DATA INTO LINE IN /LINES/
      IMPLICIT INTEGER (A-Z)
      REAL UNIT
      COMMON/RANGES/MAXXIN,XINSTT,XINEND,XINLEN,XOUTLEN,XREDUC,
     1              MAXYIN,YINSTT,YINEND,YINLEN,YOUTLEN,YREDUC
      COMMON/LINES /LINE(1736)
      DIMENSION PACKED(227)
C                                 READ IN NEXT BLOCK
      BUFFER IN (7,1)(PACKED(1),PACKED(227))
      IF(UNIT(7).EQ.0.0) GO TO 5000
C                               FIND END OF SET OF 8 BEFORE 1ST REQUIRED
      XIN8STT=((XINSTT-1)/2)*8
C                               FIND END OF SET OF 8 OF LAST REQUIRED
      XIN8END=((XINEND+1)/2)*8
C                               UNPACK REQUIRED FIELDS
      CALL GUNPACK (LINE,PACKED,8,XIN8END,0)
C                               UNTWIST SETS OF EIGHT 8 BIT FIELDS
C                                ENSURING TO START AT BEGINING OF SET
      IPNT=XIN8STT
  600 TEMP         =LINE(IPNT+5)
      LINE(IPNT+5)=LINE(IPNT+2)
      LINE(IPNT+2)=LINE(IPNT+3)
      LINE(IPNT+3)=TEMP
      TEMP         =LINE(IPNT+7)
      LINE(IPNT+7)=LINE(IPNT+6)
      LINE(IPNT+6)=LINE(IPNT+4)
      LINE(IPNT+4)=TEMP
C                               INC POINTER TO NEXT SET OF TWISTED 8
      IPNT=IPNT+8
      IF(IPNT.LT.XIN8END) GO TO 600
      RETURN
C
 5000 WRITE(6,8000)
      CALL NOTIFY ("PREMATURE EOF ON TAPE",3HABT)
C
 8000 FORMAT("0***ERROR*** EOF DETECTED ON TAPE WHILE READING DATA - CON
     1SULT ANALYST")
      END

MANGUEIRINHA FIRST STRIP X=(300,416)  Y=(1121,1320)
   1
 300 416   1
11201320   1

***F
```

Appendix 2. Computer program to estimate the individual classification accuracy of the classes used in the supervised program.

```
      PROGRAM CHECLAS (CMAPS,INPUT,OUTPUT,TAPE5=INPUT,
     1                 TAPE6=OUTPUT,TAPE7=CMAPS)
      IMPLICIT INTEGER (A-Z)
      COMMON/MAPS   /MAXX,MAXY,MAPSIZE
      COMMON/       /VALS(1)
      DIMENSION TITLE(8)
      REAL EOF
C
      DATA AFEW / 8 /
C
      WRITE(6,9000)
 9000 FORMAT(1H1/20X,"CHECLAS V1.0"/20X,"-------------"//)
C                                   READ MAP DATA TITLE
      READ(7,9100) TITLE
 9100 FORMAT(8A10)
      IF(EOF(7).EQ.0.0) GO TO 200
      WRITE(6,8000)
 8000 FORMAT("0***ERROR*** NO MAP DATA FILE FOUND - RUN TERMINATED")
      CALL NOTIFY ("NO MAP DATA FILE FOUND",3HABT)
C
  200 WRITE(6,9600) TITLE
 9600 FORMAT(20X,"MAP TITLE : ",8A10)
      READ (7,9100) TITLE
      IF(EOF(7).NE.0.0) GO TO 5000
      WRITE(6,9700) TITLE
 9700 FORMAT(32X,8A10/)
C                                   READ BOUNDS OF MAP
      READ (7,9200) MAXX,MAXY
 9200 FORMAT(2I4)
      IF(EOF(7).NE.0.0) GO TO 5000
      WRITE(6,9300)MAXX,MAXY
 9300 FORMAT(20X,"WIDTH OF MAP IS",I6," PIXELS"/
     1       20X,"DEPTH OF MAP IS",I6," PIXELS"/)
C                                   TELL USER MEMORY REQUIRED FOR MAP
      MAPSIZE=MAXX*MAXY
      NOWRDS=LOCF(VALS(1))+MAPSIZE+AFEW
      WRITE(6,9400) NOWRDS
 9400 FORMAT(20X,"...OBTAINING",I10," WORDS (TOTAL) FOR PROCESSING MAP..
     1.")
      CALL SETFLS  (NOWRDS,3HABS)
C                                   CHECK VALUE CLASSIFICATIONS
      CALL CMPVALS (VALS,MAXX,MAXY)
      STOP
C
 5000 WRITE(6,8100)
 8100 FORMAT("0***ERROR*** PREMATURE EOF ON MAP DATA FILE - RUN TERMINAT
     1ED")
      CALL NOTIFY ("PREMATURE EOF ON MAP DATA FILE",3HABT)
      END
      SUBROUTINE READBLK
C     ROUTINE READS BLOCK SPECIFICATION CARDS, RETURNING THE TYPE OF
C     THE NEXT VALID BLOCK IN TYPE AND ITS EDGES IN LEFT, RIGHT,
C     TOP, BOT.
      IMPLICIT INTEGER (A-Z)
      COMMON/MAPS   /MAXX,MAXY,MAPSIZE
      COMMON/BLOCKS /TYPE,LEFT,RIGHT,TOP,BOT,BLKSIZE
```

