ATLANTIC ZONE PROGRAMME

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LAND USE AND LAND USE DYNAMICS

IN THE ATLANTIC ZONE OF COSTA RICA

Marleen Belder

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WAGENINGEN - AUW

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The Atlantic Zone Programme (CATIE-AUW-MAG) is the result of an agreement for technical cooperation between the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), the Agricultural University Wageningen (AUW). The Netherlands and the Ministerio de Agricultura y Ganadería (MAG) of Costa Rica. The Programme, that was started in April 1986, has a long-term objective multidisciplinary research aimed at rational use of the natural resources in the Atlantic Zone of Costa Rica with emphasis on the small landowner.

PREFACE

General description of the research programme on sustainable Landuse.

The research programme is based on the document "elaboration of the VF research programme in Costa Rica" prepared by the Working Group Costa Rica (WCR) in 1990. The document can be summarized as follows:
To develop a methodology to analyze ecologicaly sustainable and economically feasible land use, three hierarchical levels of analysis can be distinguished.
1. The Land Use System (LUS) analyses the relations between soil type and crops as well as technology and yield.
2. The Farm System (FS) analyses the decisions made at the farm household regarding the generation of income and on farm activities.
3. The Regional System (RS) analyses the agroecological and socio-economic boundary conditions and the incentives presented by development oriented activities.

Ecological aspects of the analysis comprise comparison of the effects of different crops and production techniques on the soil as ecological resource. For this comparision the chemical and physical qualities of the soil are examined as well as the polution by agrochemicals. Evaluation of the groundwater condition is included in the ecological approach. Criterions for sustainability have a relative character. The question of what is in time a more sustainable land use will be answered on the three different levels for three major soil groups and nine important land use types.

Combinations of crops and soils

	Maiz	Yuca	Platano	Piña	Palmito	Pasto	Forestal I	Forestal II	Forestal III
Soil I	x	x	x		x	x	x		
Soil II						x	x		
Soil III	x			x	x	x	x		

As landuse is realized in the socio-economic context of the farm or region, feasibility criterions at corresponding levels are to be taken in consideration. MGP models on farm scale and regional scale are developed to evaluate the different ecological criterions in economical terms or visa-versa.

Different scenarios will be tested in close cooperation with the counter parts.

Preface

From July 1993 till January 1994, I dealt in the research of the Atlantic Zone Programme in Guápiles, Costa Rica. This period, which I really enjoyed, was used as a practical training period and also for a Msc-thesis. One final report has been written dealing with both periods. In Costa Rica I was supervised by Jetse Stoorvogel. I want to thank him for his help and advice, especially during the hard periods when working with ARC/INFO and DBASE. Also thanks to Prof. Louise Fresco, my supervisor in Wageningen, who helped me writing this final report. I also want to thank Luis Quiros and Don Mario who helped me with the fieldwork.

Summary

Land use planning is becoming more and more important as the world population is growing and thus pressure on land increases. Understanding of past changes in land use and projecting future land use trajections requires understanding of the interactions of the basic (human) forces that motivate production and consumption (IGBP, 1993).
Research has been carried out to describe land use and its dynamics for a study area in the Atlantic Zone of Costa Rica. A land use map for 1992 based on aerial photo interpretation and fieldwork was made. For the aerial photo interpretation a key was made. This key describes the criteria used for determination of the different land covers.
The final map gives a regional overview of the land use in the Atlantic Zone. In the study area still a considerable amount of forest (34% of total area) is present. Part of this forest (23% of all forest) is found in protected areas. In the deforested areas pastures play an important role, 36% of the total area is covered by it. Another large area is covered by banana plantations (14%) owned by big companies. Also some plantations of ornamental plants, palmheart and macadamia trees are found. Some areas are dominated by annuals (2.7% of total area) which are often grown on small fields.
An indication of exactness with which boundaries between mapping units could be drawn was given. Exactness here is subjective because it is indicated by the photo interpreter. A more objective study dealing with land cover differences also was carried out. Mapping units (different land covers) were scanned and often a typical scan pattern could be found. By using ARC/INFO, a Geographical Information System (GIS), the map was digitized and analyses were carried out. Fifty points were plotted on the final map and on the separate photos indicating the secureness of transformation from photos to the topographic corrected map. This transformation was carried out well for a map with a scale of 1:100,000.
By creation of overlays, relations between land use (1992) and infrastructure, IDA settlements, soil type and protection of certain areas were studied. It was assumed that among others, these factors influence land use. Within IDA settlements many small farms can be found. Compared to the total study area less forest and plantation area and more annual and pasture area were found in the settlements. Also between older and newer settlements land use differences were observed. In the older settlements more banana plantations were found and less forested parts compared to the newer ones.
Land use in the Atlantic Zone started on the fertile, well drained soils and most crops are grown on this soil. Part of the unfertile and badly drained soils are still under forest. Forest was, as could be expected, the common land cover found in the protected areas. The forest reserve however has been partly deforested. Infrastructure has influenced land use in the past. Nowadays a correlation can be found between road density, parcel sizes and intensity of the land use.
Land use of 1984 and 1992 was compared and changes were described. Between 1984 and 1992 areas of natural vegetation (primary forest) decreased and are now used extensively, as pasture, banana plantation or for the growing of annuals. The area of annuals decreased. Most parts changed to pasture and banana plantation. The acreage of grassland almost doubled within 8 years at the expense of areas of (dispersed) agricultural penetration, annuals, mixed agriculture and natural forest. The area under plantation increased with 27350 ha, almost 250%. For this development the expansion of banana plantations is responsible. Areas of mixed agriculture (38%), pasture (14%), agricultural penetration (13%), abandoned area (11%), annuals (6%) and forest (3%) changed in banana plantation. From a pilot area land use from 1952 till 1992 was studied with the help of aerial photos and overlay procedures. Some land use sequences could be derived. At this moment pastures and banana plantation are dominant land uses.

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1 Introduction of the research and of the Atlantic Zone

1.1 General background of the Atlantic Zone Programme

The Atlantic Zone Programme (APZ) aims at the development of a methodology for the analysis and planning of land use. The methodology should generate alternative land use scenarios and evaluate them in terms of e.g. production and sustainability. It is based on crop growth simulation models, linear programming models and a geographical information system. The Atlantic Zone in Costa Rica for which this methodology is developed, is characterized by rapid land use changes. During the last 50 years, a large part has been deforested and colonised (Wielemaker and Vogel, 1993).

1.2 Problem definition

Land use is obviously influenced by environmental factors such as soil, climate, topography and vegetation. It also reflects the importance of land as a key and finite resource for most human activities. Control over land and its use is often an object of intense human interactions. Human activities are considered to be the proximate source of land use (change). These actions are structured by "underlying driving forces" such as property rights, structures of power, population density, agricultural pricing policies, technology etc (IGBP, 1993). Among them most obvious are population growth and concomitant growth in demand for land use products (Fresco, 1993).

Land use planning is becoming more and more important as the world population is growing and thus pressure on land increases. Failures in the past (and present) have shown that one cannot exploit the land continuously without the risk of overexploitation and soil degradation. Also environmental changes, which may be influenced by land use and which are influencing land use, emphasize the need for land use planning.
While most land cover changes are undertaken at the spatial scale of a field or a homestead, these discrete changes have attained global (or regional) significance because they are repeated frequently. In this sense, local changes in land cover reach a global (or regional) dimension by patchwork addition.
Understanding of past changes in land use and projecting future land use trajections requires understanding of the interactions of the basic human forces that motivate production and consumption (IGBP, 1993).

This study has been carried out to get an understanding in the dynamics of land use. Aiming at future land use planning, which is the goal of the APZ, knowledge of past and future land use is indispensable. In addition, one must try to understand the land use changes of the past: what are the main driving factors of land use change and which sequences in place and time can be recognized.
The research described in this report has been carried out in a study area situated in the Atlantic Zone (figure 1).

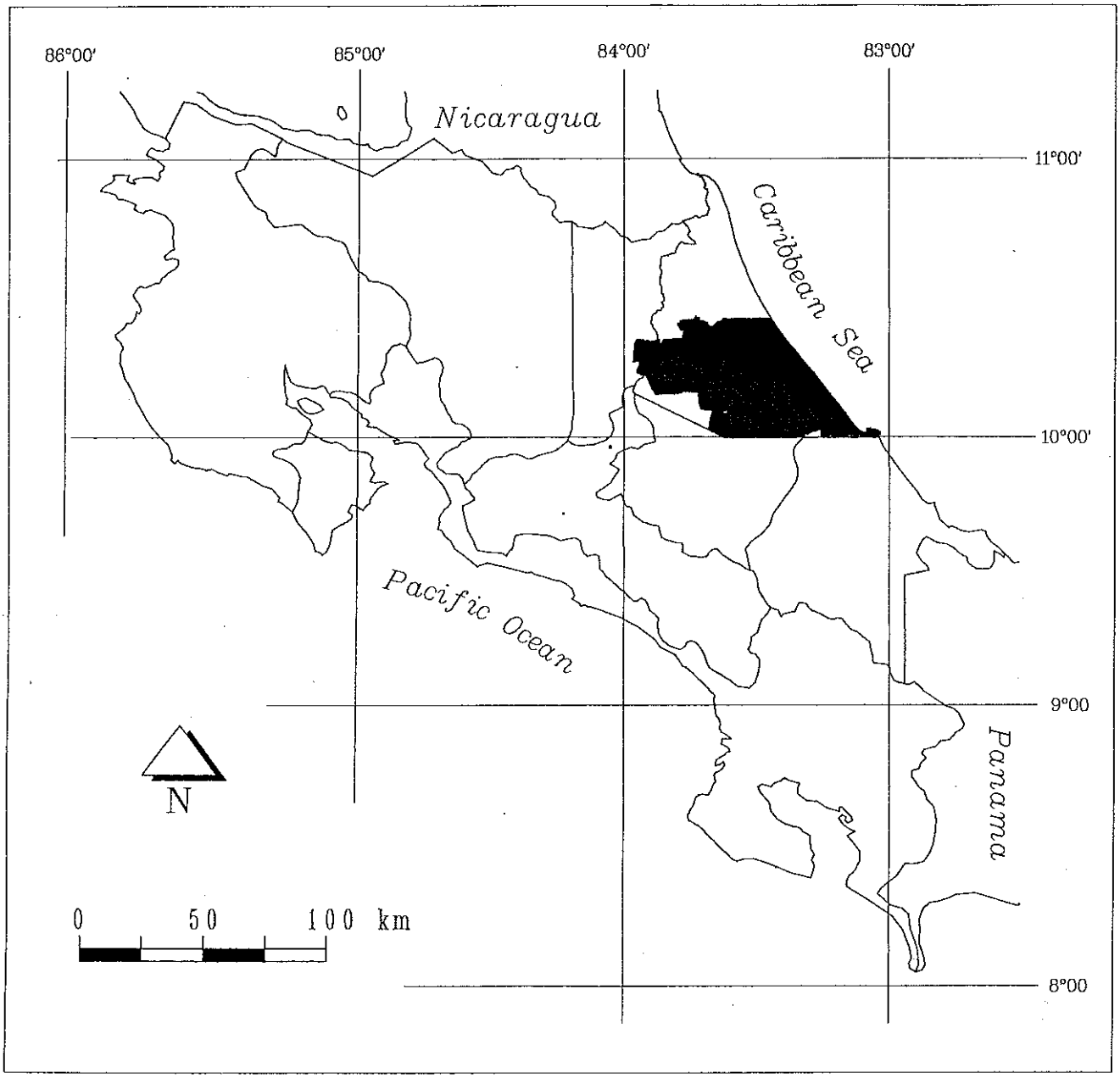

Figure 1: Costa Rica, and the study area, situated in the Atlantic Zone (in black).

Different objectives were distinguished:

1. Creation of a land use map of the study area by aerial photo interpretation.
2. Develop a concept which indicates the reliability of photo interpretation.
3. Investigation of possible relations between land use and some factors.
4. Investigation of land use dynamics for the study area (281661 ha, 1984-1992) and for a pilot area within the study area (13215 ha, 1948-1992).

1.3 Description of the Atlantic Zone

1.3.1 Physical description

The northern Atlantic Zone of Costa Rica is situated in the north-east of the country. It covers the cantons Siquirres, Guácimo and Pococi and part of Limón and Matina, which all lie in the Limón province or planning zone Huetar Atlántica.

The climate is characterized by abundant rainfall during the whole year, (3000-6000 mm/y) and high temperatures with an annual average of 26 °C (Hermsen,1989 in Paap, 1993). As a consequence the relative humidity is high with an average of 87% (Catie,1990 in Paap,1993).
February, March and April are relatively dry and therefore called summer months. During these months dry spells of days or weeks may occur. During the rainy season a daily rhythm of dry mornings and wet afternoons occur.

Soils in the area are from volcanic origin and predominantly classified as Andosols and Inceptisols. Their fertility status depends largely on the age of soil formation. The volcano slopes are dominated by mudflows (lahar) and soils are often unfertile. On the alluvial fan, near present or past riverflows young deposits can be found which may be (extremely) stony. The alluvial plain is dominated by well to poorly drained fertile soils. In the coastal area extensive swamps are found.
The most important soil constraints for agriculture are bad drainage, a low pH and (consequently) aluminum toxicity (Waaijenberg, 1986).

1.3.2 Land use

Due to the hot and wet climate crop growth is possible throughout the year. As a consequence also weeds, pests and diseases thrive throughout the year; crops have problems during flowering and ripening, many areas are insufficiently drained and agricultural activities are hindered by the rainfall (Waaijenberg 1986).
Crops are produced both at plantations and on (small) farms. Farm sizes are shown in table 1.1.

Table 1.1: Farm size distribution in Huetar Atlántica

farm size	% of total farms	% of total farm area
< 10 ha	43.2	5.8
> 10 and < 50 ha	44.0	27.2
> 50 and < 200 ha	9.9	27.1
> 200 ha	2.7	39.7

Source: Mideplan, 1991

The Atlantic Zone is Costa Rica's most important banana production area. Consequently many banana plantations are found. Other plantation crops are palmheart, ornamental plants, fruit trees and macadamia.
Crops produced by medium and small scale farmers are:

- Annuals: roots and tubers: cassava, ñame, tiquisque (Xanthosoma sagittifolium), melanga (Colocasia esculenta), chamol, yampi; other annuals like: beans, chili, maize, pineapple.
- Perennials: fruit like soursop (Annona muricata), papaya, plantain, lemon, oranges, maracuya, coconut; coffee and cacao .

It must be realized that not all crops are grown throughout the whole Atlantic Zone, but that most are restricted to specific regions.

Cattle farming is an important activity and aims at meat production, milk production or both. Meat production is by far the most important cattle activity. It is an extensive activity in terms of land and labour. In most cases dairy farming is operated by large scale farmers.

1.3.3 History of the Atlantic Zone

Originally Costa Rica was covered for 99.8% with forest (Huising, 1993). Costa Rica's first president, Juan Mova Fernandez, outlined a policy in 1828 that favoured land colonization. Individuals who colonized a piece of land or who established transitable roads into the forest were rewarded with land and money (Gómez, 1973 in Jones, 1990). Agricultural settlement in Costa Rica started in the Central Valley and Nicoya with their fertile soils and a suitable climate for many crops (a.o. sugarcane, tobacco, coffee).
Compared to other parts of the country, the Atlantic Zone has been colonized only recently (Jones, 1990). Heavy rains hindered construction and maintenance of roads.
Enclosure of the Atlantic Zone started late in the 19th century by the construction of a harbour at Limon and of a railway (1872-1890) for the benefit of the coffee export. In this period also a start was made with the cultivation of bananas (Sluys et al, 1987).
The beginning of the 20th century showed a big boom in the banana production. In the 1930's, demand for coffee and bananas decreased due to the Depression and banana production was also severely hindered due to the "Panama disease". As the economic opportunities from export market diminished in the 1930's, the natural increase in population could no longer be absorbed into cash crop production, and jobless young farmers began pushing toward the frontier regions (Jones, 1990). At the end of the 50's new resistant banana-varieties were introduced and production increased again. In this period also immigration of many people from other parts of the country began. These people occupied new lands, bought farms or came to work at plantations. Pressure on the land increased and

large parts of forest were cut. (Huising, 1993)
During 1963-1973 the number of farms decreased while the average farm size increased. After 1973 the number of farms increased again due to the settlement activities of I.D.A. (see Section 4.2.1). During the seventies, in other parts of Costa Rica (e.g. Guanacaste) the forest had been cut and extensive cattle ranching did not give many opportunities for work and many people who did not have land or jobs moved to the Atlantic zone. Apart from Costarican settlers many people from Nicaragua came to the area in the last few years (Sluys et al 1992).
In 1980, 9.3% of the population of the Atlantic Zone lived in settlement schemes (which is 14% of the rural population) (de Vries, 1986).

In 1986 a new policy was introduced with the name: "Agricultura de Cambio", (agriculture in change). This policy stopped the subsidies on cereals and stimulated new crops like palmheart, pineapple, ornamental plants etc. To stimulate these products fiscal incentives were given to export-enterprises. However small farmers often have not changed their traditional products due to lack of technical assistance and lack of credit. (Monge Alfaro, 1993)

These days much of the original forest cover has been destroyed by wood extraction and by conversion into pasture and crop land. The next Section handles deforestation more specifically.

