Working Paper No. 6

ASSISTANCE TO THE FORESTRY SECTOR PHASE -II

BANGLADESH

# REPORT ON THE UTILIZATION OF SPOT SATELLITE IMAGERY FOR THE INVENTORY OF FOREST RESOURCES OF SYLHET DISTRICT, BANGLADESH


Prepared
by

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ACKNOWLEDGEMENT

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## ABSTRACT

Data from SPOT satellite in the form of multispectral (XS) and panchromatic (PAN) imagery with 20 and 10 m resolution respectively have been used for mapping Sylhet forest resources with the support of considerable field data and partial I.R. photo coverage at 1 : 50000 scale. The analysis of XS data and production of False Colour Composites (FCC) through appropriate enhancements and the comparison with panchromatic films have been the object of a study tour to Remote Sensing Centre FAO Rome. Considering the complex, broken morphology of the area and the limited range of SPOT multispectral (XS) data, digital classifications were tried but consequently rejected with the consideration that a visual integreted interpretation could bring more reliable results. In most cases the NDVI (Normalized Difference Vegetation Index) ratio-band combined with the other two visible bands proved most effective for species differentiation and reduction of topographic shadows effects. Hardcopies of FCC with best enhancements for selected forest areas have been produced with a scale of 1 : 50000 and interpreted in combination with panchromatic stereopairs having the same scale.

Panchromatic stereopairs have shown very high interpretability mainly due to high resolution and descernible vegetation texture.

Cost and performance analysis indicates SPOT data (specially on PAN mode) as a good alternative to small scale aerial photography for intermediate forest resources assessment and monitoring for management applications.

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# 1. INTRODUCTION

To provide basic information for the establishment of a Resource Management System (RMS) to assist planning activities of the Forestry Sector, the Inventory Unit of the UNDP/FAO/Government of Bangladesh Project BGD/85/085 has been carrying out inventory work of selected forest resources since 1982 mainly based on 1 : 15000 and 1 : 50000 aerial photography. The inventory of Southern Sylhet Forest Division (Northeast of the country) started in 1986 immediately facing the problems of a very limited photo coverage and poorly mapped data. The 1984 1 : 50000 colour infrared national photo coverage does not reach the India/Bangladesh border, where over 60% of the forest areas are located, this being probably due to non-trespassing limitations. See Annex I. The newly launched French satellite SPOT (Feb '86) with its advanced characteristics has been considered the only valid alternative to provide remote sensing data for the area. (See Annex II. Secondary generation satellites).

## 2. OBJECTIVES

The computer aided Resource Management System (RMS) is based on a stand by stand (or sub-block) description such as area, species, number of trees, mean diameter, height etc. and on growth and yield functions characteristic for species and location. Inventory activities have been designed to provide such informations as detailed as possible. The delineation of sub-blocks includes management considerations more than a simple outlining of homogeneous areas ; sub-block in fact are meant to be unit of operation reasonably uniform by species composition and age classes. The information on density will mostly rely on sample plot data. For this purpose sample plots have been distributed within each sub-block or, for the area where sub-blocks could not be delineated before field work, systematically.

In this framework and with the support of a large number of sample plots (3290 of various sizes) the objective of the digital and visual analysis of SPOT data is to provide support for a guided delineation and consequent mapping of sub-blocks by species composition and age classes for planted areas, and by forest types for natural forest areas (high forest, low forest, scattered trees, bamboos etc.) and to provide other logistic information such as road network and main drainage system for all areas excluded from air-photo coverage.

# 3. DESCRIPTION OF STUDY AREA

## 3.1 THE LAND

As shown on Annex I the forest estate is divided into various forest blocks, located along the axes of six hill ranges projected into the south of Sylhet District from the Indian state of Tripura. All ranges are mantled by Pleistocene clays and sand deposits. Such hills rise from the plain and valleys (10 - 30 m.s.l.) to maximum heights of 150 m on western ranges and of 300 m on eastern ranges.

These relatively low hills show deeply engraved stream courses and steep slopes making a very rough marphology.

Rainfall amounts to over 2500 mm per year with 85% of it (2150 mm) concentrated during the monsoon period April-September. Located between 24° and 25° degrees latitude North the area presents tropical climate with mean monthly maximum and minimum temperature ranging from 27° - 8° (January) and 32° - 24° (June).

## 3.2 THE FOREST

The natural forest can be classified as tropical mixed evergreen with bamboo species as gregarious undergrowth. The natural virgin forest has almost completely disappeared leaving a secondary regrowth with various degrees of density. Large areas of the eastern side have been completely destroyed (by fire or illicit felling, shifting cultivation etc.) leaving an almost pure natural bamboo regrowth (mostly Melocanna Bambusoides) that is managed with a 4 years felling cycle.

Man made forests are mainly composed by teak with various mixture of local species (Dipterocarps spp., Shorea Robusta, Lagoestroemia Speciosa, Artrocarpus chaplasha etc.) for the long rotation working circle and by Abizzia Falcataria for the short rotation working circle. Recently Acacia and Eucalyptus species have been introduced for fuel wood production.

# 4. EQUIPMENT AND MATERIALS

As shown in Table 1, three SPOT multispectral scenes were acquired over the North-Eastern portion of Bangladesh, in the Sylhet region (see figure 1), on November 29, 1986 and six SPOT panchromatic (three stereopairs) on October 23 and 24 1986. Multispectral data have been supplied in the form of Computer Compatible Tapes (CCT) and panchromatic data in the form of 1 : 200000 positive film which have been enlarged to produce 1 : 50000 hardcopies.

Digital products (CCTs 6250 BPI - BIL Format) of the multispectral - XS 20 mt resolution data were processed on the FAO Remote Sensing Centre's 11/73 computer using DIPIX ARIES II software.

Tables 2 and 3 summarise respectively the major features of the SPOT system and the architecture of the FAO-RSC DIPIX System.

SPOT Multispectral

| Miss. no. | WRS(J/K) | Prod. level | Indent. no. | Date | Time |
|---|---|---|---|---|---|
| SPOT 1 | 240-301 | 1B | 169346U | 1986/11/29 | 04H33Mn48S |
| SPOT 1 | 239-301 | 1B | 169344S | 1986/11/29 | 04H33Mn49S |
| SPOT 1 | 239-302 | 1B | 169345T | 1986/11/29 | 04H33Mn8S |

SPOT Panchromatic

| Miss. no. | WRS(J/K) | Prod. level | Indent. no. | Date | Time | Angle |
|---|---|---|---|---|---|---|
| SPOT 1 | 239/301 | 1B | 161125U | 1986/10/23 | 04.45.29 | 11.2E |
| SPOT 1 | 239/301 | 1B | 161203P | 1986/10/24 | 04.26.10 | 21.1W |
| SPOT 1 | 239/302 | 1B | 161126V | 1986/10/23 | 04.45.37 | 11.2E |
| SPOT 1 | 239/302 | 1B | 161204Q | 1986/10/24 | 04.26.18 | 21.1W |
| SPOT 1 | 240/301 | 1B | 161127W | 1986/10/23 | 04.45.46 | 11.2E |
| SPOT 1 | 240/301 | 1B | 161205R | 1986/10/24 | 04.26.27 | 21.1W |

Table 1 : SPOT DATA

PAN data stereopairs have been requested and supplied with a B/H value of 0.5, which is the usual ratio for aerial photograph.