```
      DIMENSION      BLKEDGE(4)
      EQUIVALENCE    (LEFT,BLKEDGE(1))
      DIMENSION BLKTXT(4)
      DIMENSION ERRMESS(3,10)
      REAL EOF
      DATA ERRMESS/
     1                     10HINVALID LE, 10HFT EDGE   ,  10H           ,
     2                     10HINVALID RI, 10HGHT EDGE  ,  10H           ,
     3                     10HINVALID TO, 10HP EDGE    ,  10H           ,
     4                     10HINVALID BO, 10HTTOM EDGE ,  10H           ,
     5                     10HLEFT EDGE , 10HEXCEEDS RI,  10HGHT        ,
     6                     10HLEFT EDGE , 10HLIES OUTSI,  10HDE MAP     ,
     7                     10HRIGHT EDGE, 10H LIES OUTS,  10HIDE MAP    ,
     8                     10HBOTTOM EDG, 10HE EXCEEDS ,  10HTOP        ,
     9                     10HTOP EDGE L, 10HIES OUTSID,  10HE MAP      ,
     A                     10HBOTTOM EDG, 10HE LIES OUT,  10HSIDE MAP   /
C                                READ NEXT BLOCK SPECIFICATION CARD
  200 READ (5,9000) BLKTXT,TYPE
 9000 FORMAT(4A4,R1)
      IF(EOF(5).EQ.0.0) GO TO 300
      TYPE=0
      RETURN
C                                CHECK EDGES SPECIFIED AS VALID INTEGERS
  300 DO 400 ERROR=1,4
      IFAIL=1
      BLKEDGE(ERROR)=INTIFY(BLKTXT(ERROR),IFAIL)
      IF(IFAIL.NE.0) GO TO 2000
  400 CONTINUE
C                                SET ERROR FLAG TO NO ERROR (YET)
      ERROR=0
C                                CALC SIZE OF BLOCK
      BLKSIZE=(RIGHT-LEFT+1) * (BOT-TOP+1)
C                                CHECK EDGES MAKE UP POSSIBLE BLOCK
      IF(LEFT  .GT. RIGHT) ERROR=5
      IF(1     .GT. LEFT ) ERROR=6
      IF(RIGHT .GT. MAXX ) ERROR=7
      IF(TOP   .GT. BOT  ) ERROR=8
      IF(1     .GT. TOP  ) ERROR=9
      IF(BOT   .GT. MAXY ) ERROR=10
C                                IF NO ERRORS RETURN BLOCK INFO
      IF(ERROR.EQ.0) RETURN
C                                ELSE WARN USER
 2000 WRITE(6,8000) (ERRMESS(I,ERROR),I=1,3),BLKTXT,TYPE
 8000 FORMAT("0***ERROR*** ",3A10": ",4A4,R1/)
C                                GO READ ANOTHER CARD
      GO TO 200
      END
      SUBROUTINE CMPVALS (VALS,MAXX,MAXY)
C     ROUTINE CONTROLS COMPARISON OF USERS ESTIMATE OF PIXEL TYPE
C     WITH PROGRAM "SOUP'S" ESTIMATE
      IMPLICIT INTEGER (A-Z)
      DIMENSION VALS (MAXX,MAXY)
      COMMON/BLOCKS /TYPE,LEFT,RIGHT,TOP,BOT,BLKSIZE
      DIMENSION TOTALS(63)
C                             READ IN MAP VALUES
      DO 200 IY=1,MAXY
      READ (7,9000)  (VALS(IX,IY),IX=1,MAXX)
```