1.3.4 Documented deforestation in Costa Rica and the Atlantic Zone.

Investigation about deforestation (a common land use conversion) in Costa Rica has been carried out and described by different persons. Some results related to the study will be dealt with.
Harrison (1991) describes the relationship between population growth and deforestation in Costa Rica between 1950 and 1984. She states that government policies (1960-1970's) encouraged agriculture on steep slopes or poor soils. Later a forest conservation programme was developed. Harrison finds the following data for the frontier region, which includes the Atlantic Zone.

	1950	1984	
Forest cover	83%	29%	(% of total area)
Population	194,362 (people)	727,828	(number of people)
Farmland (including pasture)	6,437 (ha)	16,613	(ha)
Pasture	1,546 (ha)	8,148	(ha)

Deforestation is positively correlated with population growth and with the proportion of immigrants within the population. Forest loss is strongly correlated with the increase in ha of pasture (more than crops as a whole or than coffee, sugar or brush land). Also in already settled regions, often pasture increased at the expense of crops. Harrison calls this a demonstration of cattle promotion policies and she states that domestic beef markets may have played a considerable role in the cattle boom.
Veldkamp et al (1992) attempted to demonstrate relations between deforestation patterns and the physical environment or infrastructure. The study area lies in the Atlantic Zone of Costa Rica. Deforestation was studied with the help of aerial photographs from 1952-1984. They distinguish three deforestation periods:
Before 1960: Deforestation took place on a relatively limited scale influenced by local natural features like rivers.
1960-1972: Due to foundation of colonies and introduction of banana plantations deforestation rate increased.
1972-1984: Only a relatively small forest area was left. Forest islands decreased in size.

Deforestation in the first stage took place preferentially along the main rivers. Later the importance of rivers for the deforestation process decreased and roads became more important in terms of accessability. Banana plantations were mostly created on newly cleared areas between 1960 and 1972. However, secondary effects of the newly introduced banana plantations probably were more important for deforestation: many people searching for work were attracted and also an extended infrastructure was constructed. The search for agricultural land was one of the reasons for forest clearance, as is shown by preferential clearance on fertile soils. After 1981, relatively unfertile soils were also cleared, because hardly any fertile soils were left under forest.

Sader and Joyce (1988), investigated deforestation rates and trends in Costa Rica between 1940 and 1983. They found a strong relation between the overland transportation network and deforestation. In the proximity of roads and railroads almost no forest remained. Also a relation was found between deforestation and life zones. In Costa Rica, first the dry lifezone was deforested, secondly the tropical moist life zone and when the wet and premontane wet forest became accessible by expansion of the transportation network, also there deforestation started.

A third relation they describe is between deforestation and slope gradient. Highest rates of deforestation were found on the steeper (31-45%) slopes which were more accessible than the shallow (0-5%) slopes. Later deforestation also began on the shallow slopes.

2 Materials and methods

2.1 FOUR RESEARCH-OBJECTIVES AND THE WORK INVOLVED

In Chapter 1, four objectives related to this research were given. These objectives are more precisely described here.

1. Creation of an 1992 land use map based on aerial photo interpretation.
   It involves:
   -Development of a photo interpretation key based on land cover.
   -Photo interpretation with help of this key.
   -Fieldwork for validation of the photo interpretation.
   -Digitizing the result of photo interpretation.
2. Develop a concept for photo interpretation reliability. This concept should indicate the accuracy of the final land use map. It involves:
   -Indicating the secureness with which boundaries between mapping units could be drawn.
   -Validation of photo interpretation by scanning.
3. Investigation of land use in relation to some factors. It involves:
   -Giving an overview of land use in the study area.
   -Creation of overlays which combine information about land use and a certain factor.
   -Analysis of created overlays.
4. Investigation of land use dynamics for the study area (1984-1992) and a pilot area (1948-1992). It involves:
   -Creation of an overlay of land use 1984 and 1992 maps.
   -Analysis of created overlay.
   -Aerial photo interpretation and digitizing of photos from 1948-1992 for the pilot area.
   -Creation of overlays of land use maps.
   -Analysis of overlays.

2.2 PHOTO INTERPRETATION TO IDENTIFY LAND USE

2.2.1 Introduction

Photo interpretation may be defined as the identification of objects on aerial photographs and the determination of their significance (Avery, 1968). In the present study they are used for the identification of land cover and land use.
In many instances, it is entirely feasible to use single vertical photos for the recognition or classification of specific features. The disadvantage is that only two dimensions (length and width) can be perceived. This is the equivalent of using only one eye when looking. The third dimension is provided by stereoscopic photo viewing.
From a plane, flying at a certain altitude in level flight, overlapping aerial photographs are taken at

horizontal intervals of several thousand feet. When two successive prints are viewed through a stereoscope, each eye "occupies" one of the widely separated camera stations resulting in a three-dimensional view of the overlapping area.
Photographic flights are planned so that prints will overlap about 60 percent of their width in the line of the flight, and about 30 percent between flight strips (Avery, 1968).

The advantages of using aerial photography for mapping purposes are many. Aerial photographs can show the landscape in a three dimensional fashion and can provide the near-equivalent of field conditions. Aerial photographs often reveals details or give an overall view which cannot be seen on the ground, and may show spatial relationships which can be observed in the field only with great difficulty, or not at all (van Zuidam, 1985). Furthermore areas can be observed which are inaccessible. Aerial photographs partly replace fieldwork and therefore save time and expense. However fieldwork remains an important tool for obtaining the right information and for getting a good understanding of the land use - land cover relation.

Photo interpretation is based on recognition of land cover. Land cover is based on the pattern as seen by remote sensing and refers to the attributes of a part of the earth's land surface and immediate subsurface, including biota, soil, topography, surface and ground water, and human structures. Examples are: forest, savanna, grassland. Land use refers to biophysical activities manipulating or interfering with land cover it includes the management of the land. For example: on a aerial photo land covers refers to a forested area, land use could be hunting and gathering or commercial forestry or national park. Common land uses include grazing, forestry, mineral extraction and recreation (IGBP-IGN, 1993 and Young, 1993).

From the Instituto Geográfico Nacional (IGN), photos covering the central part of the Atlantic Zone were obtained. The panchromatic photos used for the present study were taken in February and March 1992, at an altitude of $\pm$33.000 feet, and with a scale of 1:60.000. Each photo sizes 22.5 by 22.5 cm, so each photo covers an area of 13.5 by 13.5 km. Appendix 1 shows the numbers of photos used for interpretation. The smallest useable delineated area[1] on a map is defined as 1cm^2[2]. Working with a final scale of 1:100,000, this means that 1 km^2 or 100 ha is the smallest delineated area within the map. However, the final map shows some delineated areas which are smaller than 100 ha.

The aim of this study is to analyze the land use and its dynamics on a regional scale. However, this scale is too large to identify each land use type separately. For example: cassava and maize cannot be delineated separately at a scale of 1:100,000 and therefore the concept of land use zones is used (see Huising, 1993). Benjamins and van Alphen (1993) define a land use zone as:"a bordered area characterised by a unique combination of vegetation types, landscape patterns and other objects with typical forms, sizes and shapes". A land use zone can consist of one homogeneous crop (e.g. plantations) or of an association of different crops (e.g. annuals, including cassava and maize).

[1] Every outlined area is defined as a delineated area. These areas are classified as a certain land use. Areas equally classified are defined as one mapping unit.

[2] The smallest area which can be shown as a delineated area thus depends on the mapping scale. At a scale of 1:100,000, rivers for example, were too small to be mapped.

2.2.2 Development of a photo interpretation key

Basically an aerial photograph presents a structure of grey or colour tones, which makes the recognition of elements possible. A good photo interpretation key links an observed photo pattern to a land cover or a land use. Such a key is indispensable as the study area is too big for very detailed field check.
With respect to land cover mapping aerial photo interpretation tends to distinguish areas with a minimal internal variation and a maximal external variation. This is based on aspects which can be characterized by variations in: (Buringh, 1960 in Mulders, 1986):
-texture
-tone
-structure
-shape and size
-site (geographical position) and spatial arrangement

Texture: The degree of coarseness or smoothness exhibited by photo images. Texture concerns features with sizes too small to be delineated as individual elements. Texture is depicted as repetitions of tonal changes, (e.g. forested area) and is directly correlated with photo scale (Mulders, 1986; van Zuidam, 1985).
Classes: smooth- slightly granular- moderately granular- granular.
Tone: The black and white range of a panchromatic photograph. Tonal differences within one photo are often indicative of differences in vegetation.
Classes: very light- light- medium- dark- very dark.
Structure: Describes the shape and arrangement (3-dimensionality) of features large enough to be considered as individual elements.
Shape and Size: Form or topographic expression and size as observed in a two-dimensional photo-image. This characteristic alone may serve to identify some man-made objects (e.g. the airport of a pesticide spraying company). Size, of course, is a function of the photographic scale. Both relative and absolute sizes are important.
Classes: parcelsize: small (<6 ha)- medium (6-20 ha)- big (20->200 ha).
Site and Arrangement: The spacial arrangement of a feature can be characteristic for a certain kind of land use. (e.g. homegardens around the houses). The geographical position can give some additional information, e.g. altitude, steepness. This can be an important clue in predicting the probability of encountering a particular vegetative association. (E.g. Macadamia is only grown at a certain altitude.)

Differences within one aerial photograph reflect differences between land covers. Each land cover has its specific characteristics shown by reflecting a certain amount of radiation in a certain direction. These differences in reflection habit are the basis for the interpretation key.
At first some photos were studied to obtain general knowledge of all the different types of land cover. These land covers were delineated and a first interpretation was given. This first interpretation was checked in the field. A general key could now be made and used for interpretation of all aerial photos. In the course of time this key was altered and refined to a more workable one. Normally description of an interpretation key is skipped and not defined as such, although one uses a kind of key based on experience during the interpretation. It may be advisable for repetition and as user information to write the interpretation criteria down.

Below the different classified land covers are described. Note that in some cases a name already refers to a land use. This has been done improving readability. (At the moment of cover description land use was not yet related to land cover.)

Forest

Texture	:	granular, cauliflower-like appearance
Tone	:	dark to very dark
Structure	:	recognizable height above the surface
Site	:	Often parts of (secondary) forest are situated along the borders of a river, or at steep slopes.

Extensive agriculture

Texture	:	Both smooth and granular
Tone	:	Alternating greytones: dark tones of parts of forest, medium tones of pastures.
Structure	:	Irregular: parts of forest alternate with parts of grassland.
Site	:	Often at steeper parts of a slope. This land cover often lies between large parts of dense forest and pastures.

Pastures

Texture	:	Smooth
Tone	:	Light to medium greytone
Structure	:	Variable. Some parts consist of parcels with a rectangular shape, arranged parallelly. Other parts consist of parcels with irregular forms, arranged randomly. The presence of trees (canopy) varies between 0%-30% (of total area).
Size	:	Parcel size can differ from small to big, or parcel size cannot be distinguished.

Annuals

Texture	:	Smooth
Tone	:	Light to very light
Structure	:	Parcels arranged randomly.
Size	:	Parcel sizes are small to medium

Mixed Agriculture

Texture	:	Smooth and granular
Tone	:	Light, medium and dark
Structure	:	Fields of pastures are bounded by perennials and annuals. In this way a typical land cover is formed: a patchwork quilt.

Perennials on small parcels, homegardens

Texture	:	Granular, like forest
Tone	:	Medium to dark, some lighter spots of present annuals
Structure	:	Parcels not recognized.
Site	:	This land cover often is found around the houses, or along roads.

Plantations

Some crops are grown on such a large area that a crop-specific land cover appears. These coverages are separate mapping units.

Plantations: banana

Texture	:	Moderately granular
Tone	:	In general the greytone is dark, although young plantations may have a light tone.
Structure	:	A banana plantation has a typical structure formed by its drainage system.

		The straight, white drainage canals divide the plantation into pieces of the same size. (Which are often rectangular)
Site	:	Banana plantations are found in the neighbourhood of main roads or the railway, necessary for the transport of the bananas.
shape\size	:	Big, rectangular surfaces
Plantations: Palmheart		
Texture	:	Slightly granular
Tone	:	Medium to dark grey
Structure	:	Sometimes within a plantation white, crooked lines can be seen (roads).
Size	:	Medium to big surfaces
Ornamental plants		
Texture	:	Smooth
Tone	:	Very dark and very light within one unit
Structure	:	The structure looks like the pattern of mixed agriculture: a patchwork quilt. However the fields are arranged parallelly and the fields are all rectangular. In this way a pattern which looks very neatly appears. The plantation is often divided in squares. Within these squares sometimes a fine network of lines can be recognized. Plantings of ornamental crops sometimes are grown under black nets which are used for protection against the sun irradiance. This influences the observed pattern.
Size	:	Medium surfaces
Plantations: Bamboo		
Texture	:	Slightly granular
Tone	:	Medium to dark grey
Site	:	Often found at the borders of a banana plantation
Plantations: Coffee		
Texture	:	Granular
Tone	:	Dark grey
Structure	:	Parcels and\or rows of shrubs are recognizable.
Site	:	Crop found at higher altitudes.
Fruit and Macadamia trees		
Tone	:	Medium to dark grey.
Structure	:	A grid with spots at fixed distances.
Size	:	Medium and big surfaces.
Urban areas		
Texture	:	Smooth
Tone	:	Very light
Structure	:	Separate houses or streets visible

2.2.3 The final legend

By using the interpretation key of Section 2.2.2. the available photos were interpreted. A legend based on land cover and field pattern was made. For explanation of the legend structure one is referred to appendix 5.
The following legend has been used:

Forest	
- primary virgin forest	**Fp**
- primary overlogged and secondary forest	**Fs**
Extensive agriculture [3]	
- 50%-95% forest[4], 5-50% pasture	**C1**
- 20%-50% forest, 50-80% pasture	**C2**
Pastures	
- parcels < 15 ha, irregular shape, many trees	**P1a**
- parcels < 15 ha, regular shape, some trees	**P1b**
- parcels > 15 ha, irregular shape, many trees	**P2a**
- parcels > 15 ha, regular shape, some trees	**P2b**
- parcels not yet made or not recognized rather recently deforested (< 15 years)	**P3**
Perennials and trees	
- perennials and trees on small fields; homegardens	**Th**
- perennials and trees on small fields; agglomeration of fields, mixed perennials	**Tx**
Plantations	
- banana	**JB**
- palmheart	**JP**
- macadamia	**JM**
- ornamental plants	**JO**
- fruittrees	**JF**
- bamboo	**Joo**
- coffee	**JC**
Annuals	
- > 70% annuals, parcels < 6 ha	**A1**
- > 70% annuals, parcels ± 6-20 ha	**A2**
Mixed Agriculture[5]	
- annuals and pastures, parcels ± 3 ha	**M11**
- annuals and pastures, parcels ± 8 ha	**M12**
- perennials, annuals and pastures, some woody area can be included, parcels ± 3 ha	**M21**
- perennials, annuals and pastures, some woody area can be included, parcels ± 8 ha	**M22**
Built on land	
- urban areas and plants	**Bu**
Waste land	
- swamp	**Ws**
- shrub formation and barren land	**Wt**

The mapping unit for annuals, often contains perennials for the remaining <30%. Some mapping

[3] In fact this mapping unit is an association of two land use types: forest and pasture.

[4] Percentages of forest cover are based on the observed crown cover.

[5] Mixed agriculture here indicates farms having pasture and crops, and also a cluster of farms either having pasture or crops. Mentioned parcelsize is the average size.

units can be clustered to one mapping unit to get a better general view of land cover, see for example figure 6. Sometimes it is useful to work with the more detailed legend. It gives information about field sizes and differentiates between plantation types. Clustering is possible for Fs-Fp, C1-C2, P1-P2-P3, Tx-Th, JC-JB-JP-JO-Joo-JM-JF, A1-A2, M21-M22-M11-M12, Bu-Ws-Wt.

2.2.4 Validation of interpretation key; field check

During photo interpretation field checks were carried out. These were meant to validate the developed key and also were nesecary to provide additional information about land use in part of the area. Field checks were always carried out with a field assistant. A certain area was checked by comparing the photo interpretation with field observations while walking or driving through this area. Difficulties arose because of the gap in time between the moment of field check (july - september 1993) and the moment of photo taking (march 1992). At some places land cover had changed during these 1.5 years. For example pasture had changed into a young banana plantation or annuals were changed in pasture. By asking local farmers about the former land use of an area the right information (land use of 1992) could be obtained. Also other people informed about land use in certain areas which was valuable especially in remote areas. No information from other maps was used during photo interpretation. After some photo interpretations and field checks a general overview of land use in the Atlantic Zone was present and the key was changed somewhat into a more workable one.
In general the key functioned well and interpretation based on this key could be carried out. However at some places additional field information remained necessary.

2.2.5 Boundaries between mapping units: criteria and problems

During photo interpretation decisions about where to draw a boundary had to be made. As it can be difficult to differentiate between land covers, criteria for drawing a boundary had to be made explicitly. The next paragraphs deal with examples of different "boundary-problems" and the criteria used to separate different mapping units.

Forest, (primary virgin - overlogged, secondary) **Fp, Fs**
Based on photo characteristics like tone, structure, texture, it is almost impossible to distinguish between primary virgin forest and primary overlogged /secondary forest. The delineation is based on the assumption that small parts of forest surrounded by other land use are overlogged or secondary forest and that large parts of continuous forest are primary virgin forest. A study about deforestation in the Amazon by Skole and Tucker (1993) shows that logging into the forest takes places around the borders of deforested parts. This intrusion wood can be found 1 km into the forest, around the boundaries of deforested parts.

