ASSESSMENT OF SPOT SATELLITE DATA FOR TROPICAL VEGETATION INVENTORY AND MONITORING IN SUMATRA

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ABSTRACT

Following a previous vegetation mapping in Sumatra island (Indonesia), an assessment of SPOT satellite capability to handle specific problems related to vegetation identification and monitoring from remote sensing data has been undertaken.

Results of visual interpretation and multispectral analysis have shown the usefulness of SPOT data for the appraisal of tropical vegetation at medium scale. This was particularly striking for the swampy vegetation types including mangroves and for the secondary vegetation, for which significant improvements have been brought by multispectral classifications. A 20 m ground resolution is neither sufficient to provide information on primary forest patterns, nor to identify properly logged over areas. Nevertheless, several degrees of depletion of the forest and all the serial stages have been identified, which is a considerable progress compared with previous remote sensing means.

SPOT is a very good alternative to medium scale aerial photographs for the production of medium scale (1 : 100 000 to 1 : 250 000) vegetation and land-use maps.

BACKGROUND AND JUSTIFICATION

Since 1980 BIOTROP, the SEAMED Regional Centre for Tropical Biology, has conducted not only a mapping inventory of land-use units and natural vegetation types in Sumatra which involves remote sensing analysis, but also very detailed field studies on various plant formations and their dynamics, floristics, structure and ecology. Results have been synthesized in the form of ecological vegetation maps (Laumonier 1983, Laumonier *et al.* 1986, 1987) and related surveys (Laumonier 1981, Blasco *et al.* 1983).

The mapping was mostly done using conventional means, i.e. interpretation of a 1/100 000 scale panchromatic aerial photograph cover (1974-78) which appeared to be of rather poor quality. Moreover, the Landsat MSS imageries have proved insufficient in discriminating many peculiar vegetation or land-use types. This necessitated an unusually detailed field work to supplement the lack of information obtained from space, but it gave researchers of the team a fairly good knowledge of the area.

The second phase of the BIOTROP study implemented in 1988 is concerned with specific areas selected according to management problems spotted during the small-scale mapping phase. Such development schemes would require an elabora-

- various shrubby secondary vegetation types identical from space, but floristically entirely different often mixed with cultivation and usually classified as "mosaics".

A. *Visual interpretation and manual classification*

The visual interpretation of black and white prints allows to differentiate 19 land-cover and vegetation units (Table 4 and Figure 3). The standard FCC gives less information compared with the black and white interpretation of the 3 bands. Improved false colour composites (XS - Bi - Vgi and XS3 - Bi - Vgi) allow a better discrimination of secondary types, burnt or newly planted areas.

B. *Digital classification*

For the scene of Pasirmayang, a multispectral classification has been performed for two windows, one in Pasirmayang area (512 x 512 pixels) corresponding mostly to natural vegetation cover, the other in Sitiung area (512 x 512 pixels) consisting of cultivation and settlements.

XS1, XS2 and XS3 means and standard deviations plotted on bi-dimensional diagrams provide a satisfactory discrimination of vegetation and land cover units (Figure 4). In Pasirmayang window, 10 classes corresponding to 6 vegetation types and 4 other land-use units were recognized (Figure 4, Plate 2), whereas in Sitiung 5 vegetation types and 3 land-use units could be distinguished (Figure 4, Plate 3).

Table 4. Classification of vegetation in Muarabungo's lowland area by visual interpretation

 1. Lowland primary forest
 2. Hill forest
 3. Logged-over or depleted forest
 4. Tall secondary forest mixed with rubber trees
 5. Secondary growth forest mixed with remnant primary forest trees
 6. Secondary growth forest mixed with rubber
 7. Shrubby, thicket secondary vegetation
 8. Young secondary growth forest mixed with shrubs and herbaceous vegetation
 9. Newly planted rubber mixed with young secondary growth forest
10. Grassland
11. Riparian forest
12. Fresh water swamp forest
13. Swampy secondary shrubby vegetation and grassland
14. Paddy field
15. Newly opened, recently burnt area
16. Mosaic of secondary growth and newly planted food crops (paddy, cassava, banana & fruit trees)
17. Fruit trees, coconut and habitat (homestated mixed gardens)
18. Rubber tree estate
19. Bare soil

tion of larger scale vegetation and land-use maps and more precise knowledge and understanding of the land-use patterns identified on remote sensing documents. The very high ground resolution obtained with SPOT offers new perspectives in the mapping of those patterns. A first evaluation of such data was initiated during the PEPS program (Programme devaluation Preliminaire de SPOT) organized by the French Space Agency (Laumonier *et al.* 1987). Its aim was to assess the capabilities of SPOT satellite to tackle some of the most striking problems met during the first phase of the project in Sumatra, specially with the identification and classification of vegetations and land-use units.

The present study is a follow up of this investigation backed up by related researches (Barkey 1987, Djailany 1987, Gastellu-Etchegorry 1988) concerned with an evaluation of visual versus digital interpretations and classifications, a comparison of SPOT data with conventional aerial photographs and Landsat MSS data already analyzed in the area (Deshayes 1981, Ducros-Gambart & Gastellu-Etchegorry 1984, Ducros-Gambart *et al.* 1984) and an assessment of panchromatic (P) versus multi-spectral (XS) mode. It is also supported by the ground sampling already completed by the BIOTROP team for the characterization of complex heterogeneous success-ional stages, primary forest patterns and land-use units in Sumatra (Laumonier 1981, Torquebiau 1986, Djailany 1987).