Multispectral image quality of frames 239-301 and 239-302 has been reduced by a cloud coverage higher than expected (SPOT IMAGE specifications gave all quarter image cloud free except NW quarter of frame 239-301 with 10%-25% coverage) and by consistent atmospheric haze. Specifications for the XS bands information content are given in chapter 5.1.1 statistical content analysis.

All PAN images have been utterly cloud free. Photographic quality has been excellent for the first five films supplied but of lower standard for the last film (Id. no. 161205R) where image showed poor contrast.

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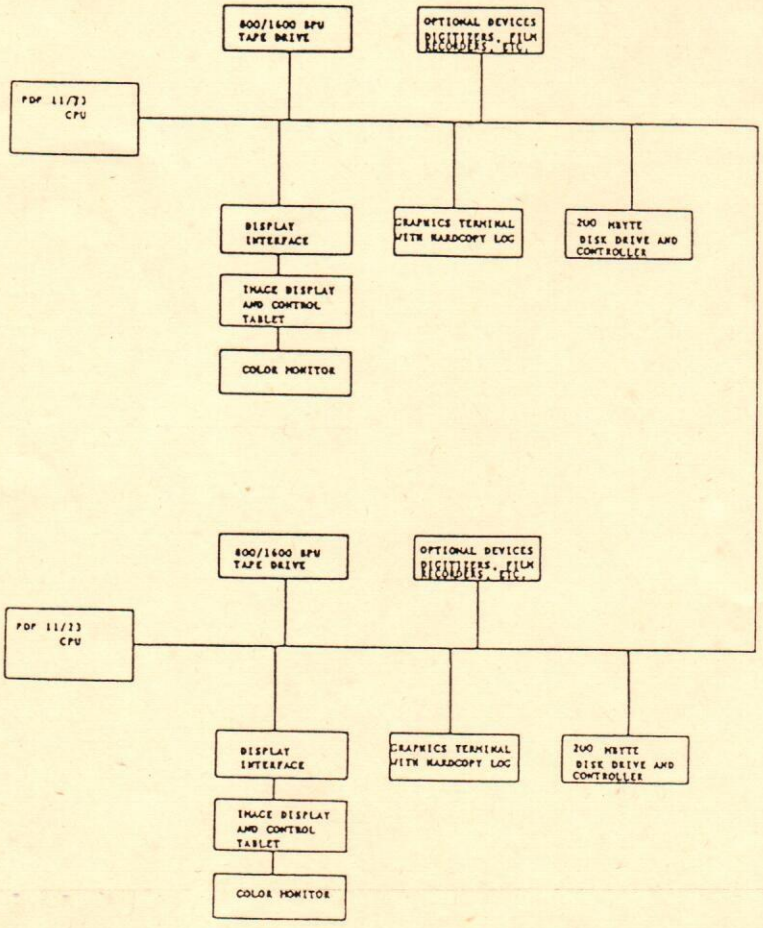
Table 2 : MAJOR FEATURES OF THE SPOT SATELLITE SYSTEM

| | | |
|---|---|---|
| - Pointable, high resolution visible (HRV) imaging sensors (across-track ±27 ) | | |
| - Stereoscopic Imaging | | |
| - Multispectral: | .50 - .59 um (green) | ) |
| | .61 - .68 um (red) | ) 20m Ground IFOV Pixels |
| | .79 - .89 um (near infrared) | ) |
| - Panchromatic: | .51 - .73 um | ) 10m Ground IFOV Pixels |
| - 60 km swath width, each sensor | | |
| - 117 km swath width, both sensors (3 km overlap) | | |
| - 98.7 orbital inclination | | |
| - 832 km orbital altitude | | |
| - 26-day repeat cycle | | |
| - 10:30 acquisition, local solar time | | |
| - Direct X-band telemetry (50M bits/s), or tape recorders | | |

Table 3 : DIPIX SYSTEM. FAO RSC ROME



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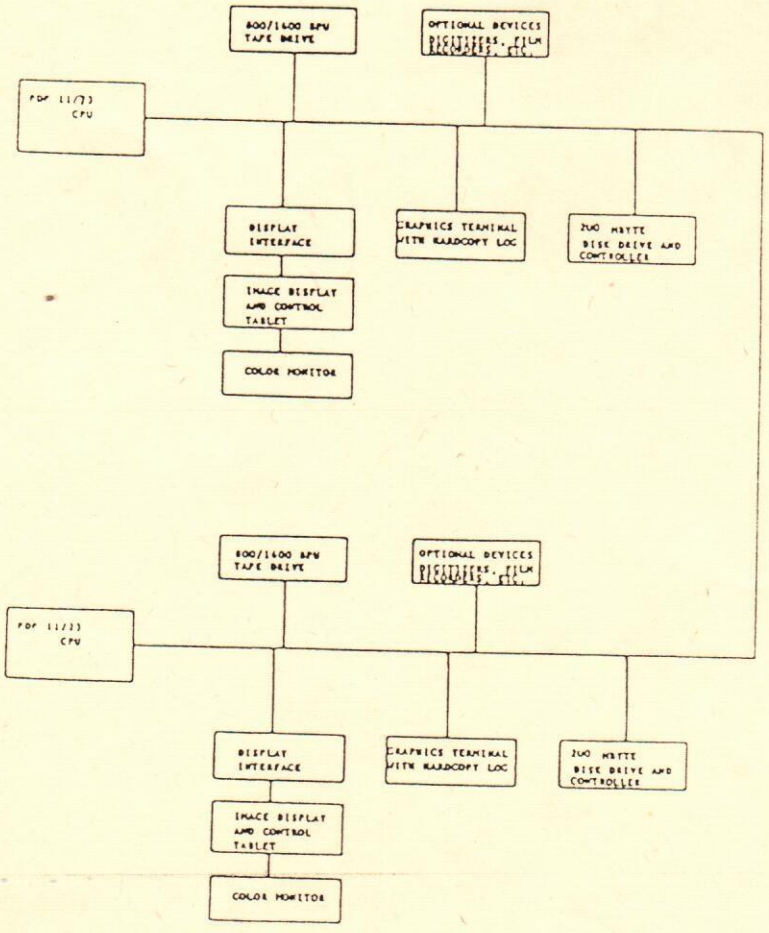


# 5. METHODOLOGY

Two distinct steps can be identified :

- Digital image analysis of multispectral data and production of 1 : 50000 FCC of best enhancement. RSC, FAO.
- Integrated interpretation of multispectral and panchromatic data and comparison with aerial photograph where available. Chittagong, Bangladesh.

## 5.1 DIGITAL IMAGE ANALYSIS

9 study sites were selected from the three original scenes. Listed below are their location, computer area name and size (both in line x pixel and km x km) :

| Site no. | Area name | DIPIX | Line x Pixel | Km x Km |
|---|---|---|---|---|
| 1) | Putijuri | 3A1 | 550 x 500 | 11.000 x 10.000 |
| 2) | West Banugach | 3B1 | 1150 x 550 | 23.000 x 11.000 |
| 3) | Rajkandi North | 3C1 | 750 x 600 | 15.000 x 12.000 |
| 4) | Bathera | 3D1 | 650 x 450 | 13.000 x 9.000 |
| 5) | Raghunandan | 3A2 | 1110 x 550 | 22.200 x 9.600 |
| 6) | Tarap Hill | 3B2 | 768 x 600 | 15.360 x 12.000 |
| 7) | Rajkandi South | 3C2 | 630 x 498 | 12.600 x 9.960 |
| 8) | Patharia | 4A1 | 1600 x 600 | 32.000 x 12.000 |
| 9) | Hararganj | 4B1 | 1200 x 650 | 24.000 x 13.000 |

The first phase of this study consisted of the selection of a test area where computer-assisted techniques, such as statistical analysis, image enhancement and supervised classification were evaluated.