Secondary forest **Fs** -Homegardens **Th**
Contrast between Fs and Th sometimes is nihil. Assumed is that when a Fs or Th-like pattern is seen around the houses this will be a homegarden.

Extensive agriculture **C1, C2** - forest **F** -pasture **P**
Difference between C1 and C2 is defined by the percentage forest within the mapping unit ($>50\%$ or $<50\%$).
The difference between C and F is indicated by the appearance of pasture. When parts of pasture (which are too small to be delineated separately) are present within the forest ($>5\%$), the delineated

area is defined as C.
The delineation between C and P is not easy, no percentage of tree cover can be used. However a texture difference is present: C contain forest while P may contain trees, C is found close to the primary forest. P-units are pastures which are more or less intensively used. C are pastures used extensively on which tree logging and land speculation are important activities.

Pastures **P1, P2, P3**
Difference between pastures are based on parcel size. Normally living fences are used to border fields. In contrast to barbed wire, these living fences can be clearly recognized on the aerial photographs. No fences (indicating parcels) were visible for P3. Often these areas are recently deforested, still lacking living fences. P3 may contain very large parcels used rather extensively. However, sometimes during field checks it became clear that within these big parcels also borders existed. Big cattle farms are found within this unit.
P-b: In general b units are more intensively used pastures. On the aerial photos these units look neatly: parcels have regular shapes and not too much trees in the field.
P-a is characterized by variation in height of the grass vegetation and sometimes the grasslands are invaded by shrubs. Always many trees are present.
Pastures are almost always easily distinguished from annuals and perennials; annuals have a lighter tone, perennials have more texture and often a darker tone.
Mapunits often exist of both parcel sizes: >15 ha and $<$ 15 ha. A mapping unit is defined by the class covering more than 50% of the area.

Homegardens **Th** -Perennials on small fields **Tx** -Annuals **A**
These units partly overlap because homegardens often consist of perennials (fruittrees) and annuals. Typical for homegardens is that parcels are very small and cannot be recognized separately on the aerial photos.

Swamps, shrub formation, barren land and pastures **Ws, Wt, P1**
Distinction of these classes is very difficult. Pastures sometimes consist of long grasses which appear as swamps or waste lands on a photo. However areas of swamp are relatively small. Areas of waste land, sometimes are grazed (depending of the height of the bush), so a clear demarcation of Wt, Ws and P1 cannot be made.

2.2.6 Discussion

During photo interpretation the following problems arose:

Greytone:
-The greytone of an equal feature differed considerable between photos. Some photos are printed darker than others. However interpretation based on the relative greytone (greytone compared to the greytone of other features on one photo) still was possible.
-The greytone may be influenced by the position of the sun in relation to camera position. (angle between plane and field.) Reflection can be more or less (and consequently the greytone can be lighter or darker) due to a certain angle, making interpretation more complicated.
-Clouds on one photo make a three-dimensional view impossible.
-Clouds on both photos make interpretation impossible. Clouds only were present on the northern photos and only covered a small area.

Mapping decisions:
-Sometimes fruittrees are found in a pasture. Strictly taken, this is a form of mixed land use. However land use is classified as pasture in these cases.

Fieldsize:
-Mapping of fieldsizes gave some problems; fieldsize can differ from field to field. The classification of a delineated area always indicates the most common fieldsize. Some general rules can be given: the fields around the houses are small and all kinds of crops are grown; farther onwards bigger fields are found: pastures or plantations or some fields with annuals/perennials.
-Recent deforested areas conversed to pastures, do not show an indication of fieldsize (living fences are not yet present or still very small). These pastures are indicated as P3 and further fieldsize indication fails.

2.3 FROM PHOTO TO MAP; DIGITIZING AND CORRECTION

This section describes the process of creating the 1992 land use map using the interpreted aerial photographs. The map is stored in a Geographic Information System (GIS), where also other maps related to the Atlantic Zone are stored. A GIS enables analysis and reproduction of the map.
All procedures described beneath were carried out in the GIS-programme ARC/INFO. For more detailed information about the described procedures, and for defenition of terms, see appendix 6.

As the sequential photos are taken with a certain overlap not all photos needed to be interpreted separately. At the end of the photo interpretation 32 sheets covering 32 photos were available to be digitized. Appendix 2 gives the numbers of the digitized photos. These photos were digitized separately using the ARC DIGITIZE SYSTEM (ADS). In this way, all geographical information drawn on the photo was transformed to geographical information available within the GIS. To each digitized photograph 4 TIC POINTS had to be given. Tic points are topographic reference points. By using these tic points a connection can be made towards a general coordinate system. Tic points have to be points which can be identified in an already existing coordinate system.
To transform the digitized maps to a topographic base, the tic points had to be digitized on an existing topographic base. A backcoverage of rivers was also given and made it easier to find the exact places of the tic points.
Three digitized photographs did not fit within the boundaries of the topographic base map and therefore were not used in further analysis.

The digitized photographs had to be transformed to the topographic base map. Two transform methods exist: affined and projective. The projective method was chosen because it gave the best result. After the transformation the result was seen in ARCPLOT. Some photos were turned somewhat in a wrong direction. For these photos the other transformation possibility was used: affined. The transformed photos had to be combined to form one map. For combining photos a lot of options exist. Chosen was the option update. Update creates a new coverage by overlaying two sets of features. After the update command a dissolve command was given to erase all arcs separating polygons with same labels (same mapping unit).
At random 50 points were plotted on both the updated map as well as on the digitized photos. The mean deviation indicates the secureness of the updating process and was 31 metres. At a final scale of 1:100,000 this deviation is acceptable.
Using the command eliminate, small polygons (area $<$ 6 ha) without a label were merged into adjacent polygons.

Calculations for analysis of the land use map were quickened by simplifying the topology of the map. The command generalize was given which weeds vertices within coverage arcs. Vertices smaller than 15 m were erased.
The last command before the analysis could start was the CLIP-command. The already existing land use map of 1984 and the 1992 map were cut resulting in two maps covering exactly the same area.

2.4 CREATION OF OVERLAYS FOR ANALYSIS

Land use maps of 1984 and 1992 are now available in GIS. For analysis it is possible to create overlays. In a polygon overlay, features from two map coverages are geometrically intersected to produce a new set of features. Characteristics (map attributes) of the new coverage are derived from both the original coverages. Data, e.g. surface areas of polygons (see appendix 6 for definition), is listed in tables. By calculation interesting data can be gathered from this tables. For example: an overlay of land use 1984 and 1992 was made. In one table data about land use in 1992, in 1984 and the surface area from each polygon could be found. In appendix 4 all created overlays are listed.

3 An indication of reliability of photo interpretation

3.1 SECURENESS OF BOUNDARIES BETWEEN MAPPING UNITS

Not all boundaries between legend units can be drawn with the same exactness. Between some mapping units a clear boundary does not exist and thus cannot be drawn (see also Section 2.2.5.). In some cases a boundary also could have been drawn a km farther on. To indicate the exactness for all possible boundaries a table was made (see table 3.1 and figure 2). Four classes were used to indicate the exactness with which a boundary could be drawn. These classes are defined by the author and only give a qualitative indication. The four classes are:

1 Very clear
2 Clear but sometimes doubt
3 Often doubtful
4 Hardly possible to draw a line

Table 3.1: Boundary reliabilities

	FP	FS	C1	C2	P1A	P1B	P2A	P2B	P3	Th	Tx	JB	JP	JM	JO	JF	Joo	JC	A1	A2	M11	M12	M21	M22	Bu	WS
FS	4																									
C1	3	3																								
C2	2	2	2																							
P1A	1	2	1	2																						
P1B	1	1	1	1	2																					
P2A	1	1	1	1	3	2																				
P2B	1	1	1	1	1	3	2																			
P3	1	1	1	2	2	2	2	2																		
Th	1	2	1	1	1	1	1	1	1																	
Tx	1	2	1	1	1	1	1	1	1	3																
JB	1	1	1	1	1	1	1	1	1	1	1															
JP	1	1	1	1	2	1	1	1	1	1	1	1														
JM	1	1	1	1	1	1	1	1	1	1	1	1	1													
JO	1	1	1	1	1	1	1	1	1	1	1	1	1	1												
JF	1	2	1	1	1	1	1	1	1	1	1	1	1	3	1											
Joo	1	2	1	1	1	1	1	1	1	1	1	2	2	1	1	1										
JC	1	2	1	1	1	1	1	1	1	2	1	1	1	2	1	1	1									
A1	1	1	1	1	2	2	2	2	1	1	1	1	1	1	2	1	1	1								
A2	1	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	3							
M11	1	1	1	1	2	2	2	2	1	3	2	1	1	1	2	1	1	1	2	2						
M12	1	1	1	1	2	2	2	2	1	2	2	1	1	1	1	1	1	1	2	2	2					
M21	1	1	1	1	2	2	2	2	2	2	2	1	1	1	1	1	1	1	2	2	2	2				
M22	1	1	1	1	2	2	2	2	2	2	2	1	1	1	1	1	1	1	2	2	2	2	2			
Bu	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
WS	1	1	1	2	3	2	3	2	2	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	
WT	1	3	1	2	3	2	3	2	2	2	3	1	3	1	1	1	1	1	2	2	1	1	2	2	1	3

Figure 2 shows the same information as table 3.1. Difficulties in determining boundaries especially occur in the southern region (presence of steep slopes) and in the coast region (presence of swamps). Figure 6 , the land use map for 1992, shows the same boundaries between mapping units as figure 2.

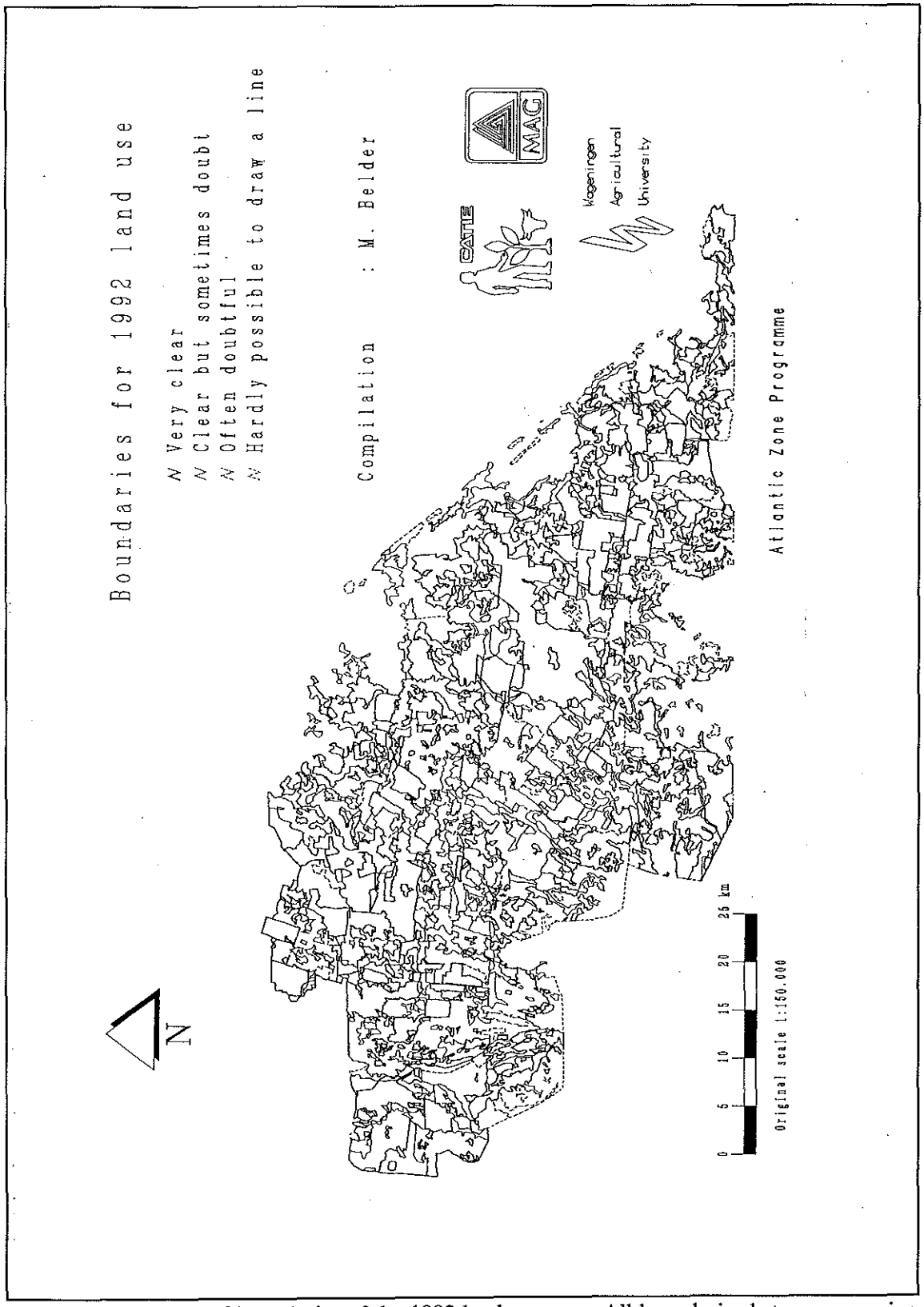

Figure 2: Exactness of boundaries of the 1992 land use map. All boundaries between mapping units are drawn with an indication of its exactness.

3.2 SCANNING OF MAPPING UNITS

3.2.1 Introduction

Some problems arise when results of aerial photo interpretation are presented, as the reliability of these results can hardly be determined and expressed. Indicators for the quality of photo interpretations are necessary to evaluate the accurateness of the study. In Section 3.1 an attempt was already made to indicate the reliability of the boundaries of the mapping units. In this present study it is tried to use scanning for the identification of differences between mapping units.
A mapping unit may, among others, be identified by a specific grey tone pattern. Scan-diagrams, showing the grey tone along a transect on the photo, may indicate whether differences in grey patterns between mapping units exist and in addition, they help to describe these differences. If clear differences exist, one can draw the conclusion that the classification of mapping units does not present many problems.

3.2.2 Method

Scanning is a method of recording graphic information in digital form. From square parcels of land, called pixels the reflectance indicating a greytone or colour is measured. The scanner assigns a number to the reflectance of each square and this information is displayed as an array of numbers called the digital image file (Pazner et al, 1993).
For most mapping units delineated areas were selected on the aerial photographs and scanned. Scanning was performed with two different levels of contrast. The size of the pixels was 0.25 mm x 0.5 mm, where the short site was taken in the direction of maximal variability.
The grey value of the pixels was plotted against the distance and was expressed in relative brightness between 0 to 20. The average brightness can not be considered to differentiate between two mapping units as the darkness of a photo is not uniform.

3.2.3 Results and discussion

The different patterns obtained by scanning were analyzed. For some mapping units these diagrams showed additional information which could not be seen by stereoscopic viewing. Some diagrams enforced the already existing pattern description (Section 2.2.2) and some diagrams did not show any useful information.
Below some examples are given.

Additional information:
Although according to table 3.1 the boundary between primary virgin forest and primary overlogged forest could hardly be drawn in fact some differences can be observed when viewing the scan results. (see figure 3)
-Primary virgin forest: A very regular pattern with peaks to both sides. These peaks (darker and lighter spots) are the result of internal reflection and of large trees which crowns rise above the other trees.
-Primary overlogged forest: The pattern is less regular compared to virgin forest, more peaks are present, which may be the result of gaps in the forest created by cutting trees.

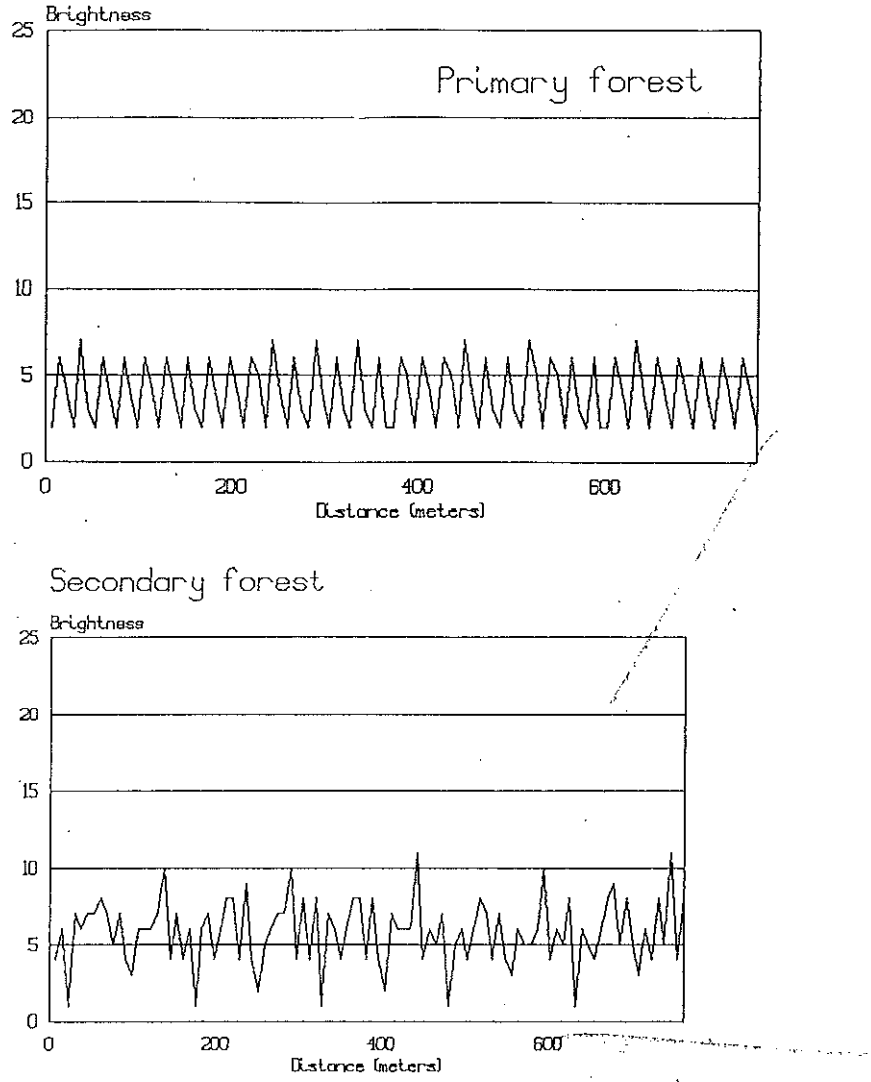

Figure 3: Scan diagrams of the mapping units Fp (primary virgin forest) and Fs (primary overlogged or secondary forest).