MATERIALS AND METHODS

Four scenes have been requested both in P and XS modes at the processing level 1B (Table 1) corresponding to specific problem areas in Central and South Sumatra (Figure 1). The Muarabungo area (Western part of Jambi province) has been chosen as an example of a forested area with problems of local agricultural practices and modern plantation schemes. Baturaja (South Sumatra) is the test site for another type of land use where the original vegetation has almost disappeared and has been replaced by complex secondary types. Lastly, the delta of Musi-Banyuasin was selected as a good example of management problems in swampy areas.

The completion of data acquisition during the requested period (1986) occurred over a region where the cloud cover was always very high at the equator. The SPOT lateral viewing capability could be responsible for the relative ease in their acquisition.

The materials used in the study included Computer Compatible Tapes (CCT), negative films at 1/400 000 and 1/200 000 scales for each XS band, standard false colour composites (2 scenes only) at 1/80 000 or 1/100 000 scales, and negative films at 1/200 000 in panchromatic mode.
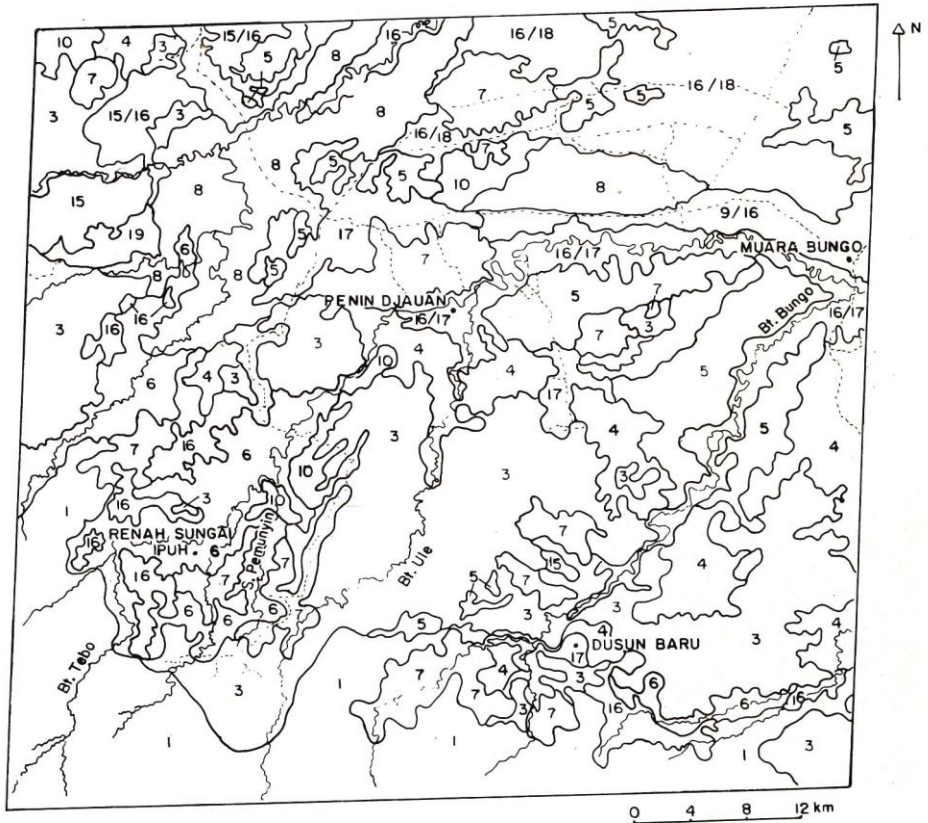
Figure 3. Manual interpretation of vegetation types and land-use units on the black and white SPOT imageries, scale 1/40 000, 1986 (Legend see Table 4).
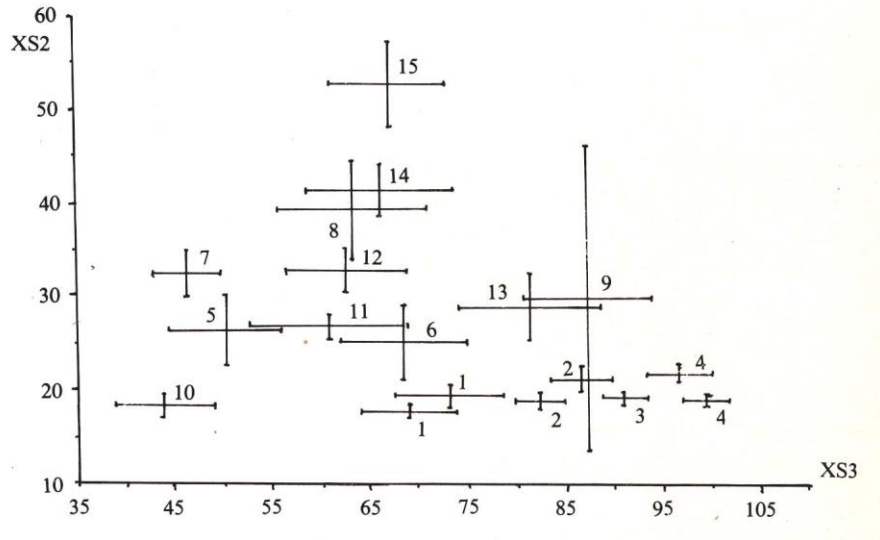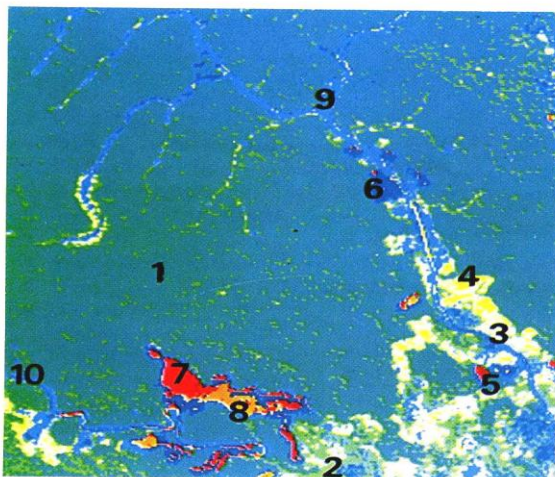
Figure 4. XS3/XS2 diagram of the 15 spectral classes selected in Pasir Mayang scene