```
      IF(EOF(7).NE.0.0) GO TO 5000
  200 CONTINUE
 9000 FORMAT(80R1)
C                                 INIT TOTAL USER SPECIFIED PIXEL COUNT
      TOTSMPL=0
C                                 READ FIRST PIXEL BLOCK SPECIFICATION
      CALL READBLK
C                                 ERROR IF NONE SPECIFIED
      IF(TYPE.NE.0) GO TO 300
      WRITE(6,8000)
 8000 FORMAT("0***ERROR*** NO PIXEL BLOCK SPECIFICATIONS FOUND - RUN TER
     1MINATED")
      CALL NOTIFY ("NO PIXEL BLOCK SPECIFICATIONS",3HABT)
  300 WRITE(6,9900) TYPE
 9900 FORMAT(1H1/" PIXEL BLOCKS KNOWN TO BE OF TYPE ",R1/
     1       1X,34(1H=)//
     2       16X,"LEFT",15X,"RIGHT",17X,"TOP",14X,"BOTTOM"/)
C                                  RESET SOUP PIXEL TYPE TOTALS
      DO 400 I=1,63
      TOTALS(I)=0
  400 CONTINUE
C                                  RESET TOTAL OF SIZE OF THIS TYPES USER
C                                  SPECIFIED TOTAL
      TYPSMPL=0
C                                  RESET LAST TYPE TO TYPE LAST READ
      LASTYPE=TYPE
C                                  WRITE LAST BLOCK SPECIFICATION READ
  500 WRITE(6,9100) LEFT,RIGHT,TOP,BOT
 9100 FORMAT(4I20)
C                                  ADD TO TOTALS OF TYPES PRODUCED BY SOUP
      DO 600 IY=TOP,BOT
      DO 600 IX=LEFT,RIGHT
      TOTALS(VALS(IX,IY))=TOTALS(VALS(IX,IY))+1
  600 CONTINUE
C                                  ADD TO USERS TOTAL FOR THIS TYPE
      TYPSMPL=TYPSMPL+BLKSIZE
C                                  ADD TO TOTAL PIXELS SAMPLED
      TOTSMPL=TOTSMPL+BLKSIZE
C                                  READ NEXT BLOCK SPECIFICATION
      CALL READBLK
C                                  LOOP IF SAME TYPE AS LAST
      IF(TYPE.EQ.LASTYPE) GO TO 500
C                                  PRODUCE STATISTICS FOR TYPE
C                                  WRITE TYPE AND SIZE OF TEST SAMPLE
      WRITE(6,9200) LASTYPE,TYPSMPL,FLOAT(TYPSMPL*100)/FLOAT(MAXX*MAXY)
 9200 FORMAT("0CLASSIFICATION OF TYPE ",R1/1X,24(1H=)//
     1       " SAMPLE SIZE =",I8,10X,"(",F5.1," PERCENT OF MAP)"//
     2        16X,"TYPE",18X,"TOTAL PIXELS",12X,"PERCENT OF SAMPLE"//)
C                                   WRITE ALLOCATION OF PIXELS BY SOUP
      DO 900 I=1,63
      IF(TOTALS(I).NE.0) WRITE(6,9300) I,TOTALS(I),
     1                           FLOAT(TOTALS(I)*100)/FLOAT(TYPSMPL)
  900 CONTINUE
 9300 FORMAT(19X,R1,I30,F30.1/)
C                                   LOOP IF END OF BLOCK SPECS NOT REACHED
      IF(TYPE.NE.0) GO TO 300
C                                   PRINT SUMMARY STATISTICS
```