Confirmation of existing pattern descriptions:

Some scan diagrams show a pattern which confirms the observations from photo interpretation. Examples are, (see figure 4):

-Extensive agriculture, 50-95% forest (C1), alternating parts of higher and lower brightness are observed. These different parts indicate the different land covers: forest and pasture.

-Banana plantation (JB), a regular pattern of small peaks with low brightness alternated with sharp, big peaks of high brightness which indicate drainage canals in between the banana plants.

-Ornamental plant plantation (JO), a pattern of sharp peaks with low and high brightness indicating the parcels of different ornamental plants.

-Mixed agriculture, parcels 3 ha (M21), a pattern consisting of different parts, which indicate the different land covers.

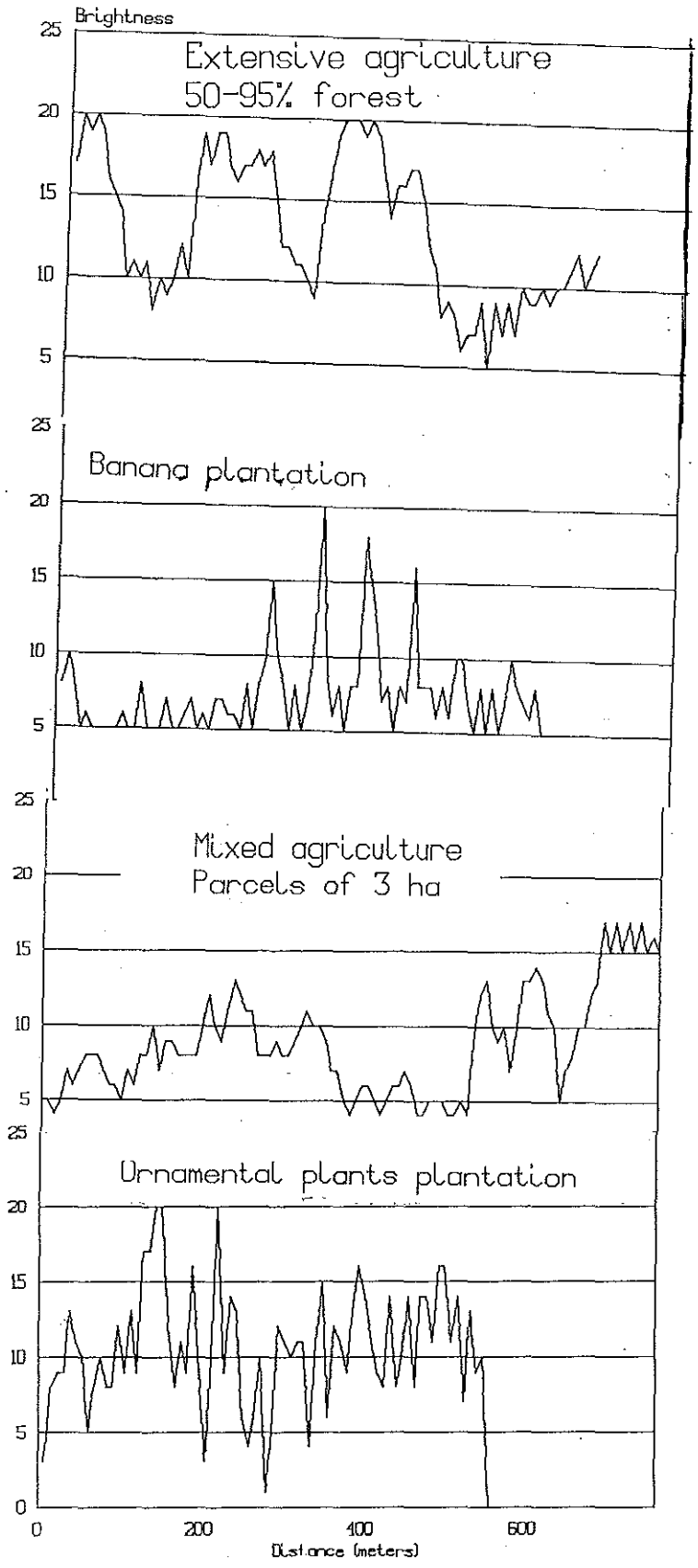

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Figure 4: Scan diagrams of the mapping units: Extensive Agriculture (C1), Banana plantation (JB), Ornamental plant plantation (JO), and Mixed Agriculture (M21).

No useful diagrams:
Some diagrams were not useful at all. An example:
-Pastures, parcels < 15 ha, many trees (P1a), an irregular pattern.

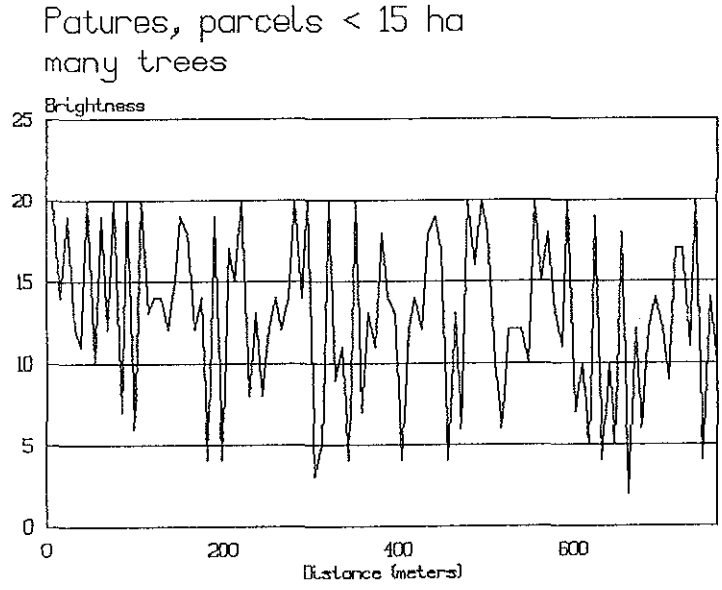

Figure 5: Scan diagram of the mapping unit P1a.

3.2.4 Conclusions

Some boundaries which are difficult to draw on "eye-basis" can be drawn with more security on "scan-basis" (Fp-Fs). However it must be realized that full automatic scanning is still very difficult. It needs a complex expert system for the classification and lacks additional advantages of stereoscopic viewing. Also spacial information (structure, site) of a feature, obtained by stereoscopic viewing is important for classifying (Section 2.2.2). Scanning can be a tool in solving difficulties in aerial photo interpretation but it cannot replace the advantages of stereoscopic viewing.

4 Analysis and Results

4.1 LAND USE IN 1992

The land use map 1992 is shown in figure 6 and its results are listed in table 4.1.

Table 4.1.: Land use 1992 in ha and as percentage of total study area.

CODE	LAND USE DESCRIPTION	HA	%
Fp	primary virgin forest	57404	20.4
Fs	primary overlogged forest and secondary forest	38641	13.7
C1	extensive agriculture, 50%-95% forest	3608	1.3
C2	extensive agriculture, 20%-50% forest	4578	1.6
P1a	pastures, parcels< 15 ha, many trees	14876	5.3
P1b	pastures, parcels< 15 ha, some trees	19818	7.0
P2a	pastures, parcels> 15 ha, many trees	9558	3.4
P2b	pastures, parcels> 15 ha, some trees	34733	12.3
P3	pastures on recent deforested areas	23544	8.6
Th	homegardens	1782	0.6
Tx	mixed perennials/trees, small fields	1595	0.6
JB	banana plantation	39711	14.1
JP	palmheart plantation	830	0.3
JM	macadamia plantation	2565	0.9
JF	fruittrees plantation	838	0.3
Joo	bamboo	1070	0.4
JO	ornamental plants plantation	1186	0.4
JC	coffee plantation	198	0.1
A1	> 70% annuals, average fieldsize 3 ha	1916	0.7
A2	> 70% annuals, fieldsize 6-20 ha	5529	2.0
M1	annuals and pastures mixed, fields 8 ha	577	0.2
M21	mixed agriculture, avg. fieldsize 3 ha	1611	0.6
M22	mixed agriculture, avg. fieldsize 8 ha	6929	2.5
Bu	urban areas	2331	0.8
Ws	swamps	390	0.1
Wt	waste/fallow land	5845	2.1
	Total study area	281661	100

Source: Author's data.

In the study area still a considerable amount of forest (34% of total area) is present. Part of this forest (23%) is found in protected areas (see 4.2.2). The total amount of forest may be overestimated due to misinterpretation of e.g. cacao . On the photos only a tree layer can be observed, thus cacao often is interpreted as forest. Also on steep slopes the amount of trees may be overestimated. The projection of tree crowns on a steep slope hides the possible present land use beneath these trees (e.g. pastures, homegardens).
In the deforested areas pastures play an important role. 36% of the total area is covered by pasture. Another large area is covered by banana plantations (14%) owned by big companies. Also some plantations of ornamental crops, palmheart or macadamia trees are found. Some small areas are dominated by annuals (2.7% of total area) often grown on small fields.

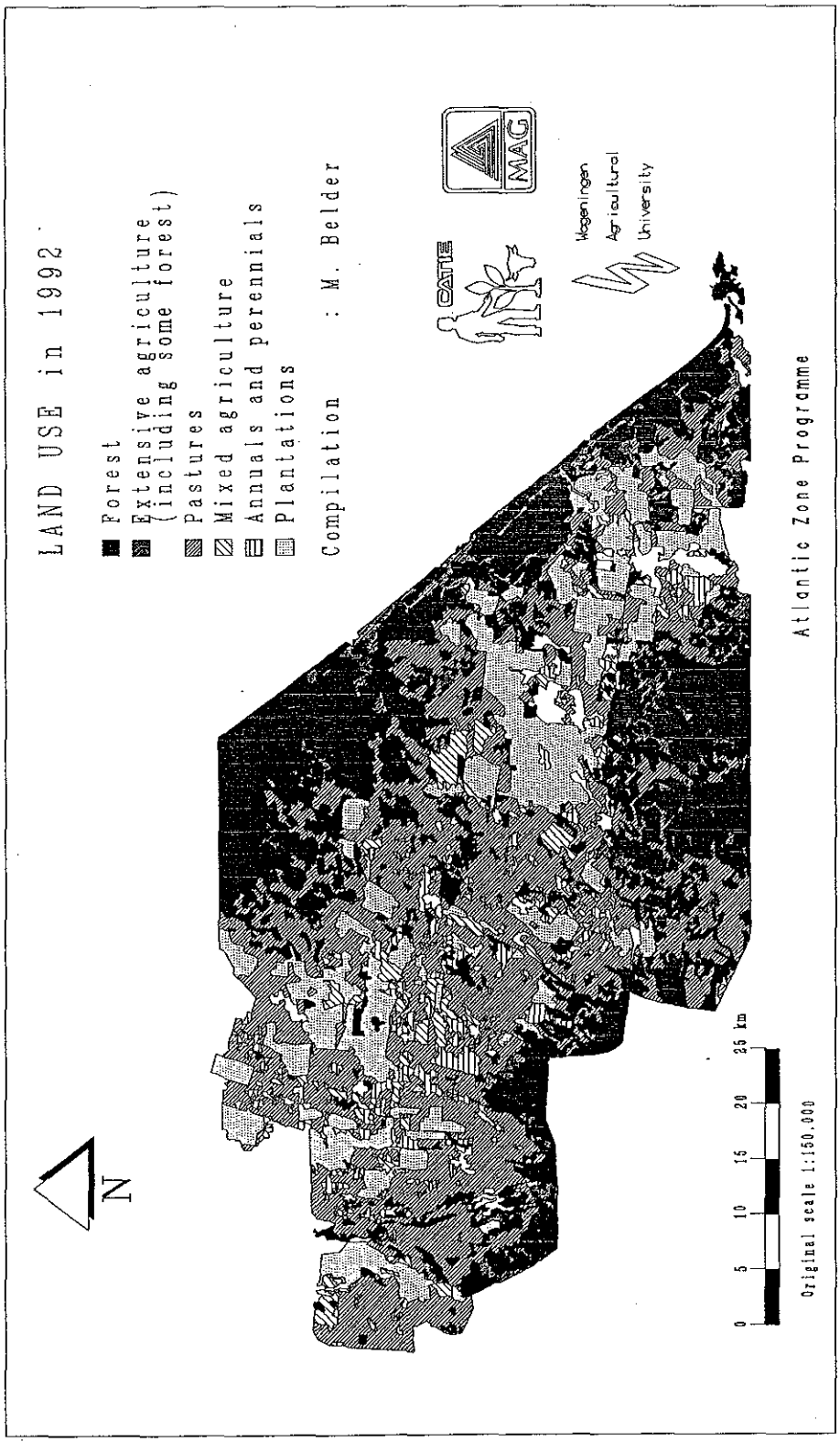

Figure 6: Land use in 1992 in the study area.

4.2 1992 LAND USE IN RELATION TO SETTLEMENTS SCHEMES, SOILS, INFRASTRUCTURE AND PROTECTION OF CERTAIN AREAS.

As has been stated before, land use is influenced by many factors. In this research some factors are chosen for analysis. These factors have been chosen because data was already available and analysis could be carried out within a short period. It is assumed that each of the factors; IDA-settlements (Section 4.2.1), protected areas (Section 4.2.2.), soil types (Section 4.2.3.) and infrastructure (Section 4.2.4.) are associated with land use. In the following Sections the possible relations are described.

4.2.1 Land use in relation with IDA-settlements

IDA stands for "Instituto de Desarollo Agraria" (institute for rural development) and deals with allocation of land. IDA buys land and distributes it under farmers for colonization. Such IDA-settlements have been founded from the early sixties (1963) until the mid eighties "with the purpose to attract migration from other regions and henceforth to create a regional labour force and a regional market" (de Vries, 1986). Only small areas of land were allocated to farmers thus in theory, only small farmers can be expected in the settlements.
The proportion of the farm area for crop production tends to increase with decreasing size of the farm (Waaijenberg in Huising 1993). For small farms the cultivation of arable crops is generally the most important activity in economic terms (Huising 1993). Consequently it is expected that relatively more annual crops will be found in the settlements than outside the settlements.
An overlay was made of the land use map with the settlement map. Table 4.2 shows land use in IDA-settlements and in the study area.

Table 4.2: Land use 1992 in IDA-settlements and in study area.
Indicated is a land use and the percentage of total area covered by it.

land use	%of area cultivated in the total study area	% of area cultivated in the settlements
primary + secondary forest	34.0	26.0
pasture, small fields	12.3	19.3
pastures (all types)	36.4	47.5
plantations (all types)	16.4	12.4
annuals (both fieldsizes)	2.6	4.9
homegardens	0.6	1.3

Source: Author's data

Forest:
Within the settlements less forest (%) is found compared to the whole study area. Some settlements (e.g. Neguev) have parts of forest but, in general land use on farms of 10-20 ha is dominated by annuals and perennials. However 26% of forested area still is a considerable amount, and somewhat unexpected perhaps in view of the fact that IDA has tried to stimulate small farm production.