Legend: Pasir Mayang

1. Logged-over or depleted forest
2. Tall secondary forest mixed with rubber
3. Secondary growth forest mixed with rubber
4. Rubber tree estate
5. Inundated area
6. Newly opened, recently burnt ("shifting cultivation") area
7. Newly opened, clear felled forest for "shifting cultivation"
8. Newly planted food-crops (dry soil slightly covered by vegetation)
9. Logging road
10. River

Plate 2. Multispectral classification of window Pasir Mayang (512 x 512 pixels)
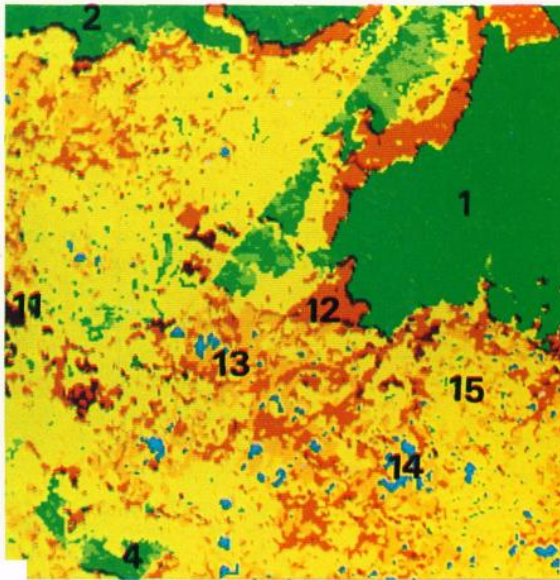
Legend: Sitiung

1. Logged-over or depleted forest
2. Tall secondary forest mixed with rubber
4. Rubber tree estate
11. Recently burnt area
12. Burnt area long time ago
13. Open dry field and shrubby vegetation
14. Gardens mixed with food-crops
15. Habitation

Plate 3. Multispectral classification of window Sitiung (512 x 512 pixels)

The multispectral analysis has brought additional information for some non-vegetated types (5,7,11,12,15; Table 5) which are more or less homogeneous or difficult to separate properly on the black and white prints. The too long period of time separating data acquisition from field check and the dynamic nature of the land use unit types have hampered the proper evaluation of the results of the classification. Some areas classified as "dry open fields" in July 1986 appeared to be rainfed paddy areas in October 1987. All burnt areas (shifting cultivation) face similar problems in that, the spectral response varies a lot between nearby windows (types 11 and 12 in Sitiung and in Pasirmayang for instance). Once again, the problem of having the same spectral value for entirely different object on two different windows and vice-versa hampered the classification in Figure 4. The confusion between classes 8 and 14 or 9 and 13 is obvious. The haze occurring in the Sitiung area may be responsible for the slightly different spectral values compared with the same object in Pasirmayang. A general classification cannot be applied to these two windows. Moreover, the very simple classification method used may be responsible for some difficulties in separating the objects. Separation of spectral value using the box classification method faces the problem of a statistical distribution represented by the standard deviation of the centre point of the box. Furthermore,

Table 5. Spectral characteristics of the 15 classes, defined on a 2 x (512 x 512 pixels) of Pasirmayang scene

Vegetation Types	Pasirmayang		Sitiung		Pasirmayang		Sitiung		Pasirmayang		Sitiung	
	XS1	Sd	XS1	Sd	XS2	Sd	XS2	Sd	XS3	Sd	XS3	Sd
1. Logged-over or depleted forest	32.24	0.96	34.76	1.36	17.78	0.71	19.48	1.3	68.97	4.85	73.16	5.39
2. Tall secondary forest mixed with rubber	33.97	1.21	37.28	1.28	18.88	0.91	21.31	1.21	82.39	2.6	86.67	3.17
3. Secondary growth forest mixed with rubber	34.88	1.02	–	–	19.31	0.72	–	–	91.09	2.4	–	–
4. Rubber tree estate	35.02	0.92	38.51	1.18	19.11	0.71	21.9	0.93	99.47	2.45	96.63	3.36
5. Inundated area	37.39	3.54	–	–	26.49	3.79	–	–	50.38	5.74	–	–
6. Newly opened, recently burnt (shifting cultivation) area	37.92	3.36	–	–	25.24	3.89	–	–	68.48	6.64	–	–
7. Newly opened, clear felled forest for shifting cultivation	42.3	2.74	–	–	32.41	2.56	–	–	46.37	3.32	–	–
8. Newly planted food crops (dry soil slightly covered by shrubby vegetation)	48.29	5.19	–	–	39.45	5.34	–	–	63.39	7.64	–	–
9. Logging road	42.5	12.25	–	–	29.89	16.28	–	–	87.33	6.63	–	–
10. River	31.54	1.26	–	–	18.39	1.23	–	–	43.9	5.02	–	–
11. Recently burnt area	–	–	40.41	1.58	–	–	26.76	1.28	–	–	60.92	8.02
12. Burnt area long time ago	–	–	44.81	2.25	–	–	32.79	2.43	–	–	62.68	6.27
13. Open dry field and shrubby vegetation	–	–	43.12	2.7	–	–	28.99	3.42	–	–	81.5	7.3
14. Gardens mixed with foodcrops	–	–	51.55	2.95	–	–	41.45	2.85	–	–	66.2	7.44
15. Habitation	–	–	60.56	4.52	–	–	52.72	4.62	–	–	67.24	5.92

unknown spectral values are always classified into smaller box and this results in unsolved problems in decision boundaries delineation in a bi-dimensional space.

