CLASSIFICATION OF LAND COVER IN THE TAÏ NATIONAL PARK (CÔTE D'IVOIRE) BY REMOTE SENSING TECHNIQUES

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(edited by H.H. Bartelink)

CONTENTS

PREFACE

This study forms part of the Tropenbos programme in Côte d'Ivoire, and was carried out from October 1990 till December 1991. The first phase of the study consisted of a three month period in Wageningen to prepare the data processing and the fieldwork period in Côte d'Ivoire. The second phase was conducted in Côte d'Ivoire; during 7 months ground-truth data were gathered in the study zone, and images were processed and interpreted. The last months of the project were again spent in Wageningen to work out the results and write the report.

During the study I was lucky to work with some very nice colleagues at DGCTx in Côte d'Ivoire. Anzoumana Koné, Jean-Claude Vanié and Coulibaly were not only a great help during my work but became close friends. Gerrit-Jan van Herwaarden, Fred Vooren en Renaat van Rompaey from the Centre Néerlandais introduced me to the aspects of living and working at Côte d'Ivoire. Their experiences facilitated my life and work greatly. In Wageningen I owe a lot to mr. Buiten and John Stuiver for their technical assistance and critical comments on methodological aspects of the project. Mr. de Graaf was very helpful in arranging facilities and in discussing silvicultural and management aspects of the tropical forest in Côte d'Ivoire.

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1. INTRODUCTION

1.1 Problem description

The Taï forest (Fig.1) is one of the last remnants of undisturbed equatorial rain forest in West Africa. Already in 1926 the value of this forest was recognized and it was declared a 'Parc refugié de la région forestière'. In 1972 Taï National Park (340,000 ha) was established. A buffer-zone was created around almost the entire park in 1977. In 1989 this 66,000 ha peripheral zone obtained the same status as the original park area.

Until 1965 the area around the park was almost uninhabited. In 1965 the government of Côte d'Ivoire started to promote the development of the south-west part. Logging activities were increased and large agro-industrial plantations were projected. Logging activities provided roads which gave access to the interior of the forest. As a result, immigrants invaded the area from 1967 onwards. The first to arrive were the Baoulé (an ethnic group from the centre of Côte d'Ivoire), in search for land to plant cash crops (coffee and cocoa). At that time the market prices for coffee and cocoa were high and planting of these crops was encouraged by the government. In 1971 the Baoulé were followed by the Mossi (from Burkina Faso). In that year foreigners got the official right to own land. Because the savanna region suffered from a series of bad harvests due to serious water shortage between 1966 and 1973, many people tried their luck elsewhere. At the onset of the eighties migration by Ivorians had stopped but non-Ivorian immigration was still full in swing. In 1971 population density was estimated to amount 3.3 persons/km², wheras by 1985 this had increased to 13 persons/km² (De Rouw et al., 1990).

Nowadays, outside the park there is almost no unoccupied land left and the pressure on the park has become very high. The government has realised that something has to be done to preserve the forest. In the most recent policy report on forestry (Anon., 1988), some of the goals mentioned are:
- to maintain the exploitable potential of the natural forest,
- to restore the vegetation cover especially in savanna areas by protecting the national parks,
- to reforestate and manage the 'forêts classées' (forest areas assigned reserves by the government),
- to increase permanently the return of forest exploitation,
- to ameliorate the transformation and commercializing of forest resources.

To achieve these goals, identification of boundaries of forest reserves on topographical maps has given a high priority (Anon., 1988).

1.2 Objectives of the study

Sustainable forest management requires information on forest areas and boundaries, location of access roads, and occurrence of (human and natural) threats. To supply such information, a field inventory can be carried out. This, however, is time-consuming and expensive, especially in tropical forests were accessability and orientation are serious problems. Remote sensing techniques (RS) probably offer an easier (additional) way to get this kind of information.

2.2 Satellite image enhancement

Satellite images are enhanced to increase their interpretability. Several enhancement methods were presently compared, regarding their information value for image interpretation. Enhancement methods were performed on bands 4, 5 and 7 of the TM-image, as other bands and images were of too low quality to be suitable for interpretation. Two representative samples of 512x512 pixels were chosen, one situated in the agricultural zone, the other in the forest, to select the most suitable enhancement method. The following criteria were applied:
- the information value of the enhanced image had to be higher than that of the original image;
- boundaries between different features, especially vegetation, had to be clear;
- the method had to be quick and easy to perform.