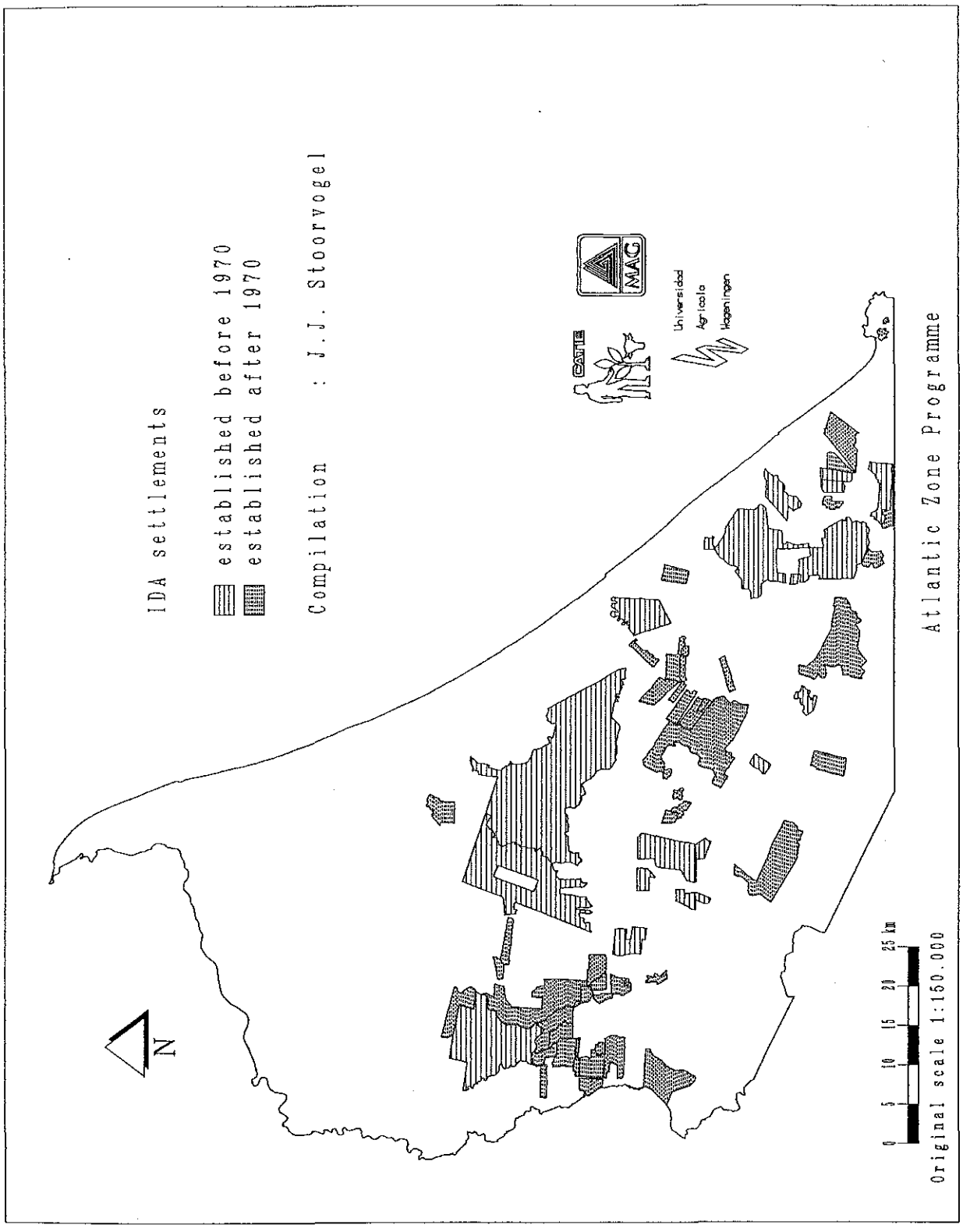

Figure 7: IDA settlements in the Atlantic Zone, established before and after 1970.

Pastures:
In general more pasture is found in the settlements and more specifically, more pasture on small fields is found within the settlements. Huising (1993) states that in case of grassland the size of the fields are related to farmsize. The size of the fields depend on the cattle size and thus is indicative of the farmsize. Thus considering the presence of many small farmers it seems logical that more small fields are found within the settlements than outside.

Plantations:
Less plantations are found in the settlements than outside, in terms of percentage of total area. However, because of small farm sizes, no plantations were expected. How is it possible that 12.4 % of the area is covered by plantations? An explanation is that old settlements (> 20 years) are no longer only occupied by small farmers but also by big enterprises. This argument is investigated farther onwards in this Section. Another explanation is that several small farmers rent their ground (as they are not allowed to sell) to companies for 50 years. In this way these companies get access to a considerable acreage at which they can run a plantation.

Annuals and homegardens:
Annuals are relatively important in the settlements. Of all annuals in the study area, 69% is found in the settlements covering 4.9% of the area. These figures confirm the statement that annuals are relatively more important for small farmers. From all homegardens, 61% is found in the settlements, covering 1% of the area. Homegardens often cover an area too small to be mapped. In the settlements however, a concentration of homegardens can be found which is big enough to be mapped. Outside IDA settlements homegardens are also present but often could not be mapped.

IDA settlements are in normal cases maintained and supervised for 20 years, whereafter people are the official owners and can sell.
At this moment some older settlements are no longer supervised by the IDA. It is investigated if land use in IDA settlements older than 21 years (found before 1970) differ from younger ones. It is assumed that more small farmers are present in the younger settlements than in the older ones because hiring and selling ground resulting in larger farms or plantations still remains restricted in the younger settlements. Data from IDA (of 1992) about the elderness of settlements has been used. Table 4.3 shows land use in settlements founded before and after 1970. For a more detailed table, one is referred to appendix 7.

Table 4.3: Land use in IDA-settlements founded before and after 1970. Land use is expressed in ha and in percentage of total area.

	IDA AFTER 1970		IDA BEFORE 1970	
	HA	%	HA	%
primary forest	4277	15.6	5811	10.1
secondary forest	4653	17.0	7790	13.5
extensive agriculture	440	1.6	804	1.4
pastures < 15ha trees	4334	15.8	5407	9.4
pastures < 15ha	1158	4.2	5537	9.6
pastures > 15ha trees	1403	5.1	3673	6.4
pastures > 15ha	3515	12.8	6747	11.7
pastures no parcels	2489	9.1	5377	9.3
perennials\trees	22	0.1	1739	3.0
banana plantation	1603	5.9	8049	14.0
other plantations	146	0.5	456	0.8
> 70% Annuals	1579	5.7	1562	4.4
urban areas	164	0.6	448	0.8
waste land	271	1.0	1195	2.1
Total area	27402		57776	

Source: Author's data

Plantations:
Almost all plantations are found in older settlements. The area covered by plantations is 14.7% in old settlements and 6.4% in newer ones. These figures confirm what was said above about mechanisms for hiring or selling land to plantation enterprises.

Forest, pastures with many trees:
In the older settlements less forest (23.4%) is present than in the younger ones (32.5%). Also less trees within pastures are found in older settlements. In young settlements 44.5% of all pastures are covered by many trees, in the older ones this is 34.0%. More forest / trees are found to be cut when the soil has been used longer. When colonization starts, a lot of forest is found on farms and farming starts by clearing (part of the) forest, but not all trees are cut at once. Step by step more trees/ parts of forest are removed. In the course of time, logs on the ground will be sawn for timber and standing trees in pastures will be cut one by one. Consequently, in younger settlements more forest and trees are found compared to older ones.

Annuals:
In younger settlements relatively more land is used for annuals. Again this confirms the relation between small farmers and the growing of annuals.

4.2.2 Land use 1992 in the protected areas

The protected areas in the northern part of the Atlantic Zone cover 152,086 ha of which 126,343 ha lie outside the study area.
An overlay of the protected areas with the land use (1992) was made and indicates the actual land use in the protected areas (see table 4.4)

Table 4.4: Land use in the protected areas
Total ha per type of protected area in the study area is given. Land use in each type of protected area is given in percentage of total ha.

	total area	percentage of total area classified as:				
	(ha)	forest (Fp, %)	forest (Fs, %)	ext. agr. (C, %)	pasture (P, %)	waste land (Nt, %)
-national park	7960	99	0	1	0	0
-forest reserve	14871	67	14	9	10	0
-indigenous reserve	2935	83	0	7	9	1
-border area	0	-	-	-	-	-

Source: Author's data.

The land cover in the protected areas mostly consist of primary virgin forest. Some parts were classified as, extensive agriculture, pasture or waste land. This may be logical land use in an indian reserve but not in a forest reserve where forest is protected against colonization. In fact, colonization does take place in this area. In contrast, the national park seems very well protected (99% of the area is covered with primary forest). 23% of all forest is found in the protected areas.

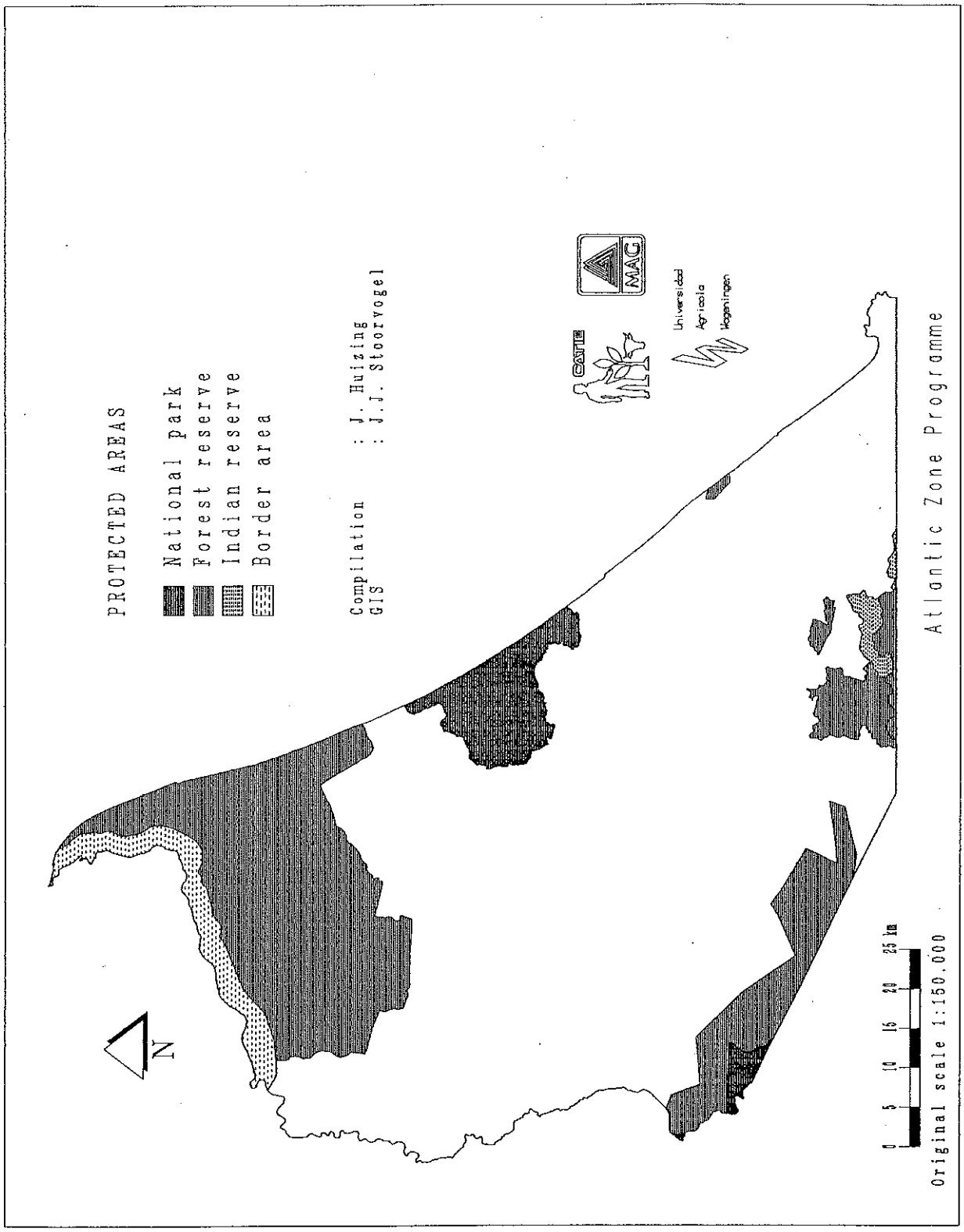

Figure 8: Protected areas in the Atlantic Zone.

4.2.3 Land use on different soil types

The soils in the Atlantic Zone have been described and clustered into three major soil types. Clustering was based on the soil properties fertility and drainage (Source: AZP, see a.o. Wielemaker, 1993). These soil types are:
Soil 1: fertile soils, well drained 136.483 ha in study area
Soil 2: fertile soils, badly drained 53.699 ha in study area
Soil 3: unfertile soils, well drained 51.937 ha in study area

It has been calculated which percentage of a certain soil type is covered by a certain land use. Table 4.5 indicates by which land use types a certain soil is covered. However in this table important land use types in the study area (e.g. pasture) rank high for all soil types. Table 4.6 indicates which soil is relatively (un)important for a certain land use. In appendix 7 these tables are presented with more detail (containing all original land use classes).

Table 4.5: Land use distribution on different soil types*. Indicated is the percentage of total area of a soil type covered by a land use class.

LAND USE	SOIL1	SOIL2	SOIL3
primary forest	6.8	45.8	34.3
secondary forest	3.7	10.1	18.4
extensive agriculture, 50%-95% trees	4.2	11.3	22.0
pastures, parcels< 15 ha, many trees	7.7	1.3	4.0
pastures, parcels< 15 ha, some trees	9.9	1.4	5.4
pastures, parcels> 15 ha, many trees	3.3	3.3	3.2
pastures, parcels> 15 ha, some trees	15.5	4.7	9.9
pastures, parcels no parcels recognized	5.7	8.7	13.1
banana plantation	17.1	15.1	1.1
other plantations	4.1	0.1	0.9
annuals and perennials	5.4	0.6	1.8
mixed agriculture	4.3	2.4	0.9
urban areas	1.1	0.6	0.7
swamps and waste land	3.1	1.4	0.0

Calculation: 100(ha land use)/(total ha's of soil type)
Source: author's data.

Table 4.6: Relative importance of the soil type for land use types*.
The total area of a certain land use is put 100%. This table indicates that for certain types of land use one type of soil is much more important than the other two. The weakness of this table is that relative small areas are overvalued (e.g. swamps). In these cases table 4.5 gives a better view.

LAND USE	SOIL1	SOIL2	SOIL3
primary forest	7.8	52.7	39.5
secondary forest	32.5	23.9	43.7
extensive agriculture	13.1	41.1	45.8
pastures recognizable parcels	52.7	15.0	32.3
pastures, no parcels recognized	20.6	31.7	47.8
homegardens, perennials\trees, small fields	70.8	9.7	19.4
banana plantation	51.5	45.3	3.2
other plantations	82.4	5.4	12.2
> 70% Annuals	65.5	8.8	25.7
mixed agriculture	56.8	32.6	10.6
urban areas	44.4	25.3	30.2
swamps	34.2	65.8	0.0
waste land	62.7	23.6	13.7

Calculation: 100(ha land use on a soil type)/(total ha of this land use).
Source: author's data.

These tables show the following:
-Only a small percentage of primary forest is found on fertile soils. On these soils initial colonization

of the Atlantic Zone started (Sluys et al ,1987). The first colonization areas were situated near the railway principally constructed for the transport of coffee from the Central Valley to the West. Large areas along the railway were handed to the United Fruit Company, thus starting the banana industry (Sluys et al, 1987). The railway was situated mainly on the fertile soils and consequently on these soils most forest is cleared for growing bananas and later also for growing other crops as well. The badly drained soils found in the north, and poor soils found in the south of the study area were remote from this railway and often have less favourable conditions (steep slopes, poor drainage). People could not reach these remote areas and could not grow crops at those steep slopes. Thus it is reasonable that almost all fertile soils were deforested in the course of time, while the other soils still are partly under forest.

-Secondary forest is found in considerable amounts on all the three soil types, mostly on unfertile soils, where other land use is difficult.

-In general the crops grown on plantations are found for a major part on the fertile, well drained soils. Very clear examples are palmheart plantations and plantations with ornamental plants. Exceptions are the banana plantations and the coffee plantations. Half of all banana plantations are found on fertile badly drained soils. The construction of drainage canals solved the problem of water excess, removing the constraint for using these soils for banana plantations. The other exception are the coffee plantations. In this research coffee plantations only covered 198 ha (0.07% of total investigated area). Consequently no reliable conclusions can be drawn.

-The badly drained soils are covered for 55% by forest, for 15% by banana plantations and pastures cover another 20%. This soil type is not suitable for more intensive land use without drainage applications.

-The unfertile soils are covered by forest for 53%, by pastures for 35%, by extensive agriculture for 5.5%, jointly covering 93.5% of all infertile soil.

-Most annuals, perennials and fruit-or macadamia trees are grown on the fertile, well drained soil (31.5% of total area of fertile, well drained soil).