In the Muarabungo scene, three windows have been chosen (Sei Pemunyin 1 and 2, Rimbo Bujang), each of 512 x 512 pixels. The first two corresponds mainly to tropical rain forest and its degradation types, the third (Rimbo Bujang) to agricultural land-cover types found in transmigration areas.

For this scene, the box classification of XS1, XS2 and XS3 means and standard deviations gathered from the three windows gives 18 classes, 13 representing vegetation types, and 5 corresponding to open areas, roads and rivers (Figure 5 and Table 6).

Results are very similar to those of Pasirmayang. Implementation of that classification into each window needs some adjustments to avoid misclassification. Plate 4, Table 7 and Plate 5, Table 8, are the results of such an implementation. The same problems of some pixel being not classified as in Pasirmayang scene has occurred.

Compared with the classification by visual interpretation of the black and white prints, certain classes (11, 12, 13; Table 4) are very difficult to identify properly in the digital classification process.
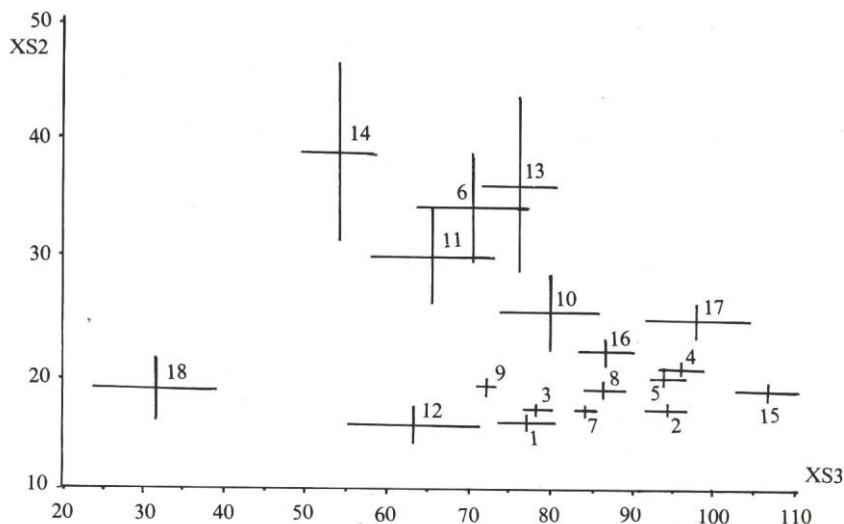
Figure 5. XS3/XS2 diagram of the 18 spectral classes selected in Muarabungo scene.

Table 6. Spectral characteristics of the 18 classes, defined on a 3 x (512 x 512 pixels) of Muarabungo scene

|	Vegetation Types	Pixels	XS1	Sd1	XS2	Sd2	XS3	Sd3
1.	Lowland primary forest	1730	30.83	2.12	16.2	1.44	76.81	7.08
2.	Logged-over or depleted forest	72	33.08	1	17.51	0.88	93.94	5.4
3.	Tall secondary forest mixed with rubber trees	2690	32.52	1.21	17.51	1.27	78.14	6.84
4.	Young secondary forest	370	37.76	1.11	20.99	1.07	95.82	4.96
5.	Secondary growth forest mixed with rubber and shrubs	1469	35.88	2.39	20.24	1.76	93.62	5.63
6.	Newly opened, recently burnt area	238	42.51	5.42	34.38	9.76	70.32	13.64
7.	Secondary growth forest mixed with remnant primary forest trees	713	32.09	1.01	17.28	0.78	84.12	5.63
8.	Mosaic of food crops and sparse fruit trees	893	34.62	1.45	19.02	1.32	86.33	5.13
9.	Rubber tree estate	240	32.66	0.83	19.14	1.12	72.05	2.49
10.	Newly opened, recently burnt area	330	39.31	4.32	25.56	6.46	79.71	12.22
11.	Fruit trees, coconut and habitat (homestated mixed gardens)	401	40.72	4.9	30.18	8.04	65.53	15.42
12.	Riparian forest	452	29.97	1.19	15.91	0.98	63.05	8.18
13.	Road	162	44.36	4.88	36.46	7.66	76.09	4.59
14.	Bare soil	99	44.19	7.08	39.09	15.35	54.23	15.18
15.	Shrubs and grassland alang-alang	406	35.64	0.92	19.14	0.79	106.4	7.81
16.	Newly planted rubber mixed with young secondary growth forest	214	37.75	2.3	22.23	2.31	86.6	6.88
17.	Herbaceous and slightly open area	120	42.23	2.61	25.07	2.94	97.74	12.99
18.	Rivers	15	32.06	8.34	18.6	5.64	31.26	15.68
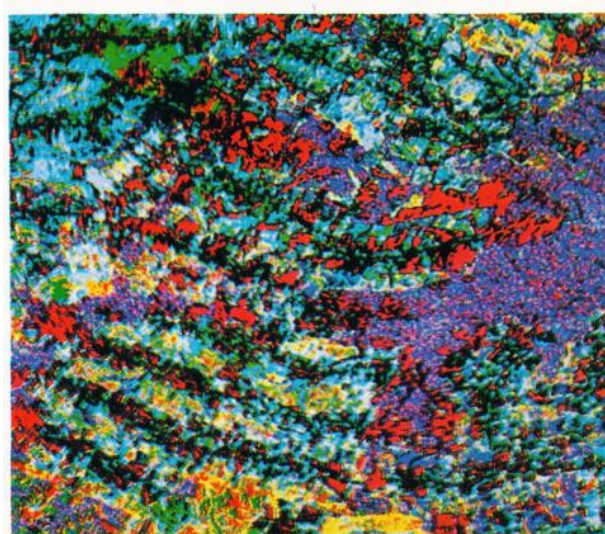
Plate 4. Digital classification of window Rimbo Bujang, Muarabungo