From the enhancement methods available, only the most promising ones were chosen, based on the results of the pilot study (Schmidt, 1990):
- band substitution   - vegetation index
- contrast stretching   - ratio
- principal components   - IHS
- Laplace   - texture

Presently, the best results were obtained by plain contrast stretching. A detailed description of the applied enhancement methods and the respective results can be found in Appendix IV.

2.3 Construction of the base maps

General

The available topographical maps were not accurate enough to orientate, which is necessary for collecting ground-truth data (see §2.4). Hence two alternative methods were applied to construct suitable base maps. For the northern part of the study area the aerial photographs were used to derive the necessary geographical information, which was added to the RS-images (see Schmidt, 1990). For the southern part a method described by Chavez (1986) was applied: Landsat TM data were digitally merged with a SPOT panchromatic image to provide more detailed information on roads and settlements. This image became only available after the first field trip.

The northern part: applying photographs

Field coordinates of geographical features were derived by aerotriangulation (see Appendix II), a method correcting for different camera positions and viewing angles during film exposure, allowing the photogrammetric transformation of photo-coordinates into field coordinates. Features clearly to distinguish on neighbouring photographs, such as a corner of a house, a small tree, or a sharp bending in the road, were chosen as transfer points. The accuracy with which the transfer points could be located (local field coordinates) was about 3 meters. The ground-control points, in contrast, showed an error of about 30 meters in the XY-plane (Table 1), due to the fact that only a few points were found that could be located on both the topographical map and the photograph with high accuracy. However, this uncertainty was acceptable because it coincides with the resolution of a pixel in a TM-

image. The field coordinates of the control points were calculated from the topographic map. As there are no significant elevation differences in the area, the height error was expected to remain below 10 meters. The overall accuracy of the constructed map was about 6.5 meters in the XY-plane.

Table 1 Accuracy in meters of points used for aerotriangulation

	n	dX	dY	dZ
Projection centres	64	4.64	8.53	5.07
Ground-control points	24	31.75	28.64	10.42
Transfer points	626	2.52	3.36	4.84
Ground-control & Transfer	650	6.58	6.41	5.16
All points	787	6.13	6.32	4.91

From the aerotriangulation separate sets of transformation parameters for each photograph resulted, enabling the calculation of field coordinates from photo-measurements. Next, using a stereoscope, roads, rivers, valleys and villages were located on the aerial photographs. After digitizing, the programme Arc/Info was used to store the data. A format conversion was carried out on the photo-database to make it suitable to be read by an I^{2}S image analysis system. The part of the TM-image corresponding to the area covered by aerial photographs was selected and after contrast stretching (Appendix IV) the information of the photo-database was super-imposed on the TM-image. A print of the resulting image was obtained by an Optronix, which converts digital data into colour intensities. The picture (enlarged to a scale of 1:50,000) served as a base map for the first field trip.

The southern part: merging TM and SPOT-panchromatic

When a panchromatic image and a multispectral image are merged, the new image contains the high resolution information of the panchromatic image while maintaining the basic colour content of the original multispectral data. To combine the two images they should have identical size and pixel-positions. Hence, the raw TM-image (resolution 30 meters) was re-sampled, and warped according to the geometrically corrected SPOT-image (resolution 10 meters). To visualize the combined SPOT and TM image it is necessary to incorporate the information of the SPOT-image in the TM-image, for it is not possible to visualize more than three bands at a time. The following formula was used:
0.75 x band 4 TM + 0.25 x SPOT   (band 1)
0.50 x band 5 TM + 0.50 x SPOT   (band 2)
0.75 x band 7 TM + 0.25 x SPOT   (band 3)

The contrast of the resulting so-called PXS-image was clearly ameliorated compared to the original RS-images.

To facilitate the use of a Global Positioning System (GPS: see §2.4) during the fieldwork, a so-called UTM-grid was fit into the PXS-image. Digitized coordinates from the topographic map were translated into a grid, which was superposed on the PXS-image. The accuracy of the UTM-coordinates on the image was about 50 meters. A print of the PXS-image (scale 1:50,000) including the UTM-grid served as a base map during the second field trip.