The study area for this test is a sub-area of the site no. 5 (3A2, Raghunandan). This 7.5 x 9.0 kilometers sub-area is primarily dedicated to arboriculture (teak, moluccana plantations) ; the remaining portion includes tea gardens, natural forest and agricultural lands.

The topography is a very important factor affecting the reflectance of the forest and plantation canopy in this area (as well as in all the other 9 study sites) because of its rolling-hilly structure.

This is (as it will be detaily described later) an unfavourable factor because of the "shadow effect" influencing negatively both the automatic and visual discrimination between different cover-types.

5.1.1 STATISTICAL CONTENT ANALYSIS

Statistical analysis of the within-bands correlation was performed in order to evaluate the amount of total information contained in the three multispectral SPOT bands.

Tables 4 and 5 show respectively the 1-D and 2-D histograms for all the bands.

From the analysis of these diagrams it was evident that :

- the dynamic range for all the bands was very little (low variance = poor contrast), 24% of the total available brightness in the best case (band 3, NIR) and 14% and 12% respectively for the visible bands (XS02 and XS01).
- furthermore the two visible bands showed a very high correlation (see table 5C) ; that is, they had almost the same information content.

We reached the same conclusions through Principal Components Analysis : the eigenvalues and eigenvectors (see table 6) show that more than 99% of the total variance of the image was explained by the first two PC (67.95% and 31.57% respectively), while the third one contained predominantly noise.

Also of importance is that the NIR band was the major contributing original band for the first PC (eigenvector = 0.97) end that the second PC appeared to be an equally weighted sum of the two visible bands.

5.1.2 IMAGE ENHANCEMENT

Band rationing, linear and non-linear contrast stretching and spatial filtering were the techniques used in the attempt of producing the best band combination for FCC production.

Band Rationing : The only ratio-band produced and then utilized was the NDVI (Normalized Difference Vegetation Index) defined as the ration (NIR-VIS)/(NIR+VIS) which was proved (Tucker, 1980) being directly proportional to the biomass.

The advantages due to the use of this synthetic band stand in the effect of enhancing variation between different densely vegetated zones, and of partially reducing the topographic shadow effects.

Table 7 shows the NDVI histogram where two main peaks can be clearly identified : one relative to the vegetation, the other relative to the soils.

Finally this band was used in the production of the FCCs of sites 2,3,5,7 and 8.

Linear and non-linear contrast stretching : Efforts were made to optimize the use of this technique by interactively density slicing each of the four bands (three originals plus NDVI) assigning arbitrary colours to different gray levels. By this method it was possible to isolate the ranges of brightness in which forest areas fell for each visible band and for the NDVI, but not for the NIR band which did not show any correlation between the spatial distribution of the brightness tones and the vegetation.

The peaks in histograms in Table 4 were found corresponding to the vegetated (forest, plantations and crop areas) portion of the image.

After this preliminary work it was decided to apply linear contrast stretches over the all range in band 3 (NIR) and over the vegetation range only for the others.

Other non-linear contrast stretches were tested with no significant result. This methodology was then extended to all the 9 study sites with one exception : Tarap Hill, site 6.

Since this area was partially covered by thin clouds which hid land features, the standard linear contrast stretch, based on the parameters extracted from the cloud free portion of the image, produced saturated colours in the cloudy area. It was decided to apply a logarithmic c.s. ($B_{out} = K_1 * (\ln B_{inp} + 1) + K_2$) to the visible bands in order to enhance the dark portion (vegetation)of the histograms preserving the information in the bright (hazy areas) one.

Spatial filtering : Because of the topography of the test area (as well as for all the study sites) and of the particular kind of application, forest-type mapping, any attempt of enhancing the image through spatial filtering techniques did not yield significant results.

It is important to point out that the imageries obtained by the application of 3 x 3, 5 x 5 and 9 x 9 high-pass filters appeared sharper than the original but the features enhanced were primarily the tone variations related to the morphology of the area ; thus the forest tonality variations, depending on species or density changes were reduced.

### 5.1.3 SUPERVISED CLASSIFICATION

Training areas of specific forest and plantation cover types were selected based on ground truth data, namely field survey maps indicating location and density of each of the species under consideration.

9 classes were identified, but in order to take into account the intraclass

variability due to different illumination conditions (sunlighted/shadowed slopes), 15 training areas were defined as listed below :

| | | | |
|---|---|---|---|
| 1 | SUNGRASS | LIGHT | 1 |
| | | DARK | 2 |
| 2 | OLD TEAK | | 3 |
| 3 | 1961 TEAK | LIGHT | 4 |
| | | MEDIUM | 5 |
| | | DARK | 6 |
| 4 | 1975 TEAK | | 7 |
| 5 | 1976 TEAK | LIGHT | 8 |
| | | MEDIUM | 9 |
| | | DARK | 10 |
| 6 | 1978 MOLUCCANA | | 11 |
| 7 | 1982 MOLUCCANA | | 12 |
| 8 | 1983 MOLUCCANA | | 13 |
| 9 | NATURAL FOREST 1 | | 14 |
| | 2 | | 15 |

The statistics (mean values, variance-covariance matrices) of each of the 15 samples were computed and put into a Maximum Likelihood Classifier. Note that 1st and 2nd PC were used instead of the 3 original bands (see statistical analysis). This first attempt yielded no particularly useful results.

At this point it was decide to examine the 2-sigma ellipses of each class through a statistical-graphic program (developed by the image processing consultant)in order to evaluate the inter-class variability. The 2-D plot in fig. 2 shows the fifteen 2-sigma ellipses generated in the PC1/PC2 space.

Most of the ellipses overlap, however, by rejecting the dark and medium subclasses we were left with 8 well separated ellipses (shaded in fig. 2) and one still overlapping, namely 1975 teak, It was finally excluded because could not be separated from classes old teak and 1961 teak.

The exclusion of the shadowed areas yielded much better results in the second ML classification performed with 8 classes (common statistics were computed for Nat. For. 1 and 2), especially after the application of a post-classification filter which allowed the replacement of isolated classified and unclassified pixels with locally dominant classes.

Although improved after the reduction of the classes and the application of the filter, the digital classification technique showed limited sensitivity and could not compete with a visual contestual interpretation of the images where integration was possible with other data sources such as SPOT panchromatic and survey/sampling information.