Table 7. Digital classification of Rimbo Bujang, Muarabungo

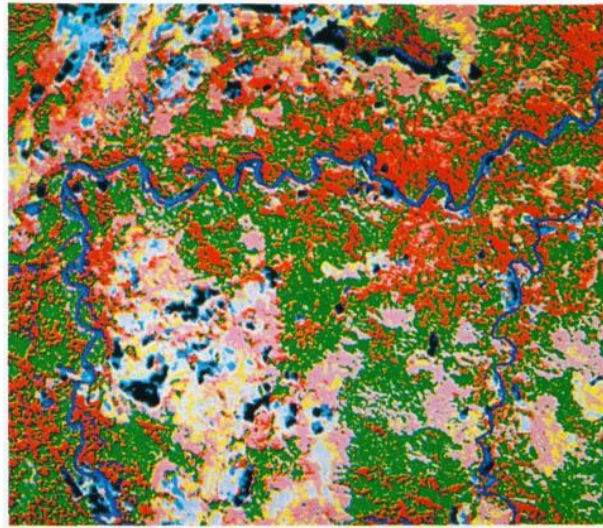| Class	Vegetation Types	Pixels	Surface (ha)	Percentage (%)	Colour
1	Unclassed	5953	238.12	2.3	black
2	Logged-over or depleted forest	16283	651.32	6.2	red
3	Tall secondary forest mixed with rubber trees	9648	385.92	3.7	whitish (bright) red
5	Secondary growth forest mixed with rubber and shrubs	24661	986.44	9.4	pale pink
7	Secondary growth forest mixed with remnant primary forest trees	5940	237.6	2.3	green
8	Mosaic of food crops and sparse fruit trees	20400	816	7.8	yellowish green
9	Rubber tree estate	31970	1278.8	12.2	violet
10	Newly opened, recently burnt area	62956	2518.24	24	brown
11	Fruit trees, coconut and habitat (homestated mixed gardens)	26999	1079.96	10.3	dark purple
15	Shrubs and grassland alang-alang	8315	332.6	3.2	yellow
16	Newly planted rubber mixed with young secondary growth forest	37104	1484.16	14.2	whitish grey
17	Herbaceous and slightly open area	11915	476.6	4.5	dark yellow

Plate 5. Digital classification of window Sei Pemunyin, Muarabungo

Table 8. Digital classification of window Sei Pemunyin, Muarabungo

Class	Vegetation Types	Pixels	Surface (ha)	Percentage (%)	Colour
0	Unclassed	723	28.92	0.3	black
1	Lowland primary forest	21623	864.92	8.3	red
2	Logged-over or depleted forest	62353	2494.12	23.8	pale pink
3	Tall secondary forest mixed with rubber trees	49591	1983.64	18.9	bright red
4	Young secondary forest	11824	472.96	4.5	whitish (bright) red
7	Secondary growth forest mixed with remnant primary forest trees	79407	3176.28	30.3	green
10	Newly opened, recently burnt estate	7042	281.68	2.7	brown
15	Shrubs and grassland alang-alang	11840	473.6	4.5	yellow
16	Newly planted rubber mixed with young secondary growth forest	7191	287.64	2.7	whitish grey
17	Herbaceous and slightly open area	2885	115.4	1.1	dark yellow
18	River	7665	306.6	2.9	blue

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3. Sungai Sembilang — Banyuasin delta

Sungai Sembilang - Banyuasin delta has undergone drastic changes since it has been chosen as a pilot area for transmigration resettlement. In spite of the numerous development aid studies conducted there, it still needs an urgent and accurate monitoring. Mangroves used to flourish in the area and the remaining ones are likely to suffer from high population pressure in the future if not managed properly now. Besides the mangrove belt, the lowland plain is consisting of extensive peat swamps which are also very difficult to manage for agricultural purposes.

Vegetation types which are often difficult to identify and segregate properly are:
- The mangrove forest and the adjacent fresh water swamp forest just behind it (this usually leads to an over-estimation of the actual mangrove area).
- The fresh water swamp forest on alluvium or shallow peat and the peat swamp forest itself on deeper peat soils, altogether with various peat swamp forest types.
- The swampy grasslands and the paddy fields occurring within swampy areas.
- The various secondary shrubby swamp vegetation types and the low natural "pole" swamp forest which look identical when seen from the air. Important to investigate also is the proper identification of such secondary vegetation types like the "Gelam" *(Melaleuca cajuputi)* formations.