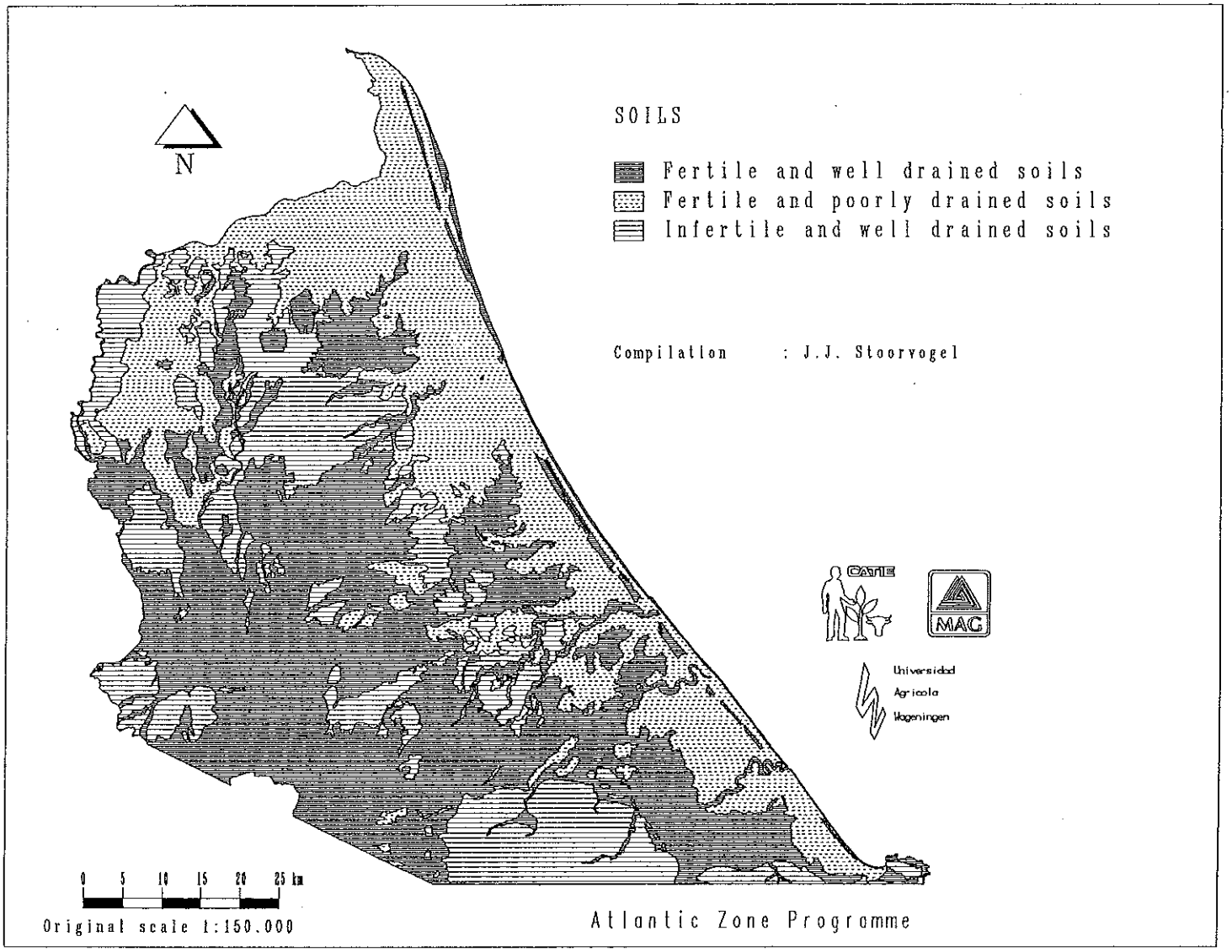

Figure 9 Distribution of soil types in the Atlantic Zone.

Note that the mapping units often consist of different soil types of which the biggest one has been chosen as a mapping unit. However, calculations have been carried out with all original data and not with the mapping units shown at this figure.

4.2.4 Land use and infrastructure

In ARC/INFO, a road map dating from 1984 is available. By using an overlay of this map with the land use map the total length of roads (metres) per land use (= mapping unit) could be calculated. Note that the road map dates from 1984. Between 1984 and 1992 new roads are constructed. A more reliable analysis can be done when the roads map of 1992 will have been produced. Table 4.7 shows the road density (metres per ha) ordered from high to low density. Also the total areas of land use (mapping unit) are given.

Table 4.7: Road density (m/ha) per land use (or mapping unit).

LAND USE	ROAD DENSITY (m/ha)	TOTAL AREA OF LAND USE (ha)
urban areas	46.75	2330.9
mixed agriculture, av. fieldsize 3ha	23.47	1611.5
coffee plantation	21.79	197.8
ornamental plants plantation	21.32	1186.3
> 70% annuals, av. fieldsize 3 ha	20.59	1916.1
perennials\trees on small fields	20.45	1594.8
bamboo	18.51	1070.4
palmheart plantation	18.50	829.9
homegardens, small fields	18.13	1781.8
macadamia plantation	16.53	2564.8
fruittrees plantation	15.20	838.4
> 70% annuals, fieldsize 6-20 ha	15.10	5528.8
mixed: annuals and pasture	14.42	577.1
mixed agriculture, av. fieldsize 8ha	13.97	6928.5
pastures, parcels< 15ha, many trees	12.83	14875.7
pastures, parcels> 15ha, many trees	12.72	9557.5
pastures, parcels< 15ha, some trees	12.42	19818.3
pastures, parcels> 15ha, some trees	11.46	34732.5
banana plantation	10.59	39711.0
pastures, parcels not made\recognized	10.23	23543.9
waste land	7.91	5844.7
extensive agriculture, 50%-95% trees	7.88	3607.7
secondary forest	5.36	38640.5
extensive agriculture, 20%-50% trees	4.45	4578.2
primary forest	2.27	57404.0
swamps	2.05	390.1

Source: Author's data.

The table shows that:
-Land uses which have two classes for fieldsize all show the same pattern: those with the smallest fieldsize show a higher road density than same land uses with bigger field sizes.
-The more extensive a land use type, the lower the road density.
-For banana plantations a higher road density was expected, as good export facilities are important and most of the time are actually present. Transport within the huge banana plantations is done along cables. Only one road is necessary to transport the bananas from the plantation to the main roads.
-As could be expected and also seems very logical, the urban areas outrank all other land uses in terms of linkages with the road density.

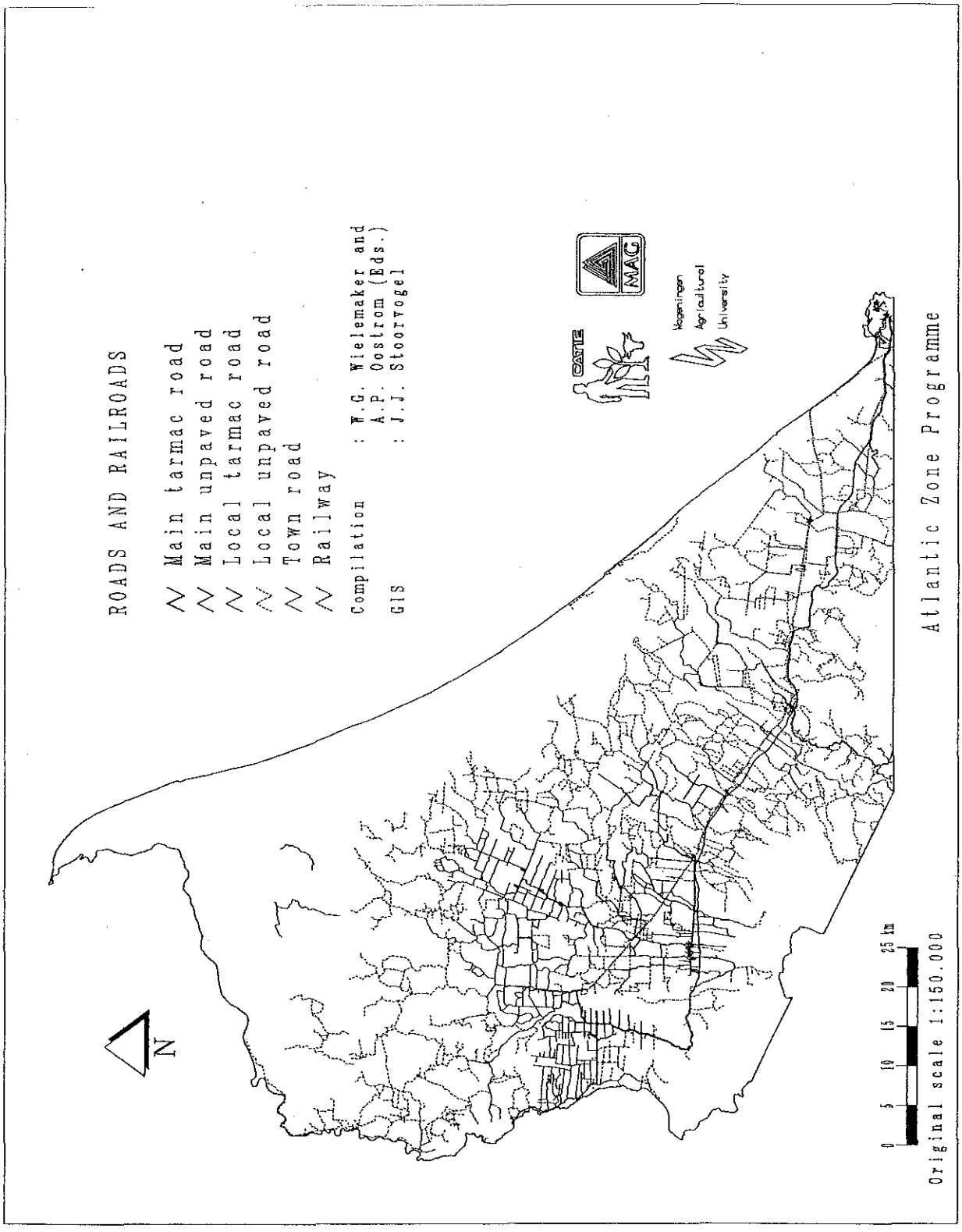

Figure 10 Roads and railroads in the Atlantic Zone, in 1984.

4.2.5 Conclusions

The presence of IDA settlement schemes influences land use. Many small farms can be found within these settlements. In general, small farms grow more annuals and less plantation area is found, compared to what was found for the whole study area. Also, field sizes in settlements are generally smaller. As has already been stated in Section 4.2.1, production of arable crops become more economical by decreasing farm sizes. These trends are more marked in the younger than in the older settlements. The process of deforestation and tree logging out of pastures is taking place in the course of time.

Policies influencing land use in an area by protection seem workable, at least for national parks. The national park still consist for 99% of primary virgin forest. However, the forest reserve has been partly deforested, and colonization seems to occur.

Soil fertility and drainage capacity certainly are correlated to land use. Most plantations are found on the fertile soils. Sections of the badly drained soils are not appropriate for other land use than forest. Most crops are restricted to the fertile, well drained soil, pastures are found on all soil types. Banana plantation companies often have sufficient capital to get access to the more fertile soils or to construct a good drainage system. The construction and presence of the railway directed the early colonization period on to the fertile soils.

A relation between land use and infrastructure is present. The general trend is that road density increases when fieldsizes become smaller and land is used more intensively. However, it is difficult to determine whether land use influences infrastructure or visa versa.

4.3 LAND USE DYNAMICS BETWEEN 1984 AND 1992

In ARC/INFO a land use map for 1984 is available. Information from this map and from the 1992 map has been compared. An overlay of both maps was made and analyzed. The two maps have not been made with the same level of detail and do not use the same criteria for land use classes. This caused problems when the two maps were compared. For example: at the borders of the forested areas, grassland has been interpreted as grassland (1992) and not as "areas of agricultural penetration"(1984). An area of "agricultural penetration" in fact is a combination of a forested area and a grassland area. In these areas there actually might not be that much change but the land use has been classified differently. This also explains why in the 1992-map the mapping unit primary overlogged/secondary forest is present. This land use type also existed in 1984 but then it was classified as agricultural penetration or as mixed agriculture.
Table 4.8 shows land use in 1984.

Table 4.8: Land use in the Atlantic Zone in 1984; number of ha and percentage of total area.

LAND USE	HA	%
Natural vegetation forest	60252	21.4
Dispersed agricultural penetration	2195	0.8
Agricultural penetration,	80334	28.5
Annual crops	15682	5.6
Mixed agricultural use	34913	12.4
Dominant pasture	55344	19.7
Banana plantations	17953	6.4
Bamboo plantations	835	0.3
Tree plantations	260	0.1
Urban area	1243	0.4
Water area	709	0.3
Industrial area	175	0.1
Abandoned area	11487	4.1
Total	281460	100.0

Source: Atlantic Zone Programme.

The land use changes are listed below in table 4.9 and table 4.10. Table 4.9. shows to what land use a certain 1984-class changed. Table 4.10 shows in what land uses a 1992-class consisted in 1984.

Table 4.9: Land use in 1984 and its use in 1992 (in ha).
This table shows to what land uses the former land use of 1984 changed (if changed at all). The gaps in the table indicate not existing changes, e.g. urban area (1984) never changed to annuals or banana and therefore at that places in the table a gap is present. Fp stands for primary virgin forest, Fs for primary overlogged and secondary forest, C1 for extensive agriculture with 50-95% forest, C2 for extensive agriculture with 5-50% forest.

	land use 1984											
lu92	natural forest	(disp) penetr	agr. penetr	annuals	mixed agric.	pasture	banana	bamboo	tree plant.	urban area	water area	abandon. area
forest Fp	43105	766	11858	214	661	385				161	208	
forest Fs	7066	4288	15339	849	2668	3879	394					3694
ext. agr C1	1923	107	971			178					141	771
ext. agr C2	2419	540	1352		272	96						
pasture	3809	6613	28381	5678	15818	36144	1657	86		38	222	2568
banana	1219	1664	2070	2008	10132	5200	14207		250			2791
annuals	239			1720	1253	2548	351					
mixed agr.	1258	886	1258	1195		2020	554					433
Waste land				563				692			77	1059
fruittrees				794		1800	100					281
homegardens												
perenn small						770						
urban area										1030	35	
total	60252	15982	66547	15682	34913	55344	17953	835	260	1243	709	11487

Source: Author's data.

Table 4.10: Land use 1992 and its use in 1984 (in ha).

Horizontal: land use classes of 1992
vertical: land use classes of 1984
Fp= primary virgin forest
Fs= primary overlogged and secondary forest
ext. agric.= extensive agriculture
p1/2a= pasture with many trees
p1/2b= pasture with some trees
p3= pastures, fieldsizes not recognized
JM= Macadamia plantation
agr.pen. = agricultural penetration
aban. area= abandoned area
JO= ornamental plants (plantation)
Joo=bamboo

	land use 1992													
1992: 1984	forest Fp	forest Fs	ext. agric.	past. P1/2a	pastur P1/2b	pastur P3	banana	urban area	JM	fruit trees	Joo	annual	mixed	JO	palm-heart
forest	43105	7066	4342	546	875	2388	1219					214			
agr.pen.	12624	19637	2970	9468	11727	14536	3734	122	692	203		1206	2144		
annuals	214	849		1087	4270	311	2008	89	647	147		1720	2079	812	
mixed	661	2668		4211	8631	3185	10132	315	172		201	1243	1195		
pasture	385	3879		7210	26145	2889	5190	299	732	280	117	2548	2020	128	778
banana		394		630	969		14207	118					381	191	
bamboo											692				
urban area								1030							
aban. area	298	3396		667	1304		2791		198	83			390		
total	57404	38641	8186	24434	54551	23544	39711	2331	2565	838	1070	7445	8540	1186	830

Source: Author's data.

The tables 4.9 and 4.10 show the following:
-During the period 1984-1992 deforestation took place: areas of natural vegetation (84) decreased. Parts of natural forest in 1984, are used extensively (wood, cattle), as pasture, banana plantation or for the growing of annuals in 1992.
-The areas of (dispersed) agricultural penetration in 1984, mainly consist of forest and pastures in 1992. As said before this difference may be caused due to the criteria used for classification. Some parts of agricultural penetration have changed in banana plantation or mixed agriculture.
-A decrease of 8237 ha was found for annuals. Most former parts of annuals changed to pasture and

banana plantation.
-More than half the area of mixed land use in 1984, consists of pasture in 1992. Another part changed to banana.
-The acreage of grassland increased from 55,344 ha to 102,528 ha. This means that the acreage almost doubled within 8 years. However, from the area covered with pasture in 1984, only half still was pasture in 1992. The other half changed to banana and other plantations, annuals or mixed agriculture. The new pasture areas were areas of mixed agriculture (12,237 ha), forest (3809 ha), annuals (5568 ha) or areas of agricultural penetration (35,731 ha) in 1984.
-During 1984-1992 the area under plantation increased with 27,350 ha. This is an increase of almost 250%. and is caused by the expansion of banana plantations. In 1992 39711 ha of banana were cultivated, an increase of 11,758 ha. Areas of mixed agriculture (38%), pasture (14%), agricultural penetration (13%), abandoned area (11%), annuals (6%) and forest (3%) changed into banana plantation. These figures contradict the usual statements that the increase of the area of banana plantations directly caused deforestation. In this study only 3% of all new banana plantations was found on an in 1984 forested area.

Some recently introduced crops like palmheart and ornamental plants and some, in 1984 not classified crops like fruittrees, coffee, and macadamia also caused some increase in plantation acreage. Waaijenberg & de Haan (1992) show that in 1984 830 ha of palmheart was present in the Atlantic Zone, of which $\pm$ 300 as plantation within the study area

Table 4.11: Plantation type; area in 1984 and 1992 (in ha).

PLANTATION TYPE	1984	1992	DIFFERENCE
banana	17953	39711	+ 11758
bamboo	835	1070	+ 235
tree	260	0	- 260
macadamia	0	2565	+ 2565
palmheart	300	830	+ 830
fruittrees	0	838	+ 838
coffee	0	198	+ 198
ornamental plants	0	1186	+ 1186
Total	19048	46398	+ 17350

Source: Atlantic Zone Programme; author's data; Waaijenberg and de Haan (1992).

-Considering the population growth during last decades, a.o. caused by a considerable migration into the Atlantic Zone (Mideplan, 1991), the increase of urban area, last 8 years, is logical.