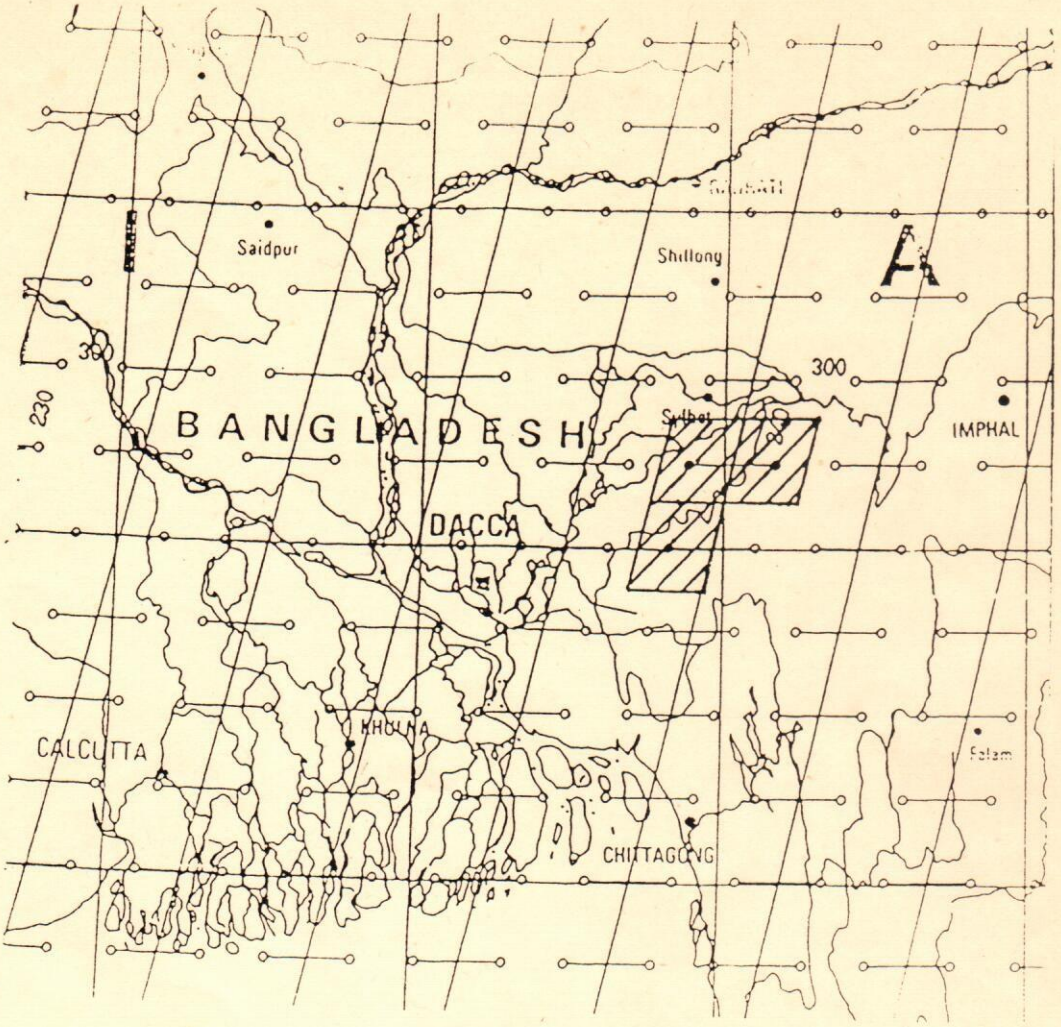



Figure 1

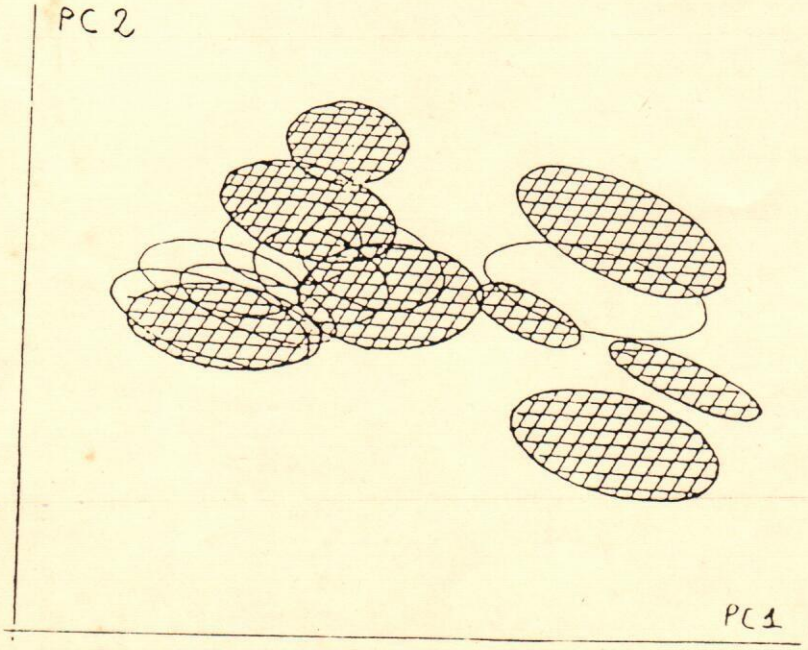
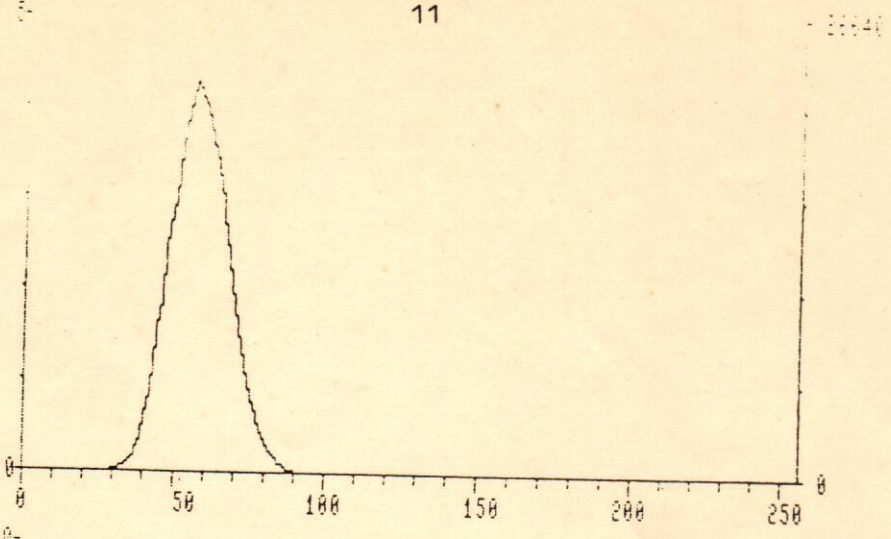
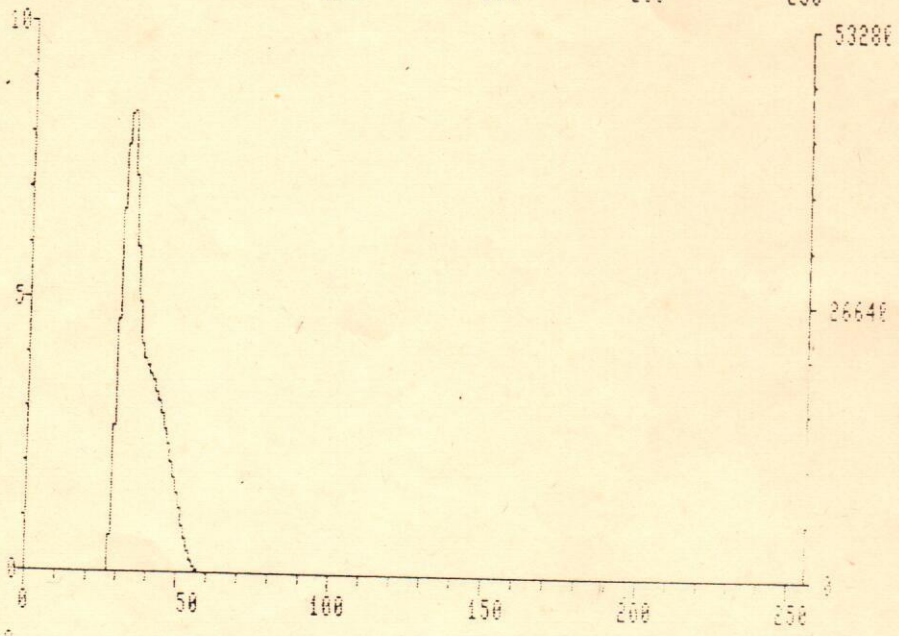