A. *Interpretation and manual classification*

The visual interpretation gives very interesting results as all the types are perfectly distinct (12 land cover types), from mangrove swamps, fresh water swamp forest and various peat swamp forest types.

B. *Digital classification*

The multispectral classification performed with SPOT gives 9 classes among which 6 are vegetation types (Plates 6a & 6b). Several types or communities are visible within the mangrove itself, and the distinction between mangroves and fresh water swamp forest is easy.

Possible applications

1. *Well-drained lowlands*

a) Primary lowland forest

Appraisal of the mosaic patterns was studied in panchromatic mode at 1/50 000 scale and with multispectral data. It was impossible in any case to recognize any pattern even if some degrees of natural disturbance could be pointed
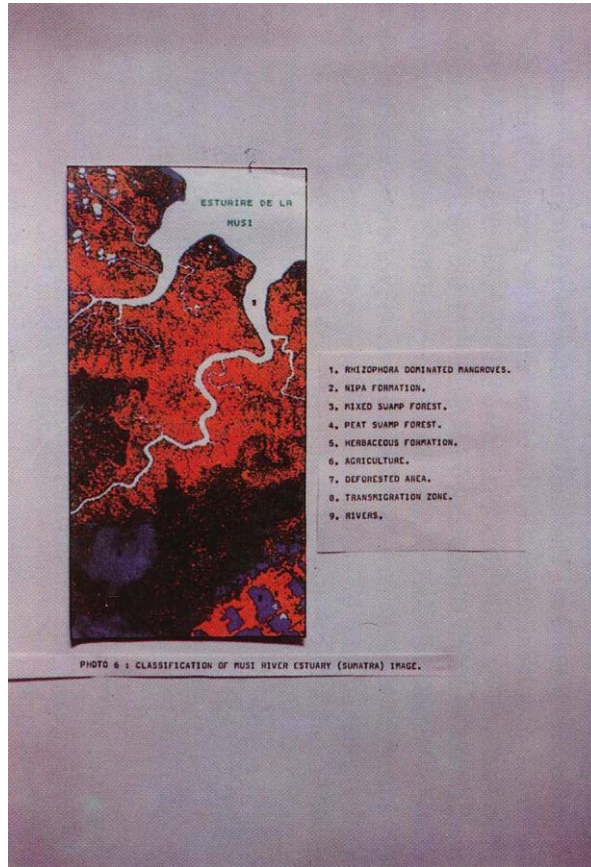
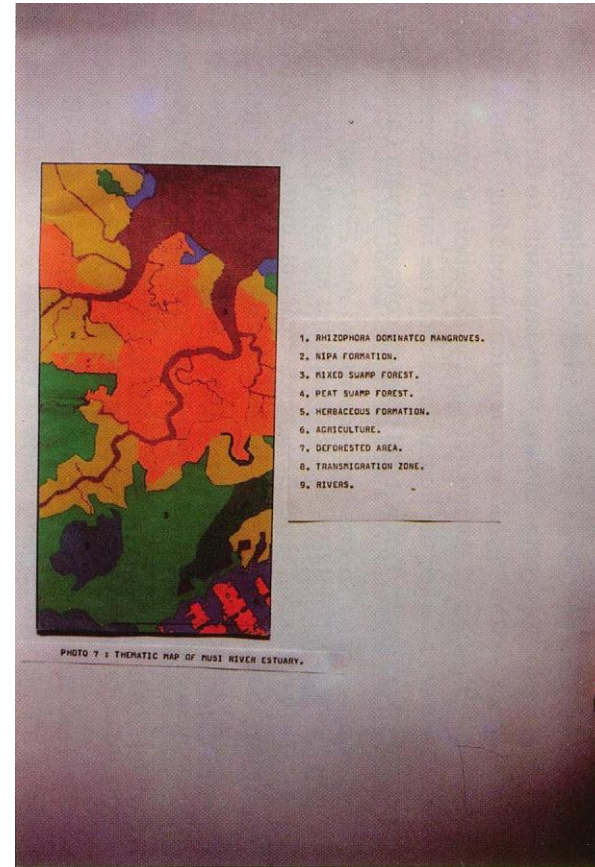Plate 6a. Digital classification of window Sungai Sembilang-Banyuasin delt a (after Barkey 1987)

Plate 6b. Thematic map of window Sungai Sembilang-Banyuasin delta (After Barkey 1987)

out. Riparian forest types, even along small rivers, have been located with accuracy.

b) The logging activities have been easily spotted, but indirectly through the visualization of the logging roads. In fact, it was impossible to differentiate the undisturbed forest from the logged-over one in the surroundings. This is a major concern for an evaluation of the intensity of the depletion of forest resources in the region. However, when the human impact on the forest increases, some degrees of depletion appear. This is a real progress compared with Landsat MSS documents.

c) For the monitoring of serial stages, SPOT capabilities appeared to be most striking. The complete vegetation series from newly clear-cut, burnt, newly planted to young regrowth stages mixed with rubber cultivation can be pointed out. In addition, several secondary forest types mixed with rubber trees, as well as various shrubby secondary vegetation types or low secondary forest types, usually classified as "mosaics" have been discriminated. These results constitute a very noteworthy input for agricultural development of the area.