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2.4 Fieldwork

The field trips were organized to collect data on actual vegetation cover and land-types (the 'ground-truth'). Based on a previous study (Schmidt, 1990) it was assumed that the study area was homogenous; the field trips were hence planned based on the presence of certain land-types, whereas the location of these features was considered to be less important.

The first field trip was restricted to the northern part of the area (around the village Taï) as initially only the aerial photographs were available for fieldwork. At recognizable points on the field document (especially road-crossings) the vegetation type and its area were recorded. Because there were not many crossings, extrapolations along the road were made, using a 50 meter measuring tape.

During the second field trip (to the southern part of the study area) the same procedure was followed. A GPS ('Pathfinder') was used to trace locations not recognizable on the images. Applying a GPS requires an open space to receive satellite signals, as data transmitted by the satellite are blocked by foliage; the size of the open space required depends strongly on the height of the surrounding vegetation.

In addition to the fieldwork, timber exploitation records were searched for, intended to serve as a measure for logging intensities in the area. Unfortunately, the only information that could be obtained was the year in which a certain concession was released.

2.5 Classification

Classification basically aims at translating a RS-image (a collection of pixel-values) into a map containing recognizable information on terrain features. Classification was presently carried out on the PXS-image. Based on the field visits a preliminary legend was developed, distinguishing a number of different land-types. Both a supervised classification and a visual interpretation were carried out.

Supervised classification starts with selecting restricted areas in the RS-image that have known ground truth. The spectral reflectances of these so-called training areas serve as a reference, as they can be attributed to certain legend classes. The computer is used to determine the particular combinations of reflectance values (in each of the wave bands) that characterize a certain class (vegetation type, land-use type). The classification method to be used (e.g. minimum distance, maximum likelihood, parallelepiped) depends on the statistics of all the classes present and especially on how a class is spectrally separable from all other classes. Once the training areas have been chosen, the statistics for each class are calculated, and the whole image can be classified. Also the percentage discrimination, a reliability measure of the classification, will be determined: a high discrimination means that a classified pixel has a high probability of really belonging to that class.

Supervised classification was performed on different sets of training areas. The first set was derived from ground-truth data from the northern part of the study area (resulting from the first field trip). The maximum likelihood method was used because several classes showed spectrally overlap. The second set was derived from ground-truth data from the southern part of the study area. The third set

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3. RESULTS

3.1 Supervised classification

The columns labelled 'North area' in Table 2 and 3 present the results of the supervised classification based on ground-truth data originating from the northern part of the study area. The classification was applied to the whole study area. Percentages well-classified, resulting from comparison of classification results with ground-truth (Table 2), as well as percentages discrimination (Table 3) are shown. Classification of some vegetation types revealed to be difficult; especially the class 'coffee' (12.8%) gave a very poor result. Discrimination percentages between the vegetation types appeared to be low.

Table 2 Percentages well-classified, resulting from supervised classifications using different ground-truth data sets

Class	Origin of data set		
	North area	South area	Total area
Village	99.7	97.4	97.4
River	97.3	97.5	95.3
Field	81.5	70.4	71.4
Modified forest	52.7	44.4	39.9
Coffee	12.8	27.7	24.7
Cocoa	49.1	55.3	51.5
Old secondary forest	55.0	3.2	28.5
Young secondary forest	38.8	69.2	62.3
Inundated lowlands	--	8.1	2.7
Clearing	--	60.9	61.3
Primary forest	69.1	--	70.2
Inundated forest	63.3	--	52.8

Table 3 Discrimination percentages, resulting from supervised classifications using different ground-truth data sets

Class	Origin of data set		
	North area	South area	Total area
Village	99.8	97.7	98.6
River	79.8	98.7	76.1
Field	69.3	40.9	39.1
Modified forest	35.2	54.5	26.5
Coffee	23.9	5.7	4.0
Cocoa	50.3	76.7	77.3
Old secondary forest	22.9	41.1	25.2
Young secondary forest	37.7	29.8	28.4
Inundated lowlands	--	41.7	63.7
Clearing	--	97.3	69.8
Primary forest	82.7	--	90.2
Inundated forest	63.0	--	48.5

When ground-truth data from the southern part of the study area became available, initially again a maximum likelihood classification (95% reliability) was tried, but the image analysis system failed to carry out this classification. Hence, the minimum distance method was used. The supervised

classification based on the southern ground-truth data only, resulted in roughly comparable percentages (Table 2 and 3: column 'South area'). The column 'Total area' in Table 2 and 3 presents the classification results when ground-truth data originating from the whole study area were applied.