Figure 2

XS03




XS01




XS02

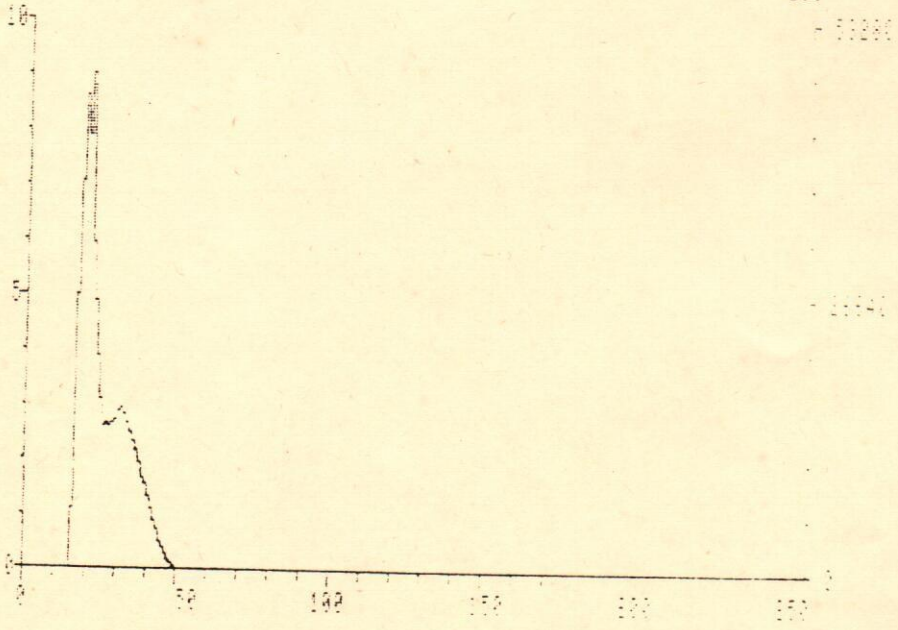
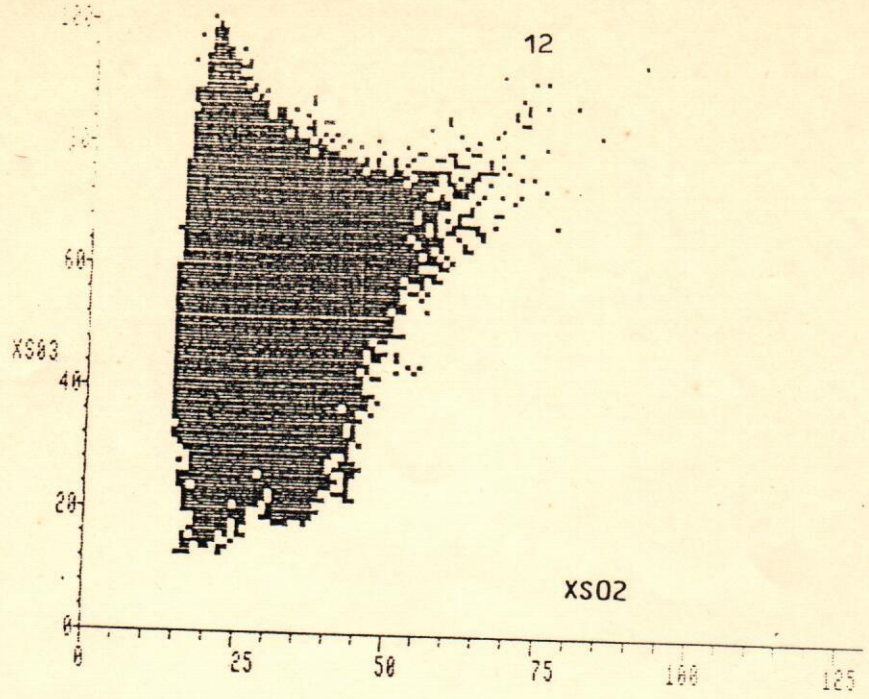
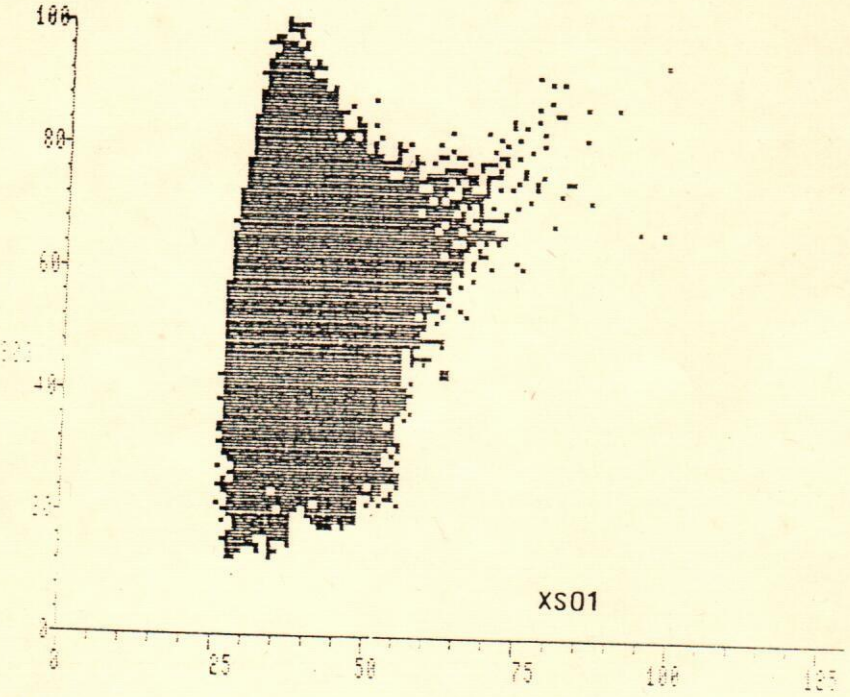