2. *Swamps*

a) It has been sometimes difficult in the past to separate the mangrove forest from the adjacent fresh water swamp forest. This usually led to an over estimation of the actual mangrove area. The ecotone of those two formations is very clear on our SPOT document (especially on black and white prints). This is due to the perfect delineation of the back-mangrove belt dominated by the palm *Onco-sperma tigillariutn* which is indirectly responsible for the perfect delineation of the mangrove area. In other places, back mangrove hills produced by mud lobsters and invaded by the fern *Acrostichum aureum* give also a very clear white border to the inland limit of the formation. Moreover, at least two if not three mangrove communities can be differentiated.

b) One of the major challenges for the agricultural development of such an area is the distinction between the fresh water swamp forest on alluvium or shallow peat and the peat swamp forest itself on deeper peat soils. Too deep peat areas are very difficult to manage for agricultural purposes. We were able to separate properly on the image the fresh water swamp forest from other types. It was even possible to differentiate several areas according to the thickness of the peat itself by locating easily the "Fresh water swamp", "Mixed peat swamp", and "Peat swamp" forest types.

c) Natural shrubby or very low forest types, sometimes known as "padang" vegetation do occur in the area and are generally confused with secondary types. The spectral analysis has allowed to separate them perfectly.

DISCUSSION AND CONCLUSION

It was possible during the present study to compare the usefulness of SPOT XS and Landsat MSS data for forestry applications using research findings from previous Landsat MSS analysis in Baturaja - Martapura area (Ducros - Gambart & Gastellu - Etchegorry 1984; Gastellu - Etchegorry *et al.* 1985). Some important remarks are stressed below:

- The number of spectral classes that can be discriminated with SPOT XS, i.e. 32, is much larger than the number of spectral classes that can be obtained with Landsat MSS, i.e. 8. This is due not only to the finer spatial resolution but also to better spectral characteristics of SPOT data.

- In order to derive a reliable and precise forest mapping (1:150 000) with Landsat MSS data, it was necessary to define complex algorithms (i.e. multi-textural analysis), whereas far better results are directly obtained with simple photo-interpretation of 1:50 000 SPOT imagery.

- The fine resolution of SPOT data allows to map many earth features such as roads and rivers, which are particularly useful for an accurate spatial registration of the SPOT derived documents and provide opportunities for obtaining at the same time cartographic products. Numerous ground control points which could not be recognized in the Landsat image can easily be located in the SPOT image.

- The only advantage of Landsat imagery was its larger synoptic overview.

Panchromatic documents were only available for two scenes and only in the form of negative films at a scale of 1/200 000 since no CCT were available, the existing black and white prints were not very useful for this work as the level of information for vegetation is quite low when compared with XS data.

The high resolution of SPOT has proved to be of high value in field checking for exact location of the image's features (e.g. small football field in a little village). However, this emphasizes the real necessity for a very fast delivery of data for proper use of remote sensing techniques in tropical environment where the character of most of the land-use and vegetation patterns is so dynamic.

Regarding the identification and classification of the humid tropical vegetation in Sumatra for environmental management purposes, SPOT has brought several advantages and encouraging application prospects:

— *Forestry management*

Several forest types, especially within mangrove and swamp forest areas and also in the uplands, have been discriminated with SPOT data. Even if some of the needs cannot be perfectly fulfilled, e.g. proper distinction between primary and logged-over forest, the fact that degrees in the forest depletion can be pointed out will be of great interest to the forester. Considerable improvement in the identification of serial stages will also facilitate the monitoring of reforestation projects.

— *Land-use management*

The improvement in the identification of some land uses is also striking. Such possibilities as the distinction between newly clear cut fields, burnt areas, and newly planted food crops, will allow easy monitoring of such areas where the shifting cultivation is an important feature of the landscape.

— *Mangrove and swamps management*

The perfect delineation of the mangrove is one of the most beneficial results of SPOT. Many different figures exist concerning the exact mangrove surface in the region. Possibilities of studying on satellite documents what could be the mangrove communities themselves ("*Rhizophora* type" or *"Sonneratia* type") was another interesting aspect which should be investigated cautiously. For agricultural management of the peat area, SPOT provides an excellent tool for an indirect evaluation of the thickness of the peat through identification of specific vegetation types.

Many of the identification problems mentioned above could probably be solved by photogrammetry using aerial photographs at scale of 1:5000 to 1:10 000. However, the cost of aerial cover in such remote places prohibits in most cases their use before implementation of development project. Moreover, there were often difficulties in the past for any extrapolation between the general data provided by Landsat MSS, and the detailed features of large scale aerial photographs.

Only simple digital image processing has been applied in this study. It gives nevertheless interesting results and the improvement of multispectral classifications of high resolution data is challenging for site quality assessment through vegetation appraisal. Increased revisiting capabilities and lateral viewing, together with a better accuracy in the localization of samples offer additional opportunities in the data acquisition and processing. The dynamic character of most of the land-use and vegetation patterns implies that ground verification has to be carried out as soon as possible after data recording.

On one hand, the use and interpretation of classes along the "brightness axis" Was interesting and must be worked out in the future for the classification of spectral classes with sparse or non-vegetation cover. On the other hand, the

"vegetation axis" gives information about the vegetation cover and biomass. The synthesized information that is displayed by Figure 2 is undoubtedly very useful for surveying forested areas, and more especially for estimating the density of the vegetation cover of land cover classes. It can provide preliminary assessment about the vegetation cover of spectral classes that were not identified or checked in the field. Finally, the validity of classes that were supposedly identified either in the field or with aerial photographs can easily be tested. For example, classes corresponding to forested areas should not be located on the "brightness axis".

This study suggests that SPOT is certainly a very good alternative to medium altitude aerial photograph coverage (1/100 000, 1/50 000) and emphasizes its value for tropical vegetation mapping at a medium scale (1/100 000 to 1/250 000) since comparisons of the cost of SPOT data versus other remote sensing tools (Hadjar 1987, Antikidis *et al.* 1988) give also a striking advantage to SPOT.