Using ground-truth from the whole area revealed that the classes 'coffee' and 'cocoa', and 'old secondary forest' and 'young secondary forest' were often wrongly classified and that they were rather difficult to distinguish; hence, these classes were merged into 'plantation' and 'secondary forest', respectively. Table 4 shows the results. It appeared that the class 'inundated lowlands' (consisting of a vegetation of bamboo and raffia-species) was not easy to classify automatically. This is remarkable because visually this class could be recognized quite easily.

Table 4 Results of the supervised classification, based on ground-truth data from the total area. The classes are rearrangement compared to Tables 2 and 3

Class	% Well-class.	% Discrimination
Village	97.5	98.2
River	95.7	77.9
Field	69.6	42.4
Modified forest	51.8	23.4
Plantation	68.6	63.0
Secondary forest	56.3	48.7
Inundated lowlands	7.5	43.6
Clearing	66.7	64.1
Primary forest	71.8	90.7
Inundated forest	57.3	49.7

3.2 Comparison with field situation

The ground-truth data from the two selected subzones, Taï and Para, had not been used for the classification, as they were to be used as independent field information suitable to check the image classifications.

A few false classifications were found. Along the road quite some places were classified as 'village' whereas no settlements were present. This was due to a broadening of the road; the computer notices then 'bare soil' and characterizes it as settlement. Cocoa plantations were often classified as 'field' with only a border of cocoa. This might be due to heterogeneity of the vegetation cover within the plantation.

The data of Table 4 were used to derive a feature space plot of the study area. The feature space plot showed that considerable overlap existed between several classes.

When scattergrams were made of the northern (Taï) and the southern subzone (Para) respectively, it turned out that the study area was not as homogenous as previously assumed. Although the same land-types appear in both the subzones, the scattergrams clearly differed with respect to pixel values of bands 4 and 5 (Fig.3, Fig.4). Even more important is that (hence) the feature space of the classes lies almost entirely outside the scattergram of the Para subzone (Fig.5).

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Figure 5: The feature space plot. The scattergrams of both the Taï and the Para subzone are indicated by their borders

3.3 Visual interpretation

Visually, the following features could be distinguished:
- settlements and campements (little settlements of one family)
- larger roads
- logging roads in the forest (visible until about 5-10 years after exploitation)
- rivers
- fresh clearings
- young secondary forest (fallows younger than approximately 15 years)
- inundated lowland in the agricultural zone
- fields with food crops

No distinction could be made between old secondary, primary and modified forests. Mature cocoa plantations did have a slightly differing tone compared to fields, but often the difference was to small to notice, especially in case of small parcels. Discrimination between coffee and cocoa plantations was not possible at all.

As mentioned before, inundated lowlands (covered with bamboo or raffia forest) in the agricultural zone were recognized rather easily, appearing in orange-brownish colours. Remarkably, on the topographical map these areas are called 'foret degradee'; probably aerial photographs have been wrong interpreted at the time of mapping, due to the fact that forests on inundated soils are less dense and lower than forests on well-drained soils. Most of the forests present in the agricultural zone are situated in such depressions.
Small stands on inundated soils within a forest area were hardly recognized. Quite some depressions were recognizable by relief (indicated by shade), as a result of the information hidden in the SPOT panchromatic image.

Within the forest some zones could be delineated. East of the Audrenisrou river a more greyish-coloured zone was found, which partly corresponded with land-unit UI1 (association of uplands and inselbergs) of De Rouw et al. (1990). The zone on the satellite image, however, did not continue as far as did UI1 on the map. Differences in reflectances between the area east of the river and the surrounding forest could not be related to geological differences (see Bos, 1964).

3.4 GPS

The open space required to receive satellite signals differed among the vegetation types. In cacao plantations, with an average plant height of three meters, an open space of 5x5 meters met the requirements. For dense forests (tree heights up to 35m), 20x20 meters was still not sufficient; positions within the forest could hence not be determined.

It was very difficult to locate the measured positions on the satellite image. Accuracy of the measurements was about 30m (3 pixels). As most of the fields were rather small (100x100m), the potential dislocations can cause positioning in other vegetation types, which will strongly restrict a valid classification.