```
      WRITE(6,9400) TOTSMPL,FLOAT(TOTSMPL*100)/FLOAT(MAXX*MAXY)
 9400 FORMAT("0SUMMARY",/" ========"//
     1        " TOTAL PIXELS SAMPLED - ALL TYPES =",I8,
     2        10X,"(",F5.1," PERCENT OF MAP")
      RETURN
 5000 WRITE(6,8100) IY
 8100 FORMAT("0***ERROR*** PREMATURE EOF AT MAP LINE ",I5,
     1        "      - RUN TERMINATED")
      CALL NOTIFY ("PREMATURE EOF ON MAP DATA FILE",3HABT)
      END
***F
```

Appendix 3. Computer program to estimate the area distribution of the crown densities of Parana Pine stands in the elevation range of the Mangueirinha area.

```
JOB(UAFA017MAP,J9,T120,M6600)  DISPERATI
MNF(E=2,R=0)
LDSET(MAP=B/ZZZZMP,PRESET=NGINF)
LGO.

      PROGRAM CONTA(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      INTEGER CAT(40),RANGE(40),TABLE(13,17),MASTER(13,17),QADRNT
      DO 5 M=1,13
      DO 6 N=1,17
      TABLE(M,N)=MASTER(M,N)=0
    6 CONTINUE
    5 CONTINUE
      ICARD=QADRNT=1
   10 READ(5,6000)(CAT(I),RANGE(I),I=1,40)
 6000 FORMAT(80R1)
      DO 20 K=1,40
      IF(K.EQ.40) GO TO 12
      IF(CAT(K+1).EQ.1R*.AND.RANGE(K+1).EQ.1R*) GO TO 20
   12 IF(CAT(K).EQ.1R .AND.RANGE(K).EQ.1R ) GO TO 15
      IF(CAT(K).EQ.1R/.AND.RANGE(K).EQ.1R/) GO TO 50
      IF(CAT(K).GT.13.OR.RANGE(K).GT.17) GO TO 17
      TABLE(CAT(K),RANGE(K))=TABLE(CAT(K),RANGE(K))+1
      GO TO 20
   15 DO 16 L=K,40
      IF(CAT(L).NE.1R .OR.RANGE(L).NE.1R ) GO TO 17
   16 CONTINUE
      GO TO 50
   17 IFROM=K*2-1
      IUPTO=IFROM+1
      WRITE(6,6100)ICARD,IFROM,IUPTO
 6100 FORMAT(1H ,*ERROR--- ON CARD*,I3,*FOR COLUMNS *I3,*  TO *,I3)
   20 CONTINUE
      GO TO 200
   50 CALL PRINT(TABLE,QADRNT)
      QADRNT=QADRNT+1
      DO 100 L1=1,13
      DO 80 L2=1,17
      MASTER(L1,L2)=MASTER(L1,L2)+TABLE(L1,L2)
      TABLE(L1,L2)=0
   80 CONTINUE
  100 CONTINUE
      IF(CAT(K).NE.1R/.OR.RANGE(K).NE.1R/) GO TO 200
      CALL PRINT(MASTER,999)
      WRITE(6,6200)ICARD
 6200 FORMAT(1H ,*TOTAL CARDS READ=*,I3)
      STOP
  200 ICARD=ICARD+1
      GO TO 10
      END
      SUBROUTINE PRINT(INFO,QADRNT)
      INTEGER QADRNT,INFO(13,17)
      WRITE(6,6000)QADRNT
 6000 FORMAT(1H ,15(/),52X,* TABLE FOR QUADRANT*I4///)
      WRITE(6,6010)(I1,I1=441,1081,40)
      WRITE(6,6010)(I2,I2=480,1120,40)
 6010 FORMAT(1H ,20X,20I5)
```

```
          DO 40 I3=1,13
          WRITE(6,6020)I3,(INFO(I3,I4),I4=1,17)
     6020 FORMAT(1H ,A15,15X,17I5)
       40 CONTINUE
          WRITE(6,6030)
     6030 FORMAT(1H ,/////)
          RETURN
          END

     ***F
```