Table 4


12
XS03
XS02
0
20
40
60
0
25
50
75
100
125


XS01
0
25
50
75
100

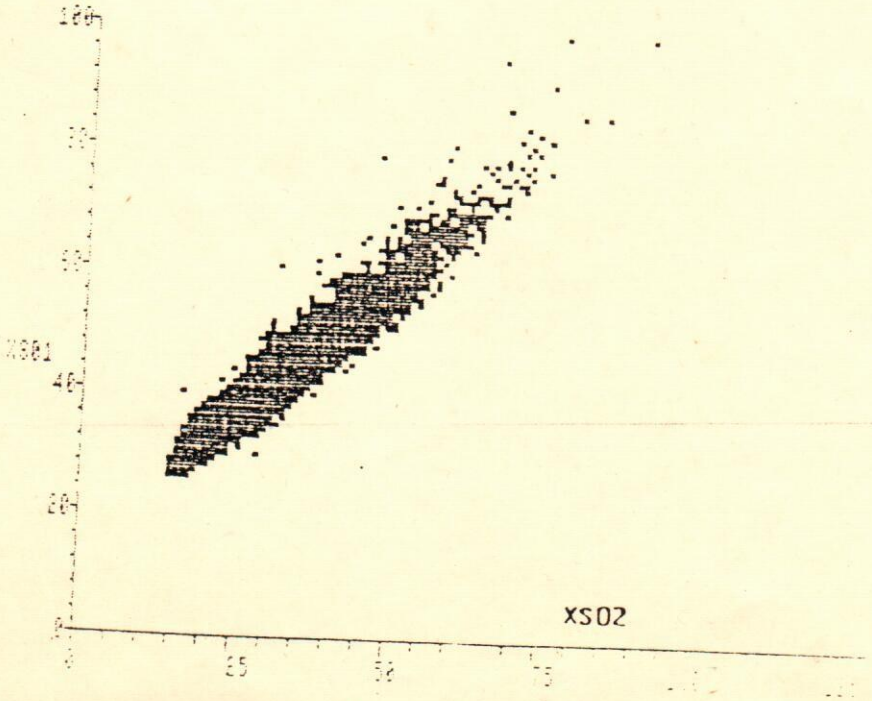

XS01
XS02
0
20
40
25

Table 5

```
 TS    TRAINING AREA FILE (TA)
 TS    SET OF THEMES (TH)
 TS    SET OF THEMES IN TRAINING AREA (TT)
 TS    CONTROL Z IF NO MORE PROCESSING FOR THESE
 TS    FEATURE FILES OR OPTION [IM/TA/TH/TT] (TA) = IM
 TS    POSSIBLE STATISTICS FUNCTIONS ARE :-
 TS    SIGNATURE GENERATION/DISPLAY [SI]
 TS    HISTOGRAM DISPLAY [HI]
 TS    SCATTERGRAM DISPLAY [SC]
 TS    CONTROL Z IF NO MORE FUNCTIONS FOR
 TS    THIS AREA OR OPTION [SI/HI/SC] = SI
  NO. OF SAMPLES     240000.
 FEATURE FILE     MEAN
  3ABFFIS03       59.12
  3ABFFIS02       21.38
  3ABFFIS01       33.62

 TS    TYPE 'Y' TO CONTINUE (Y) =
  COVARIANCE MATRIX
3   99.35
2  -14.18    31.59
1   -1.41    23.88    20.18

 TS    TYPE 'Y' TO CONTINUE (Y) =

19:54:28 *TS    * CREATING FILE 3ABMSENIM
19:54:33 *TS    * EXITING
19:54:39 *IE    * REQUESTED
19:55:14 *IE    * TABLE OF EIGENVALUES AND VECTORS
EIGENVALUE   VECTOR  3      2      1
 102.6903      0.97  -0.22  -0.08
  47.7118     -0.22  -0.74  -0.63
   0.7214     -0.08  -0.63   0.77
```

67.95% } 99.52%
31.57% }
0.48%

FOR 1 ≃ 0.97 * XS3 − 0.22 * XS2 − 0.08 * XS1
(PC1)

Table 6

| | | |
|---|---|---|
| FEATURE FILE NAME | 3A2FFNDVI | |
| HISTOGRAM RANGE | 0 TO 255 | |
| NO OF VALUES IN HISTOGRAM | 256 | |
| BIN SIZE FOR HISTOGRAM | 1 | |
| TOTAL NO OF POINTS READ FROM FEATURE FILE | 532800 | |
| NO. OF POINTS OVERFLOWED AND PERCENTAGE | 0 | 0.0000% |
| NO. OF POINTS IN HISTOGRAM AND PERCENTAGE | 532800 | 100.0000% |
| 1ST NON-ZERO VALUE | 0 | |
| LAST NON-ZERO VALUE | 250 | |
| MEAN OF VALUES IN HISTOGRAM | 127.5222 | |
| STANDARD DEVIATION | 35.0612 | |

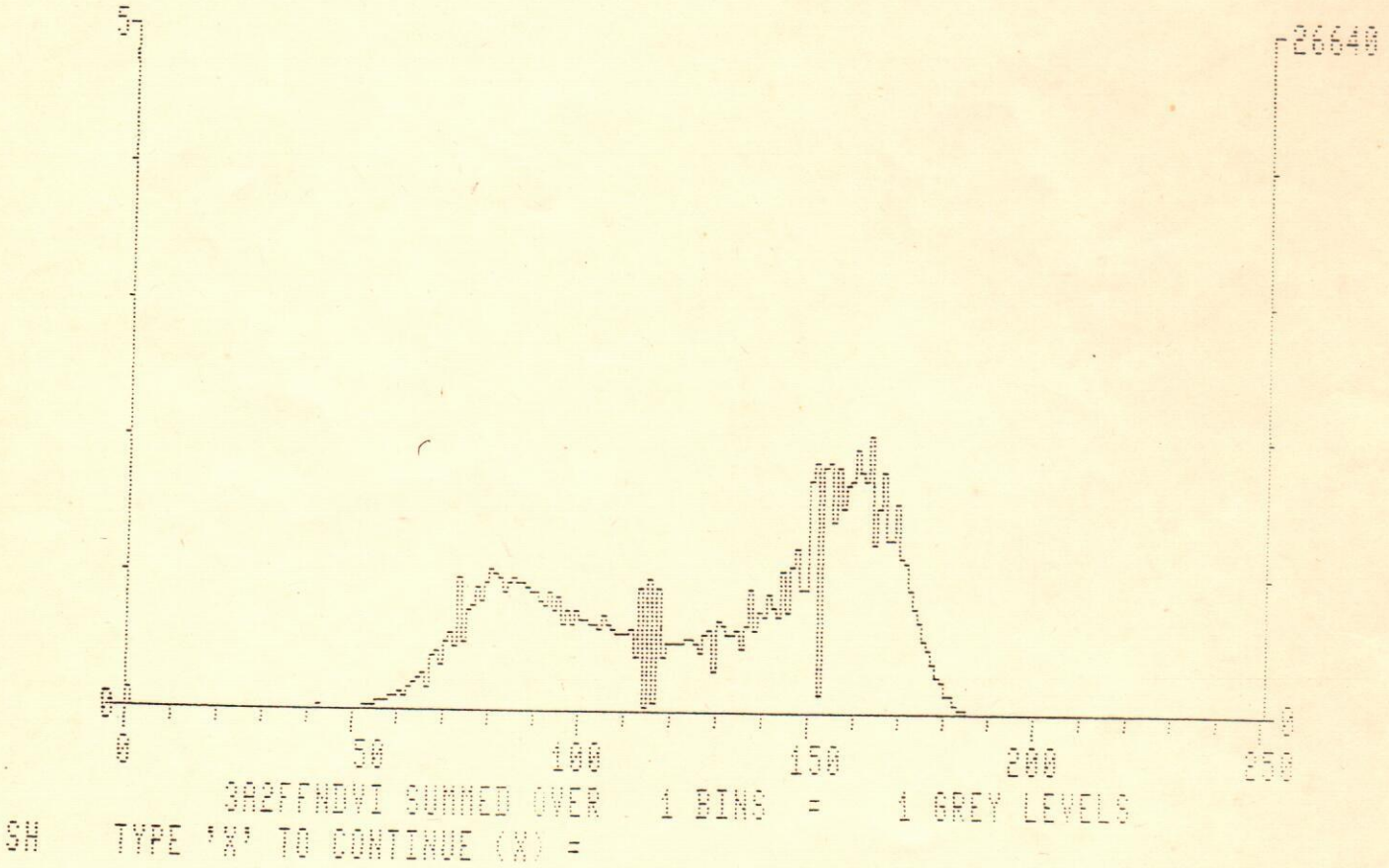



Table 7

5.2 INTEGRATED INTERPRETATION

With all FCC, PAN stereopairs and aerial photographs at the same scale (1 : 50000) interpretation could proceed by stereoscopic viewing, achieving a very immediate and comfortable comparison/combination of all data sources.