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4. DISCUSSION AND CONCLUSIONS

4.1 Remarks on material and methodology

Multi-spectral remote sensing data can be expected to be useful tools in land surveying (Buiten, 1986). The quality of the presently available images, however, was very low, thus hampering a multi-spectral analysis. In addition, the processing of RS-images also appeared to affect the quality of the image. On the SPOT panchromatic prints relief was much better visible in the print of the northern part of the study area, which had a lighter tone, than in the print of the southern part.

The most recent remote sensing material dated from 1988, so a 3-year-gap existed between the date of exposure and the fieldwork. In a region with shifting cultivation and a vast exploitation of (forest-) land by immigrants, the reliability of the collected ground-truth is hence doubtful.

None of the enhancement methods performed, gave better results than plain contrast stretching. This was a surprise, because the IHS-transformation is supposed to give an impression of relief in the image, to discriminate between overgrown and bare soils, **and** to indicate differences in biomass amounts (Goossens, 1990).

The maximum likelihood method was strongly preferred for the supervised classification, because of the spectral overlap between classes. However, this did not work out for all data-sets: the analysis system was not able to assign all the classes, probably due to the large overlap between the classes. The number of classes should hence be reduced.

Though visual interpretation is labour intensive and subjective, this study revealed that it is a useful means in information gathering. Even when only a visual interpretation is carried out an acceptable classification can result. Faults due to inhomogeneity within the vegetation can be avoided provided knowledge of the area is available. An example is the class 'inundated lowland'. Field visits and knowledge on vegetation types enable to take more factors into account than a computer can. However, a combination of supervised classification and visual interpretation seemed to be the most fruitful way of operating.

4.2 Discussion

The feature space plot showed that considerable spectral overlap existed between several of the distinguished classes. This could be attributed to the following:
1. Especially in the agricultural areas, a small-scaled pattern of land-use types existed, resulting in a lot of mixed pixels;
2. Parcels were not sharply bordered in the fiel;
3. Spectral differences between certain land-types (e.g. 'field' and 'cocoa-plantations') were small;
4. A lot of intercropping occurred, reflectance characteristics of a certain crop (e.g. cocoa) hence strongly fluctuated among locations;
5. Relatively large errors arose when the RS-images were geometrically corrected.

And of future importance:
6.	Weeding; not every farmer weeds at the same time and with the same accuracy. This makes that transitions between vegetation types are often very smooth and that it is difficult to delineate areas.

The amount of classes should therefor be reduced. In a heterogenous, small-scaled zone like the Taï-region, which is characterized by a lot of small patches of agricultural land, plantations, and forest, it is impossible to distinguish all existing land-types in the RS-images. Presently, also the classes representing different forest types were hard to discriminate, except for primary forests. For the Taï reserve it would hence be more suitable to restrict the legend to the classes 'village', 'river', 'agricultural zone', 'secondary forest', and 'primary forest'. This improved classification could not be realized within the current project.

The suitability of the RS-images will improve when phenological characteristics are taken into account. The cultivation of crops by farmers, for example, depends upon the rainfall pattern. Sowing of the various crops starts after the first rains, beginning around the end of February. Except for perennial crops as coffee and cocoa and some vegetables, the crops are harvested at the start of the second dry period of the year. Unfortunately, all current satellite images showed bare ground; the SPOT measurements were made just after the seeds had been sown, whereas by the time TM recorded reflectances the crops were already harvested.

Satellite imagery appeared a very useful tool to locate and border forest areas. Forest type classifications will be possible in case site conditions remain relatively constant over large areas (at least 100 ha). Panchromatic RS-images can give some insight in logged areas by detecting logging roads, though boundaries of logged areas cannot be determined, nor the logging intensity.

However, possibilities of satellite imagery for forest management in tropical areas are generally overrated. Satellite images do present a clear view over huge, inaccessible, and/or remote areas, but the applicability for forest management is low due to the small scale of the images and the low geometrical resolution. A serious problem remains the geometrical correction; despite the availability of a GPS, too large errors occurred.
Information needed for proper forest management such as species composition, age classes, and diameter distributions, cannot be provided by satellite imagery. A much better result will be obtained when RS-images are combined with aerial photographs (about 1:15,000), and with fieldwork. Aerial photographs also reduce the amount of fieldwork, especially in tropical forests, were fieldwork is difficult and time-consuming.