4.4 LAND USE DYNAMICS IN A PILOT AREA BETWEEN 1948-1992

From a pilot area of 13,215 ha, northeast of Guácimo (figure 12), series of aerial photographs were interpreted for land use. Photos from 1948, 1952, 1960, 1973, 1984 and 1992 were used. The same interpretation key and legend were used for all these photos. For photo numbers and photo scale see appendix 3. The aim was to obtain a general view of common land use changes during this period. The photos from 1948 and 1952 only covered part of the pilot area and therefore have been combined. Land use maps for 1948-1992 are shown in figure 12. In these maps deforestation during 1952-1992 is clearly visible. A lighter tone on the map indicates a more intensive land use. A sequence of dark (1948/1952) to light (1992) tones is visible, indicating an increase in intensity. Some parts did not change in course of time (e.g. still are forest). In this area forest still was found on badly drained soils. Between maps the size of mapping units differs. This could indicate something about changing parcelsizes, the expansion of plantation area etc. However such conclusions can not be drawn as the size of mapping units also is influenced by the original scale of the aerial photos.

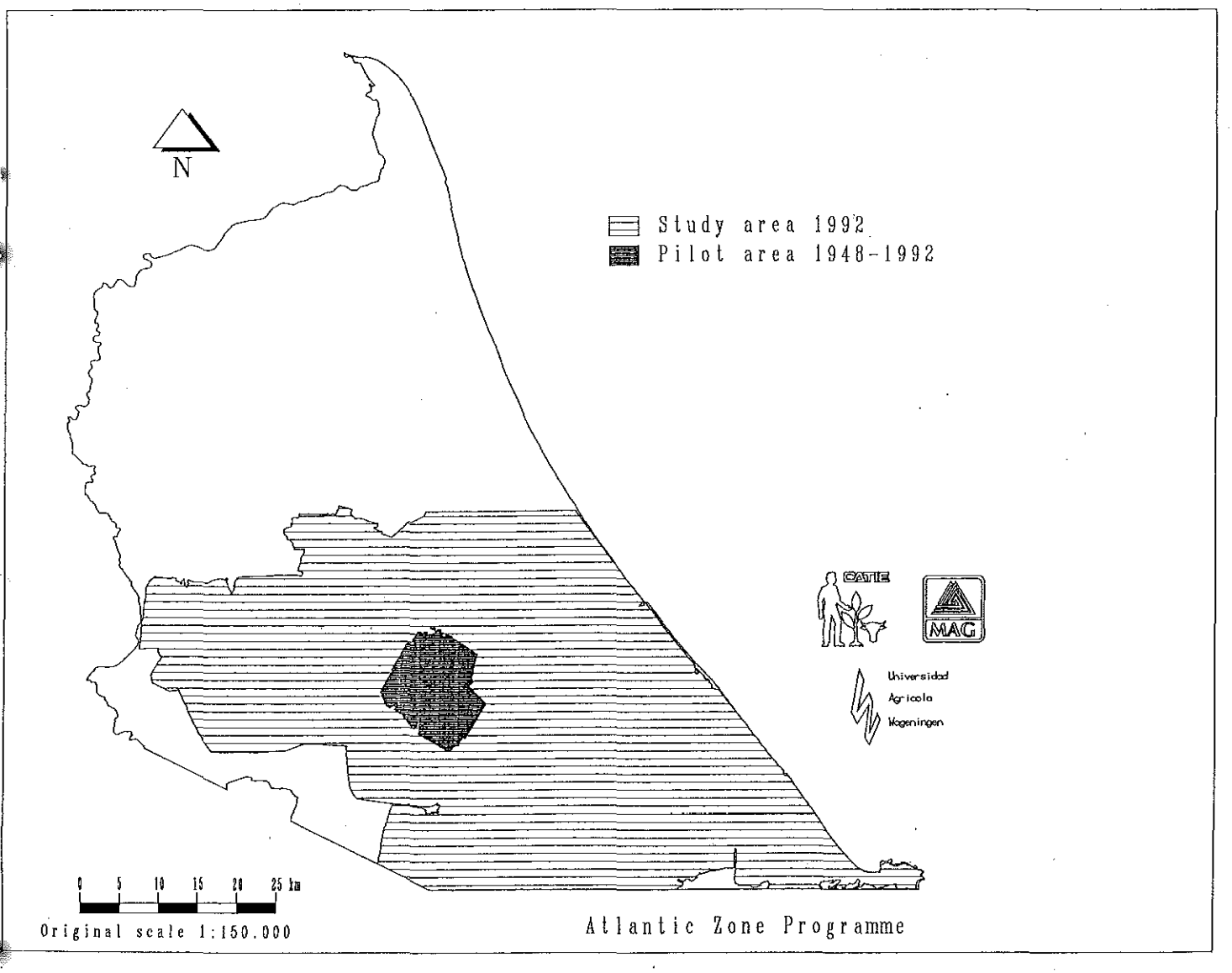

Figure 11 Study area and pilot area.

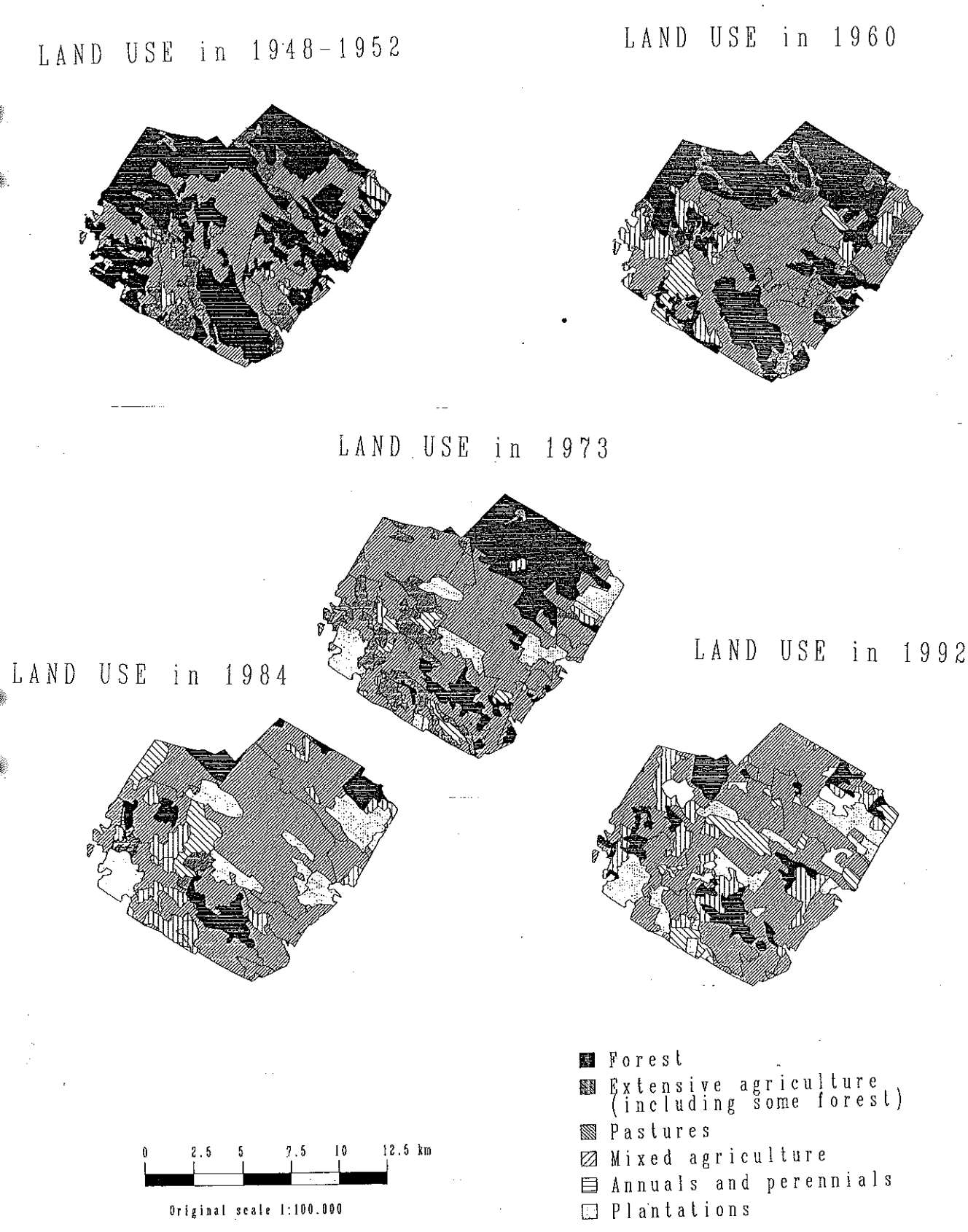

Figure 12 Land use in 1948-1992 in the pilot area.

Table 4.12 describes the land use areas for the different years.

Table 4.12: Land use in pilot area 1948-1992 expressed in ha.

YEAR	48/52	60	73	84	92
primary virgin forest	5093	4164	1312	267	21
primary overlogged/ secondary forest	1246	962	1551	887	1421
extensive agriculture, 50%-95% trees	909	802	686	-	-
extensive agriculture, 20%-50% trees	348	440	881	300	-
pastures, parcels< 15ha, many trees	1349	991	1195	1139	1491
pastures, parcels< 15ha, some trees	2.5	139	1268	1496	1741
pastures, parcels> 15ha, many trees	784	1170	-	-	-
pastures, parcels> 15ha, some trees	1892	1924	2299	3551	4049
pastures, parcels not made\recognized	1217	1029	2010	1898	-
total pastures	5245	5253	6772	8084	7281
homegardens, small fields	-	92	-	254	175
perennials\trees on small fields	62	191	15	62	-
banana plantation	-	-	1279	1232	811
palmheart plantation	-	-	-	-	23
macadamia plantation	-	-	-	-	60
fruittrees plantation	-	-	46	38	147
bamboo	-	-	22	96	-
> 70% annuals, average fieldsize 3 ha	169	-	19	342	-
> 70% annuals, fieldsize 6-20 ha	133	791	180	523	1330
mixed agriculture, average fieldsize 3ha	-	69	346	635	47
mixed agriculture, average fieldsize 8ha	-	445	-	7	715
urban areas	-	-	16	-	118
waste land	-	-	-	-	423
ornamental plants plantation	-	-	-	482	635

Source: Author's data.

Table 4.12 shows a decrease in the area of primary virgin forest and extensive agriculture and an increase in pasture area, annuals, ornamental plants, urban area, macadamia-, fruit- and palmheart plantation, between 1948 and 1992. Some figures (increase of area of annuals, decrease of banana area between 1984 and 1992) are not conform the results presented in Section 4.3. This can be explained by the specific characteristics of the pilot area: annuals are relatively important there (Rio Jimenez) and a banana plantation was closed between 1984 and 1992.
For pasture a typical pattern can be observed looking at the 1948-1992 figures. Numbers between brackets indicate what percentage of total pasture area is covered by a pasture type, in the years 48/52, 60, 73, 84, 92. The percentage of pastures with many trees decreases (41-43-18-14-20%); pasture area with few trees increases (36-39-53-62-80%); pasture area with small parcels increases (26-22-36-33-44%); pasture area on large parcels is fluctuating (51-59-40-44-56); Trees step by step disappear from pastures. This process of tree logging in pastures has already been described in Section 4.2.1 The increase of small fieldsizes can be explained by the fact that rural population grew between 1948-1992, implicating a search for land. Many people came to live in a IDA-settlement in which generally farm sizes and fieldsizes are small.
Pastures without identifiable parcels, (indication of recent deforestation) cover 20-30% of the total pasture area during 1948-1984, but this percentage becomes 0 in 1992. Apparently no recently deforested pasture is present in 1992, most suitable parts have already been deforested.

Table 4.13 shows all observed land use changes between 1948-1992.
All equal land use changes (e.g. all changes from overlogged forest to recently deforested pasture) have been counted. The result is the total ha involved in a certain land use change. With these figures the most common land use sequences could be derived . These are shown in figure 13.

Table 4.13: Land use changes between 1948-1992.

Rows indicate to what land use a certain class has changed. Columns indicate the former land use of a certain class.

E.g. column Fp, row Fs means that 197 ha changed from primary virgin to overlogged or secondary forest.

Symbols:

Fp=primary virgin forest
Fs=primary overlogged and secondary forest
C1=extensive agriculture 50%-95% forest
C2=extensive agriculture, 5-50% forest
P1a=pastures, parcels< 15 ha, irregular shape, many trees
P1b=pastures, parcels< 15 ha, regular shape, some trees
P2a=pastures, parcels> 15 ha, irregular shape, many trees
P2b=pastures, parcels> 15 ha, regular shape, some trees
P3=pastures, parcels not yet made or not recognized rather recently deforested (< 15 years)
Jh=perennials and trees on small fields; homegardens
Jx=perennials and trees on small fields; agglomeration of fields, mixed perennials
JB=banana
JP=palmheart
JM=macadamia
JO=ornamental plants
JF=fruittrees
Joo=bamboo
JC=coffee
A1=>70% annuals, parcels ± 3 ha
A2=>70% annuals, parcels ± 6-20 ha
M21=perennials, annuals and pastures, some woody area can be included, parcels ± 3 ha
M22=perennials, annuals and pastures, some woody area can be included, parcels ± 8 ha
Nu=urban areas and plants
Ns=swamp
Nt=shrub formation and barren land

	Fp	Fs	C1	C2	P1a	P1b	P2a	P2b	P3	Jh	Jx	Jb	Jp	Jm	Jf	Joo	Jo	A1	A2	M21	M22	Nu	Ns	Nt
Fp	3510	921	418	264	597	243	135	746	1835	0	0	142	0	0	0	0	0	80	258	7	131	0	0	0
Fs	197	1111	128	120	328	267	6	529	522	15	17	52	0	0	0	13	144	28	145	19	0	0	0	30
C1	329	197	129	32	83	194	25	184	224	0	14	76	0	0	4	0	0	0	143	103	9	0	0	0
C2	134	89	10	101	171	193	52	95	149	91	0	57	0	0	0	0	0	23	75	30	4	0	0	22
P1a	128	410	132	54	522	230	264	507	463	13	0	341	0	0	12	0	44	61	235	13	60	53	0	20
P1b	0	152	0	106	122	762	0	640	0	0	27	105	0	11	25	0	49	0	118	62	30	0	0	6
P2a	59	216	168	189	145	173	0	130	95	0	100	60	0	0	0	0	0	0	0	120	0	0	0	0
P2b	305	193	19	4	425	593	124	5320	41	7	0	466	0	0	59	0	17	0	309	32	324	13	0	68
P3	290	438	94	12	1281	195	166	906	657	43	0	181	23	0	0	5	84	44	186	218	126	8	0	166
Jh	21	0	0	0	0	66	0	11	0	76	0	0	0	0	0	0	0	0	0	0	0	5	0	0
Jx	0	0	0	0	18	20	14	18	19	9	0	67	0	0	31	0	0	0	6	10	0	0	0	0
Jb	0	52	0	0	11	13	0	423	0	0	0	1067	0	0	35	58	149	18	153	21	9	0	0	0
Jf	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	52	0	0	0	0	0	0	0
Joo	0	9	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	5	63	0	0	0	0	0
Jo	0	0	0	0	0	31	0	0	0	0	0	0	0	13	33	0	216	0	21	0	6	0	0	50
A1	0	34	0	16	80	5	0	89	0	0	0	18	0	0	0	0	18	0	17	0	32	0	0	0
A2	0	0	17	97	110	198	0	91	133	6	0	63	0	0	0	8	111	0	29	43	85	0	0	0
M21	53	7	0	0	5	136	0	329	0	13	0	15	0	0	0	0	0	0	124	67	0	0	0	7
M22	0	0	0	80	0	196	0	0	0	0	0	5	0	0	0	0	0	0	13	20	0	0	0	0
Nu	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Changes which took place between two successive photo interpretations could not be observed. So not all land use changes between 1948 and 1992 have been analyzed. For example a primary virgin forest (Fp) appears to change first to overlogged forest (Fs) or extensive agriculture (C1 C2) before it is changed to pasture. However figure 14 shows direct changes from virgin forest to pasture. Certainly in between, logging took place but at the moment of photo taking was not visible.

Figure 14 shows some of the results of table 4.13 in a diagram.
From figure 14 and table 4.13 it can be concluded that many ha were deforested and changed into a form of pasture. A part of pasture changed to annuals or banana plantations. Pasture with some trees at this moment seems a very stable land use.