Images have been interpreted with the help of TOPCON mirror stereoscope with Parallel Guidance and with 1.8 x magnification lenses. Any stronger magnification could only evidentiate the grain and reduce sharpness.

SPOT data have been compared to air-photo with the purpose to up-to-date previous interpretation with '84÷86 clearing and planting areas or other recent changes and to estimate SPOT XS and PAN interpretability.

SPOT PAN stereopairs with 10 m resolution has proved very rich of topographical informations and considerably sensitive to vegetation texture. SPOT XS has been useful for species and plant formation identification.

Field and administrative data such as :

- Road and paths surveyed with roadside information on plantation age, species etc ;
- Sample plot and transect-line location for easy reference with plot data summaries ;
- Reserved Forest administrative boundaries ;

were reduced to 1 : 50000 scale, traced on transparent film and superimposed to SPOT images to further guide the interpretation.

## 6. RESULTS AND COMMENTS

a - The limited dynamic range of brightness values of SPOT XS bands (12-24% of full range) and a cloud coverage higher than expected have partially reduced the information content.

b - NDVI band - rationing has proved to be in most cases the best enhancement for species and vegetation density differentiation.

c - The considerably high amount of details of SPOT images, both on multispectral and panchromatic modes can be better utilized through contestual visual interpretation than through digital classification.

d - SPOT PAN spatial resolution is sufficiently detailed to give information on vegetation texture and broad height classes. This allowed to differentiate formations with smooth crown coverage from others with coarse crown coverage e.g. Albizia Falcataria vs. Teak ; natural bamboo vs. various proportion of

mixed evergreen forest.

e - The accuracy of interpreted plantation units is directly proportional to their density and differentiation from natural surrounding vegetation. The western forest areas show plantation of average good density and mainly competing with herbaceous undergrowth that allowed accurate delineation while the eastern plantation areas are much poorer and competing with very strong bamboo undergrowth that allowed only a guesstimated delineation of their boundaries.

f - Table 6 illustrates the degree of descernibility of different classes as perceived from SPOT XS and PAN imagery with the support of consistent ground truth data.

g - A comparative analysis of remote sensing material used, in part or in foto for the interpretation is given in table 7. Cost values are taken from table in Annex III modified to include SPOT data costs as per present experience.

h - Table 8 compares the results of independent interpretations of the same area on 1983 1 : 50000 I.R. air-photo and on 1986 SPOT imagery. Considering the objective changes due to the 3 years lapse and a slight difference in forest type, results show that SPOT data can achieve a level of accuracy comparable to approximately 80% of the 1 : 50000 (small scale) air-photo potential.

Table : 6

Classes showing degree of recognizability on SPOT imagery

| CLASSIFICATION LEVEL | | | FEATURE RECOGNIZABILITY |
|---|---|---|---|
| 1 | 2 | 3 | |
| Agriculture & settlements | | | broad class not differentiated<br>very clearly visible |
| Infrastructure | Roads<br>Tracks<br>Paths | | very clear on PAN, visible on Xs<br>clear on PAN<br>somewhere discernible on PAN |
| Forest land | Natural forest | Mixed evergreen large crown<br>= = small crown<br>Bamboo/mixed open forest<br>Pure bamboo | broad class clear on Xs ; crown size sometime discernible on PAN<br>can be identified on PAN from texture<br>visible on PAN texture, confirmed on Xs |
| | Plantations | Long rotation* old ( 30) yr.<br>= = medium (15-30)<br>= = young (5-15)<br>= = very young (0-5)<br>Short rotation** old ( 8)<br>= = young (4-8)<br>= = very young (0-4) | clear on Xs and PAN if dense (closed canopy)<br>visible on Xs and PAN if dense (closed canopy)<br>difficult delineation ; strong undergrowth interfernce<br>clear on Xs, individual years clear on PAN<br>very clear on Xs, visible from PAN texture<br>very clear on Xs, visible on PAN<br>can be differentiated from long rot. only if very good pl. |
| | Marginal | Sun grass (Imperata spp.)<br>Scattered trees | clear on Xs<br>can be identified on Xs ; clear on PAN |
| | Fallow | | clear on Xs and PAN |
| | Protective | Steep slope | visible from PAN stereopairs |
| | Shifting cultvtn. | | clear on XS, very clear on PAN |
| Water bodies | Lakes<br>Rivers<br>Streams (charas) | | clear on Xs and PAN<br>clear on Xs and PAN<br>visible on PAN stereopairs |

* Mainly Teak in pure stands or mixed with Dipterocarps, Lagaestroemia etc. (Classification carried out within Reserved Forests only)

** Only Albizzia Falcataria sufficiently represented.

Table : 7

COMPARATIVE ANALYSIS OF REMOTE SENSING SOURCES

| | 1 : 50000 I.R. Air-photo | SPOT PAN Stereopairs | SPOT XS | Landsat MSS | Remarks |
|---|---|---|---|---|---|
| Special Resol. | 1.5 m<br>Small huts, paths, isolated small trees | 10 m<br>Houses, big trees, larger paths all roads | 20 m<br>Very big houses, cluster of trees, very big roads | 80 m<br>Major features, big rivers, large villages | Linear feature are visible even if narrower than resolution of approx. 40% |
| Topographic details | Very good small stream courses, slopes | Good delin. of streams assessment of slopes | Not suitable but partially helped by contestual data, shades, land uses. Topo features are stressed by principal comp. digital enhancement | Very poor | |
| Vegetation height | Good for general estimate and comparison. Not suitable for individual tree measurement | Sufficient to separate 3 main height classes :<br>Low : 1-10 m<br>Medium : 10-20 m<br>High : 20 m<br>with ± 10 m approximation | Not suitable. Some indication given by shade of large tree stands | Out of range | Estimates are facilitated by sharp height differences |
| Species identification | Good for homogeneous groups on vegetative phase and crown convening undergrowth. Need field verification | Sufficient tone differentiation. Helped by vegetation texture Need field verification | Good species differentiation when homogeneous and sufficiently large. Best results by NDVI digital enhancement. Unreliable for younger stands due to undergrowth interference texture not visible | Good for very large homogeneous stands | Generally helped by regular pattern |
| Cost US$/km$^2$ | 6 | 0.5<br>Film 1 : 200000<br>(0.25 for non Stereopair) | 0.4<br>For CCT<br>0.27 for Fcc<br>1 : 200000 film | 0.1 | |