## 4.3	Conclusions

General

*	The availability of high quality and recent remote sensing material is indispensable to perform a reliable survey in complex and fast changing environments like tropical rainforests.

* Detailed classification of vegetation and land-types based on satellite images is useless in regions where different land-types occur in small patches. Too many mixed pixels will be created, which make the classification unreliable.
* Distinguishing several agricultural land-use types within an agricultural area might be useless because the reflectance patterns can be highly comparable.
* Visual interpretation of satellite images is not a substitute for supervised classification but a very useful addition.
* Satellite imagery is a very useful tool to locate forest areas.
* The applicability of satellite images for forest management in tropical areas is limited, because the information content is very global.
* Adding information from aerial photographs will improve the applicability of the RS material for forest management purposes.
* Aerial photographs can seriously reduce and facilitate the fieldwork needed to perform classification of RS-images.
* Aerial photographs are absolutely necessary to geometrically locate certain field features in RS-images, especially when reliable maps of the area are lacking.

Taï

* Primary forest can be distinguished from other forest types on RS-images.
* No evidence was found that the differences in reflectances among vegetation types within the park Taï are caused by differences in soil, geology, or relief.

4.4 Recommendations

RS material

Remote sensing material should be of recent date, especially in regions with shifting cultivation or vast exploitation of the forest, to ensure that the RS reflectance values still refer to the present situation in the field. Fieldwork should be carried out in the same season as the RS-images were made. As changes in spectral reflectance during the growing season are species-dependent (Buiten, 1986), the exposure date will strongly affect the species appearance. Application of multi-spectral as well as multi-temporal images may strongly improve the classification results.

An advantage of SPOT is the possibility to attain stereo images, enabling the recognition of height differences of at least five meters. Differences between young secondary forest and old secondary forest can be recognized this way, as well as forest in (inundated) depressions. However, is will be difficult to attain suitable material due to the moist weather conditions in the humid tropics. The use of radar seems to be more promising for tropical areas, as it has the capability to penetrate clouds (Hoekman, 1990).

Methodology

The first problem to deal with is orientation when collecting ground-truth data. If maps and photographs are lacking, a serious problem will arise in areas with large forest areas, as also GPS is unable to calculate coordinates under an (almost) closed canopy. In such cases one should try to make measurements above the canopy. The last option would be to create gaps, large enough to receive the satellite signals.

The accuracy with which objects in the field can be traced will be about 50 meters, coinciding with the accuracy of a UTM grid. This means that an area of at least 2.25 ha is needed to make sure that at least one pixel exclusively represents that area. When the landscape is relatively small-scaled, it is recommended to define rather general land-types (like 'agricultural zone with shifting cultivation') then to try to distinguish every deviating patch. Supervised classification should be combined with visual interpretation.

To monitor changes, regularly (annually) updating the classification map by using the most recent satellite imagery would suffice. Aerial photographs should be taken once in 5-10 years, depending on the rate of change in forest composition and area, to periodically check the RS interpretations. Using a Geographical Information System is highly recommended, as it would facilitate the addition of other geographical information (soils, climate).

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APPENDIX I   'Module 1': project description

PROJECT MODULE 1:

'Classification of vegetation subject to human interference for the Taï buffer zone, by remote sensing and other information.'

Study site

Taï National park, west side of the protection zone (points 1 to 19).

Expected results

Preliminary data for the further development of a useful vegetation classification system for the determination of the conservation state of the protection zone. Qualification of three existing information sources: Landsat TM and SPOT-imagery, ground-truth and archives.

Study methods

Interpretation of available satellite imagery (SPOT and Landsat TM) will lead to the establishment of a first classification system of recognized vegetation cover types. It is unlikely that natural forest vegetation can be distinguished from a forest after low level timber extraction on remote sensing imagery. For this purpose, timber extraction records should be used, to determine the timber extraction levels for different buffer-zone sections (former forest exploitation concessions). Man-made vegetations and natural forest cover can be further distinguished through strip sampling using the recently opened protection zone boundary as a clearly indicated and accessible baseline. Short field trips for sampling purposes can hence procure valuable information on the accuracy of satellite information and timber exploitation records. A list of clearly distinguishable vegetation types with precision factors for each information source should result.