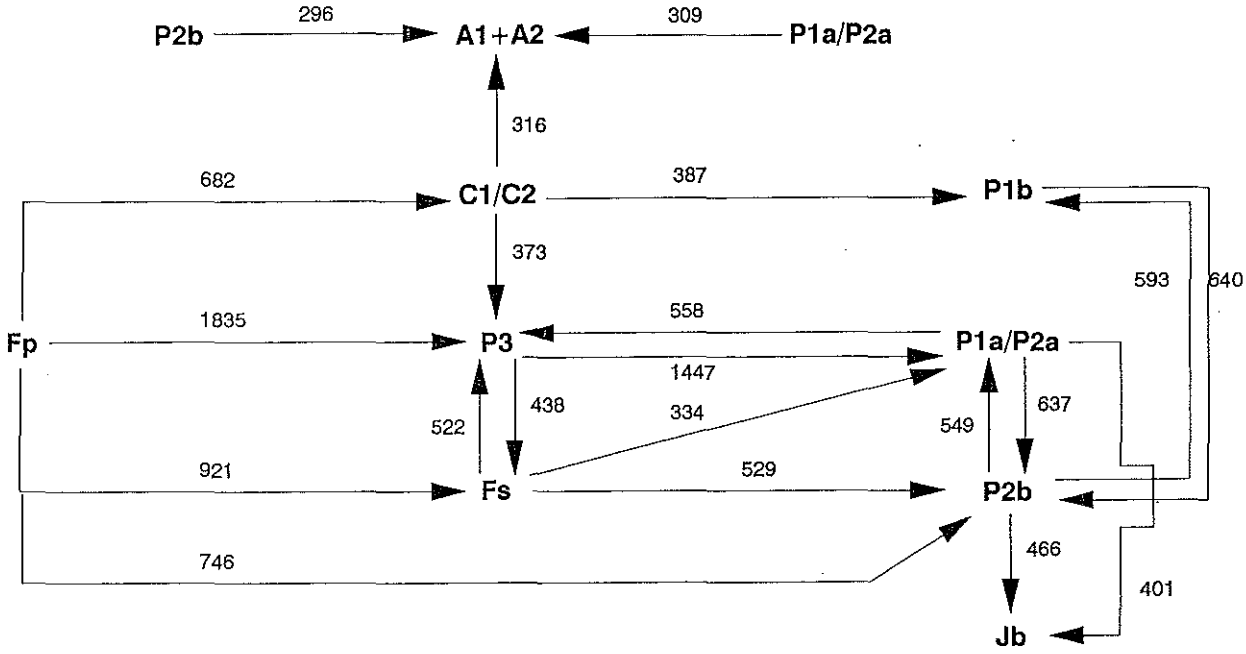

Figure 13 Observed land use sequences in the Atlantic Zone.
The numbers indicate the total area (ha) changed between 1948 and 1992.

Fp=primary virgin forest
C1/C2=extensive agriculture
P1a/P2a=pastures with many trees
P2b=pastures with some trees, parcels > 15 ha
A1+A2=annuals
Fs=primary overlogged or secondary forest
P3=pasture without identifiable parcels
P1b=pastures with some trees, parcels< 15 ha
Jb=banana plantation

Note that the land uses P1a/p2a and P2b are presented two times in this figure.

5 Conclusions and discussion

Land use in the Atlantic Zone of Costa Rica changed considerable last fifty years. Forest was cut and changed for a great part to pastures which now cover 36% of the study area. Forest still covers 34% of the study area. Another large area is covered by banana plantations (14%) owned by big companies. Also some plantations of ornamental crops, palmheart and macadamia trees are found. Some areas are dominated by annuals (2.7% of total area) which are often grown on small fields. For many farmers cattle keeping is more economical than growing crops and therefore such a large area is used as pasture.
Using an interpretation key for identification of land cover helped during photo interpretation. Scanning sometimes can be helpful in checking aerial photo interpretation and can add some information. However it cannot replace stereoscopic photo viewing.

Relations between land use and: soil, infrastructure, protected area policies and IDA settlement schemes were studied. Obviously, the best soils closest to the railway, were used first and now more than 73% of the fertile, well drained soils are covered by pastures and (plantation) crops, while part of the unfertile (53%) and badly drained (56%) soils still are under forest. Pastures are found on all soil types. Pastures with some trees are mostly found (> 50%) on the fertile, well drained soils. Banana is the only crop commonly found on the badly drained soils (45%) which can be explained by the fact that only banana companies are able to construct a drainage system. Road density increase is associated with more intensive land use and decrease of parcelsizes.
Land use in and outside IDA settlements differs. Farms in settlements are small and field sizes in general are smaller than what was found for the whole study area. Relatively more annuals and fewer plantation crops are grown. Land use in older settlements and in younger ones differs, as in the older ones processes of deforestation, tree logging and land marketing have taken place in the course of time.
Forest was, as could be expected, the common land cover found in the protected areas. The national park consist for 99% of primary virgin forest. The forest reserve, however, has been partly deforested.

Land use of 1984 and 1992 was compared and changes were described. Between 1984 and 1992 areas of natural vegetation (primary forest) decreased with 2848 ha and are now used extensively (wood, cattle), as pasture, banana plantation or for the growing of annuals. The area of annuals decreased with 8237 ha. Most parts changed to pasture and banana plantation. The acreage of grassland almost doubled within 8 years at the expense of areas of (dispersed) agricultural penetration, annuals, mixed agriculture and natural forest. Expansion of banana plantations caused an increase of plantation area of 27,350 ha, almost 250%. Also the area of recently introduced crops like palmheart, ornamental plants and macadamia increased.
In contrary to what is often stated, most new banana plantations were founded on already cleared soils (pasture) and not on still forested parts. New banana plantations were found on former (1984) areas of mixed agriculture (38%), pasture (14%), agricultural penetration (13%), abandoned area (11%), annuals (6%) and forest (3%).

A study of land use sequences for 1948-1992 in a pilot area was carried out. The general pattern shows a conversion from primary virgin forest to a forest in which trees are logged to an area partly

covered with forest and partly with grassland, to pasture. Pastures containing some trees and banana plantations are important land uses at this moment.

The Atlantic Zone is considered as an area in development (only recently colonized) and it is obvious that factors like soil, climate, infrastructure, and land tenure played an important role when land use started in this area. However these factors can only partly explain the direction of land use change nowadays. Many other factors like consumption behaviour, prices, policies, population growth, access to capital are likely to be important too.

ARC/INFO, a Geographic Information System is very useful when a lot of data has to be combined and calculated. The possibility of presenting results in maps makes this programme even more valuable. Without a GIS it would hardly be possible (at least would take much more time) to carry out a study as presented in this report. However a GIS is data-demanding; working with it implies the presence of many data. Gathering these data still cost a lot of time and also one should check the quality of these data. One should keep this in mind when working with a GIS, its results, or with data available within a GIS.

This research was focused on quantitative data (numbers of ha). More research dealing with the spatial (geographical) aspects of land use (change) could be carried out. Also research combining the information about land use, IDA-settlements, soils and infrastructure into one overview would be very interesting.

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Appendix 1: Numbers of photos used for aerial photo interpretation.

For creation of a land use map for 1992 of part of the Atlantic Zone, aerial photos, scale 1:60,000, were used.
All photos were taken in March 1992. Photos were obtained from the Instituto Geográfico Nacional (IGN), San José, Costa Rica and are stored at the office of the Atlantic Zone Programme, Guápiles, Costa Rica.

Below photo numbers are written down. Each column corresponds with a line of overlapping photos.

NO.	NO.	NO.	NO.	NO.	NO.	NO.
923	867	860	396	379	749	416
922	868	859	395	380	748	415
918	869	858	394	381	747	414
917	870	425	393	382	746	413
916	871	424	392	383	745	412
915	872	423	391	384	744	411
914	472	422	390	385		410
913	471	421	389	386		409
912	470	420	388			
911	469	419	387			
	468	418				
	467	417				

Appendix 2: Digitized photos (no.) with their name and TIC points.

32 aerial photos were digitized. 27 digitized photos were used for construction of the land use map. The other 5 photos did not fit within the topographic base map and were not used after digitalization. Digitized photos numbers, their name in the ARC/INFO subdirectory and their TIC points are written down below.

PHOTO NO.	NAME IN ARC/INFO	NO. OF TIC POINTS
917	photo2	1 2 3 4
915	photo3	36 13 11 12
914	photo4	13 14 15 16
912	photo5	17 18 19 20
869	photo7	25 26 27 28
870	photo8	29 30 31 32
872	photo9	33 34 35 36
471	photo10	37 38 39 40
469	photo11	41 42 43 44
467	photo12	45 46 47 18
425	photo13	34 48 49 50
423	photo14	51 52 53 54
421	photo15	55 56 57 58
419	photo16	59 86 61 62
860	photo17	63 64 65 66
858	photo18	67 68 69 34
396	photo19	70 71 72 73
394	photo20	74 75 76 77
392	photo21	77 78 79 80
390	photo22	80 81 82 83
388	photo23	82 84 85 60
380	photo24	82 87 88 89
382	photo25	89 90 91 92
384	photo26	93 94 95 96
744	photo27	81 97 98 99
746	photo28	98 100 101 102
748	photo29	102 103 104 105

DIGITIZED PHOTOS OUTSIDE THE TOPOGRAPHIC BASE

PHOTO NO.	NAME IN ARC/INFO	NO. OF TIC POINTS
922	photo1	- - - -
867	photo6	21 22 23 24
411	photo30	95 96 106 107
413	photo31	92 96 108 109
415	photo32	88 109 110 111466

Appendix 3: Photos used for interpretation of land use in pilot area (1948-1992)

YEAR	PHOTO NO.	TIC POINTS	SCALE
1948	12	8 9 10 11	
1952	680	11 12 13 28	1:40,000
	679	11 17 27 29	
1960	3055	9 13 11 40	1:60,000
	3164	16 5 17 19	
1973	246	1 3 30 31	1:30,000
	124	1 32 33 34	
	122	2 3 32 35	
	120	36 37 38 39	
	244	30 2 40 41	
	242	2 11 42 43	
	088	44 45 46 47	
	090	44 48 49 50	
	092	59 52 53 54	
	053	6 9 55 56	
	051	55 57 58 59	
1984	89	1 2 3 4	1:80,000
	16	1 5 6 50	

Appendix 4: Maps and overlays made during the research and stored in ARC/INFO

Five land use maps were made:

YEAR	NAME (as stored in ARC/INFO)	AREA
1948/1952	lu5248	pilot area
1960	lu60	pilot area
1973	lu73	pilot area
1984	lum84	pilot area
1992	lu92	study area

The next overlays were made:

OVERLAY INPUT 1	OVERLAY INPUT 2	OVERLAY (NAME)
land use 1992	IDA settlements	cov1
land use 1992	soils	cov2
land use 1992	IDA > 1970	cov3
land use 1992	protected areas	protlu
land use 1992	roads	cov5
lu4852	lu60	lu2
lu2	lu73	lu3
lu3	lum84	lu4
lu4	lu92	lu5

Appendix 5: Levels of legend of land use map 1992

The legend of the land use map consists of different levels. Construction of this legend is described below.

LEVEL 1
A first differentiation was based on land covers as distinguished on the aerial photographs. These land covers were:
FOREST
EXTENSIVE AGRICULTURE
GRASSLAND
PERENNIALS AND TREES
ANNUALS
PLANTATIONS
MIXED AGRICULTURE
BUILT ON LAND
WASTE LAND

LEVEL 2
The first level is basis for the legend. At the second level, details within land cover classes, is given.

FOREST	-primary forest
	-secondary forest
EXTENSIVE AGRICULTURE	-5-50% grass
	-50-80% grass
GRASSLAND	-many trees
	-some trees
PLANTATIONS	-banana
	-palmheart
	-ornamental plants
	-fruit trees
	-macadamia
	-bamboo
	-coffee
MIXED AGRICULTURE	-mix of annuals and pastures
	-mix of perennials, annuals and pastures
WASTE LAND	-swamp
	-shrub formation and barren land

LEVEL 3
The third level was based on field sizes.

GRASSLAND	-< 15 ha
	-> 15 ha
	-no parcels visible
PERENNIALS AND TREES	-small fields, < 20 ha
	-homegardens, very small fields, 0.25 ha
ANNUALS	-parcels ± 3 ha
	-parcels 6-20 ha
MIXED AGRICULTURE	-parcels ± 3 ha
	-parcels ± 8 ha

Strictly, differentiation between the classes PLANTATIONS and PERENNIALS AND TREES is based on field size, the third level. However differentiation was already done at the first level. Plantations can be distinguished easily from other covers at a first photo observation. Their cover of large, often rectangular areas is characteristic.

Appendix 6: Definitions of terms and procedures used in ARC/INFO.

TERMS

Coverage: digital version of a map.
Arc: line feature, the border of a polygon or both in a coverage. One line feature may consist of many arcs.
Polygon: area feature defined by the set of arcs which comprise its border and a label point within the polygon which is used to assign a User-id.
User-id: pc ARC/INFO item included in every feature attribute table to contain user-defined feature identification numbers.
Topology: the relations used to represent the connectivity or contiguity of map features.

PROCEDURES

Transform: Changes coverage coordinates using an affine or a projective transformation function based on control points (tics). Transform is often used to convert coverages created in digitizer units into the real-world units represented on the map manuscript.

> **Affine:** Three or more tics are required to define this transformation. If only two tics are matched , a similarity transformation will be applied.
> **Projective:** This requires four or more tics to define the transformation. The projective transformation is only used to transform coordinates digitized directly off of high altitude aerial photography or aerial photographs of relatively flat terrain assuming that there is no systematic distortion in the air photos. The accuracy of the transformation will be dependent on the surface terrain being photographed, the angle between the camera and the ground, and the elevation from which the photograph was taken.

Eliminate: The eliminate command is used to remove sliver polygons by merging selected slivers into adjacent polygons. Sliver polygons can be selected for removal using any set of logical criteria.
Clip: creates a new coverage by overlaying to sets of features. The polygons of the clip coverage define the clipping region.
Dissolve: merges adjacent polygons which have the same value for a specified item. Dissolve is used to create a simplified coverage from one which is more complex.
Eliminate: merges selected polygons with neighbouring polygons by dropping the longest shared border between them. It reduces the number of polygons or lines in a coverage. It is most often used to remove sliver polygons created in an overlay of two coverages where the arc overlay is not exact.
Intersect:creates a new coverage by overlaying two sets of features. It computes the geometric intersection of two coverages. Only those features in the area common to both are preserved. Feature attributes from both coverages are joined in the output coverage.
Update: creates a new coverage by overlaying two sets of features. The features of the update coverage define the updating region. Update uses the updating region in a "cut-and-paste" operation; update coverage features replace the area they overlap in the input coverage. The result is stored in the output coverage.
Source: ARC/INFO User's Guide.

Appendix 7: Tables presented with all original classes.

Table 5.4: Land use distribution on different soil types*.

LAND USE	SOIL1	SOIL2	SOIL3
primary forest	6.80	45.80	34.34
secondary forest	3.67	10.05	18.39
extensive agriculture, 50%-95% trees	0.54	1.29	3.61
extensive agriculture, 20%-50% trees	0.92	3.16	1.80
pastures, parcels< 15 ha, many trees	7.66	1.26	4.01
pastures, parcels< 15 ha, some trees	9.85	1.43	5.37
pastures, parcels> 15 ha, many trees	3.25	3.30	3.15
pastures, parcels> 15 ha, some trees	15.52	4.69	9.92
pastures, parcels no parcels recognized	5.65	8.70	13.14
homegardens, small fields	0.87	0.15	0.26
perennials\trees on small fields	0.89	0.09	0.22
banana plantation	17.12	15.05	1.06
palmheart plantation	0.56	0.01	0.04
macadamia plantation	1.71	0.00	0.44
fruittrees plantation	0.44	0.08	0.19
bamboo	0.68	0.00	0.07
ornamental plants plantation	0.81	0.00	0.05
coffee plantation	0.10	0.03	0.06
mixed: annuals and perennials	0.42	0.00	0.00
> 70% Annuals, small fields	1.01	0.10	0.38
> 70% Annuals, large fields	3.07	0.44	1.23
mixed agriculture, small fields	0.95	0.05	0.32
mixed agriculture, large fields	3.31	2.35	0.56
urban areas	1.09	0.62	0.74
swamps	0.13	0.25	0.00
waste land	2.97	1.12	0.00

Calculation: 100(ha land use)/(total ha's of soil type)
Source: author's data.

Table 5.5: Relative importance of the soil type for land use types*.
The total area of a certain land use is put 100%. This table indicates that for certain types of land use one type of soil is much more important than the other two. The weakness of this table is that relative small areas are overvalued (e.g. swamps). In these cases table 5.4 gives a better view.

LAND USE	SOIL1	SOIL2	SOIL3
primary forest	7.82	52.68	39.50
secondary forest	32.46	23.87	43.67
extensive agriculture, 50%-90% forest	9.93	23.71	66.36
extensive agriculture, 20%-50% forest	15.65	53.74	30.61
pastures, parcels< 15 ha, many trees	59.24	9.74	31.01
pastures, parcels< 15 ha, some trees	59.16	8.59	32.25
pastures, parcels> 15 ha, many trees	33.51	34.02	32.47
pastures, parcels> 15 ha, some trees	51.51	15.57	32.92
pastures, no parcels recognized	20.55	31.65	47.80
homegardens, small fields	67.97	11.72	20.31
perennials\trees, small fields	74.17	7.50	18.33
banana plantation	51.52	45.29	3.19
palmheart plantation	91.80	1.64	6.56
macadamia plantation	79.53	0.00	20.47
fruittrees plantation	61.97	11.27	26.76
bamboo	90.67	0.00	9.33
ornamental plants plantation	94.19	0.00	5.81
coffee plantation	52.63	15.79	31.58
mixed: annuals and perennials	100.0	0.00	0.00
> 70% Annuals, small fields	67.79	6.71	25.50
> 70% Annuals, large fields	64.77	9.28	25.95
mixed agriculture, small fields	71.97	3.79	24.24
mixed agriculture, large fields	53.22	37.78	9.00
urban areas	44.40	25.31	30.20
swamps	34.21	65.79	0.00
waste land	62.66	23.63	13.71

Calculation: 100(ha land use on a soil type)/(total ha of this land use) .