Table : 8

Results of SPOT imagery interpretation vs 1 : 50000 air-photo interpretation of the same area

| '86 SPOT \ '83 Air Photo | | A | Br | Sun | Y pl | Y Mol | Open Mol | Dense Mol | Open TK | Dense TK | FP | Tea | ST | Tot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture | A | 50 83% | | | | | | | | | (10) | | | 60 |
| Brush | Br | | 0% | | | | | | | | | | | 0 |
| Sun Grass | Sun | | | 205 79% | | (50) | | | | | 4 | | | 259 |
| Young plant (teak) | Y pl | 8 | 5 | | 82 71% | 17 | | | | 4 | | | | 116 |
| Young Moluc. | Y Mol | | | 19 | 4 | 78 77% | | | | | | | | 101 |
| Open Moluc. | Open Mol | | | | | | 38 100% | | | | | | | 38 |
| Dense Moluc. | Dense Mol | | | 8 | | (63) | | 139 66% | | | 2 | | | 212 |
| Open teak | Open TK | | | | | | | | * 0% | 38 | 60 | | | 98 |
| Dense teak | Dense TK | 2 | | | 3 | | | 10 | | 351 80% | 61 | 9 | 5 | 441 |
| Failed plant. | FP | | | 6 | | (9) | | (8) | | 3 | 101 78% | | 3 | 130 |
| Tea Garden | Tea | | | | | | | | | | | 0% | | |
| Scatt. trees | ST | | | | | | | | | 3 | 3 | | 14 70% | 20 |
| | Tot | 60 | 5 | 238 | 89 | 217 | 38 | 157 | 0 | 399 | 241 | 9 | 22 | 1475 72% |

(○) Circled are areas where differences are probably due to 83-86 real changes.

* Type "Open teak" not used on air-photo interpret. where was classified partly dense and partly failed.

Percentage value mean :

$$\frac{\text{"SPOT" area falling into corresponding "Photo" category}}{\text{Total "SPOT" area for the category}} \times 100$$

## 7. CONCLUSIONS

SPOT imagery has proved suitable for management oriented forest resources delineation provided intensive ground truthing, comparable, however, to what is required for small scale photography.

Analysis of costs and performance indicates SPOT as a good remote sensing tool for "intermediate" resources assessment such as updating few years old inventory maps and detailed monitoring work.

In the frame of a 10 years inventory cycle based on medium scale aerial photography SPOT could provide the necessary "fresh" information to support the second five years working plan with limited cost.

Hard copies at 1 : 50000 can be related to base maps as large as 1 : 15000 with a still reasonable richness of details (on PAN made).

Multispectral data should be ordered in case of necessity of species identification (alternative of TM* to be verified for similar areas) and in the condition to avail of image processing equipment and always in combination with PAN data. The use of standard false colour composite (1 : 200000 film) should be investigated.

PAN stereopairs have shown high potential. B/H value of 0.5 gives a good stereo effect but an higher value (0.7 or 0.8) could probably further improve sensitivity to heights.

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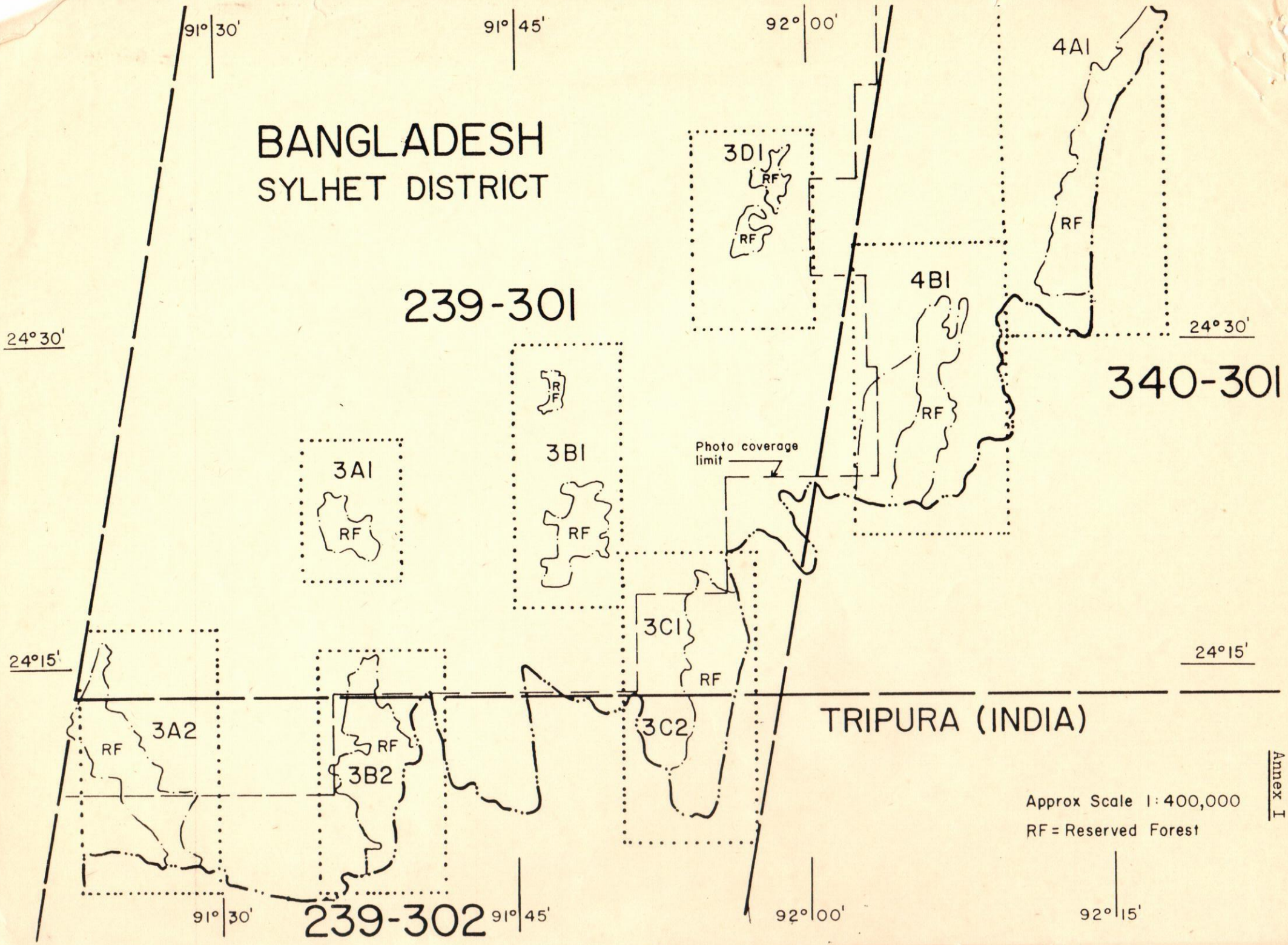
* TM = Landsat Thematic Mapper, 30 m ground resolution, 7 spectral bands.


91° 30'
91° 45'
92° 00'
BANGLADESH
SYLHET DISTRICT
239-301
340-301
24°30'
24°15'
3A1
3B1
3C1
3D1
4A1
4B1
3A2
3B2
3C2
RF
Photo coverage limit
TRIPURA (INDIA)
239-302
91° 30'
91° 45'
92° 00'
92° 15'
Approx Scale 1:400,000
RF = Reserved Forest
Annex I
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