APPENDIX II   Aerotriangulation (after Janssen, 1990)

The procedure consists of the following steps:

On every photograph the overlap with neighbouring photographs was determined. Within these overlapping regions, points were marked, the so-called transfer points. Because each of these points was located in the overlap of a photograph, exactly the same point was depicted on other photographs as well (up to a maximum of 6 photographs in total). The figure below shows this.
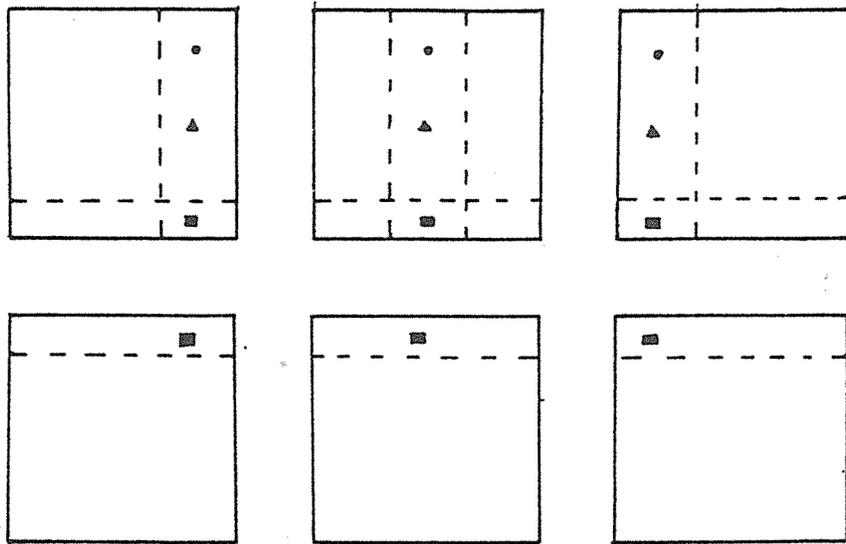
Location of the transfer points on the different photographs

The transfer points were marked on each photograph by means of a stereoscope, using a pricker with prism to match the points. Next, all points were digitized. Of every two successive photographs a model was computed which (among others) computed the common projection centres. These models have camera coordinates. All these models were joined by strip and the strips were joined into one block. By using field coordinates of some points visible on the photographs (so-called ground-control points), this block could be configured to the terrain.

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APPENDIX III Channel properties of the Thematic Mapper and SPOT

Thematic Mapper

Channel 1: 0.45 - 0.52 μm   blue light
       2: 0.52 - 0.60 μm   green light
       3: 0.63 - 0.69 μm   red light
       4: 0.76 - 0.90 μm   near infrared
       5: 1.55 - 1.75 μm   reflection in short wave infrared
       6: 10.40 - 12.50 μm   emission in thermal infrared
       7: 2.08 - 2.35 μm   reflection in short wave infrared

Vegetational information content of the respective wave bands:

1. Chlorophyll absorption in blue. Presumably better discrimination ability for softwood species.

2. Maximum reflection of green leaves in visible light. Discrimination based on types of leaves with similar structure of canopy.

3. Chlorophyll absorption in red. Discrimination based on differences in degree of canopy closure and leaf maturity.

4. Multiple scattering in near infrared (NIR). Usable for detection of differences in leaf area index and biomass.

5. Absorption by water content of leaves in short wave infrared (SWIR). Discrimination based on differences in leaf moisture content.

6. Emission in thermal infrared. Usable for detection of differences in transpiration by vegetation caused by for instance growing stress.

7. Comparable with channel 5.

SPOT

Channel   1: 0.50 - 0.59 μm   green light
            2: 0.61 - 0.68 μm   red light
            3: 0.79 - 0.89 μm   near infrared

SPOT channels 1, 2, and 3 are comparable with channels 2, 3, and 4 of TM respectively.

APPENDIX IV Results of the applied enhancement methods

Band substitution

Because the bands in the visible light of the TM-image were of low quality, the red band of TM was substituted by the corresponding SPOT-band (band 2). Therefor it was necessary to resample the pixels first by means of warping according to the configuration of the TM-image. This band was combined with bands 4 and 5 of TM.

Contrast stretching

Often the amount of grey levels in an image is limited. By distributing the pixel values equally over the entire range of grey steps, the image will show more contrast.

Result: The resulting image was good. Boundaries between different features were rather clear and discrimination appeared to be good. Relief in the forest area was well-visible.

Principal components

Generally, adjacent bands in a multi-spectral image are correlated. Multiband visible/near-infrared images of vegetated areas will show negative correlations between the near-infrared and visible red bands and positive correlations among the visible bands. The presence of correlations among the bands implies that there is redundancy in the dataset. The purpose of a principal components transformation is to transform the elements in such a way that the amount of data is reduced with only a minor loss on information, and to create new bands which are uncorrelated. The outcome of this transformation is image-intensification and data reduction.

The transformation is described by following the equation:

$$[V] = [EIG] \times ([D] - [MEAN])$$

V   the resulting vector with NROW elements
EIG   an NROW by NBAND column matrix with eigenvectors (row oriented)
D   the data vector with NBAND elements
MEAN   a constant vector with NBAND elements
NROW   the number of rows in the matrix which equals the number of components specified for the output
NBAND   the number of columns in the matrix which equals the number of bands in the image.

Result: Settlements and bare soils (features with high intensity values) could be clearly seen on the image. Overall, the image was less clear than with contrast stretching.

Laplace filter

A Laplace filter is a highpass filter. Highpass filtering is being used for sharpening or deblurring of the image by selectively increasing the contribution of the high-frequency components (Mather, 1987).

The convolution is the following:

$$\begin{array}{rrr} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{array}$$

The filter was performed on band 4 and combined with the (plain) bands 5 and 7.

Result: As expected the boundaries of different features were very clear. Further the result was comparable to contrast stretching.

Vegetation index

The vegetation index is a measure for the amount of green biomass present in each pixel. It is calculated as:

$$TVI = \frac{DN4 - DN3}{DN4 + DN3}$$

In which DN4 = the pixel value in channel 4 (near infrared)
DN3 = the pixel value in channel 3 (red light)

Result: It appeared as if elevation differences could be recognized within the forest.

Ratio

Mulders and Pijpers (1991) describe a band combination to extract information from the satellite image for the same area. The calculation of the ratio was done with SPOT-imagery and could be defined as:

$$\frac{2}{1+2+3} \times 50 \qquad\qquad \frac{3}{2+3+4} \times 50 \text{ (band 8)}$$

which is comparable with TM:

$$\frac{3-2}{3+2} \times 50 \qquad\qquad \frac{3-2}{3+2} \times 50 \text{ (band 9)}$$

The band combination for the ratio image became 3,8,9.

Result: This image was too course. Differences in the agricultural zone are reasonably visible, but a lot of detail is being lost.

IHS

IHS stands for Intensity, Hue, Saturation transformation. 'Intensity' refers to the total brightness of a colour, 'hue' to the dominant or average wavelength of light contributing to a colour and 'saturation' specifies the purity of a colour relative to grey. Digital images are typically displayed as additive colour composites using the three primary colours: red, green and blue. Values are given to pixels on a scale of 0 to 255, which represent the brightness of the colours. These values are transformed to the new parameters of intensity, hue and saturation. These parameters give an impression of respectively, relief in the image, discrimination between overgrown and bare soils and biomass.

Result: No recognition possible because there are too much colours, too much patches.

Texture

Texture is the term used to characterize the tonal or grey level variation in an image. The local texture information for a pixel can be extracted from a neighbourhood of 3 by 3 pixels, which represents the smallest complete unit (if 8 directions surrounding the pixel are taken into account). This texture unit is determined by the formula:

$$E_i \quad \begin{cases} 0 \text{ if } V_i < V_0 \\ 1 \text{ if } V_i = V_0 \\ 2 \text{ if } V_i > V_0 \end{cases}$$

in which:

E_i = element i of texture unit set TU = {E1, E2,....,E8}
V_i = intensity value of neighbouring pixel
V_0 = intensity value of central pixel

To label and order the texture units, a texture unit number (N_{tu}) can be defined:

$$N_{tu} = \sum_{i-1}^{8} 3^{i-1} E_i$$

Texture units describe the relative grey level relationships between the central pixel and its 8 neighbours. The statistics on occurrence frequency function of all the texture units is called the texture spectrum. This texture spectrum has discriminating performance for different textures (Wang & He, 1990).

Result: There was nothing visible in the image, except for a line which represented the transition between agriculture and forest. Probably the transitions were too smooth or the window was too small. If there is quite some spatial variation in the image, a small window can cause that differences over a larger distance in every direction are equal and this results in a value of 0.