ACKNOWLEDGMENTS

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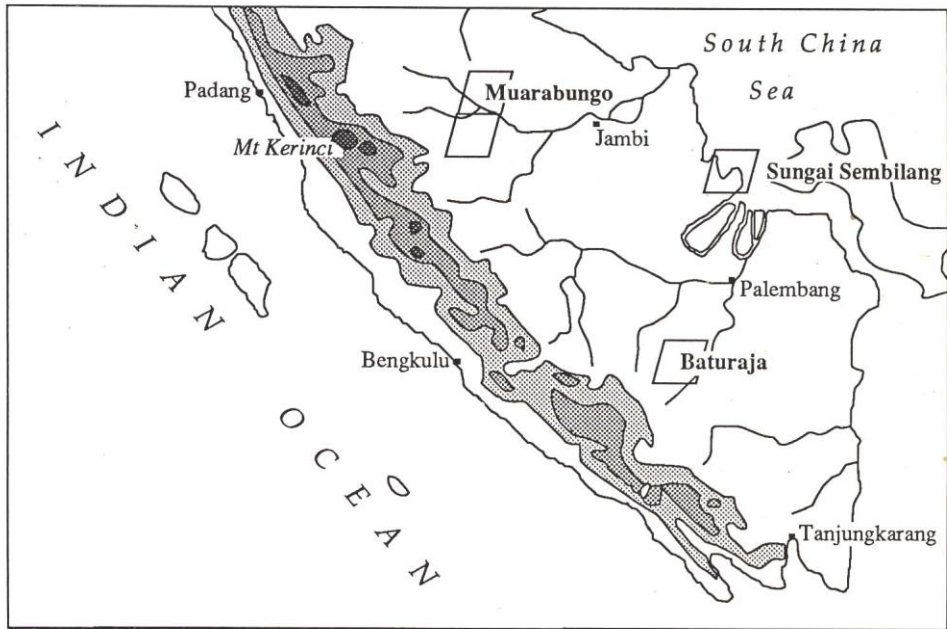TUCKER, C.J. 1977. Spectral estimation of grass canopy variables. Remote Sens, of Environment, 6: 11-26.

Figure 1. Location of study areas

Table 1. Requested products and acquisition scored

Muarabungo	K 272	XS	0000	CCT and film 1/200 000	6'2 w	7.20.86
	J 353	P	0000	film 1/200 000	6'2 w	7.20.86
Pasirmayang	K 272	XS	0000	CCT and film 1/200 000	6'2 w	7.20.86
	J 353	P	0000	film 1/200 300	6'2 w	7.20.86
Sungai Sembilang	K 272	XS	1010	CCT and film 1/200 000	22' w	7.21.86
	J 353	P	–	film 1/200 000	–	not acquired
Baturaja-Martapura	K 272	XS	0000	CCT and film 1/200 000	22' w	7.21.86
	J 353	P	–	film 1/200 000	–	not acquired

3

Both visual and digital analysis techniques have been used. Vegetation sketch maps and land cover classifications were prepared by manual interpretation of black and white XS or standard false colour composite prints at scales varying from 1/50 000 to 1/100 000. For mangroves and swampy areas, other false colour combinations have been used such as XS2 – Bi - Vgi or XS1 - PCI - PC2.

A supervised multispectral classification was performed simultaneously using a Pericolor 1000 system in France and an IBM AT/XT system in Indonesia, by simple visualization of each band using gray scales or colour table and simple transformations, such as band ratios, vegetation indices and principal component analysis. The procedure is similar to the information on techniques extracting developed for soil and leaf area indices (Richardson & Wiegand 1977; Tucker 1977; Rouse *et al.* 1973). Means, standard deviation, range of radiance values as well as coefficient of correlation for the 3 bands were computed for all samples, together with covariance matrix of all classes to assess the value of the classification. To facilitate the visualization of the field site data, XS1, XS2 and XS3 means and standard deviations were plotted on bi-dimensional diagrams. All classes have been checked in the field (one year after data acquisition by the satellite) and eventually redefined.

RESULTS

1. Baturaja - Martapura

The original vegetation is much degraded with typical huge areas of grasslands dominated by *Imperata cylindrica,* various stages of shrub savannas and pseudo-climactic forest type dominated by *Schima wallichii.* Some very degraded remnants of the original forest types and a land-use composed of irrigated or rainfed paddy fields, orchards, rubber plantations, "damar" plantations and reforestation areas are other important features of the landscape.

Some small depressions are common along the streams. A rather large one is found north east of the scene, around lake (Lebak) Datuk. The water level in these depressions fluctuates considerably and during the dry season they are mostly dry.   ,

A. *Visual interpretation*

The classification produced is given in Table 2. These results were used to produce an ecological vegetation map at a scale of 1/250 000 at the request of the Indonesian National Coordination Agency for Survey and Mapping, the BAKOSURTANAL. A total of 23 types were identified and used later as legend of the published map (BIOTROP - BAKOSURTANAL 1988).

Table 2. Classification of the vegetation in Martapura region by visual interpretation

  1. Very depleted lowland forest (high secondary forest with remnant primary forest tree species)
  2. High secondary forest (often mixed with rubber)
  3. Mosaic of high secondary forest and food crop cultivation
  4. High secondary forest dominated by *Schima wallichii*
  5. Shrub, secondary regrowth
  7. Grassland
  8. Swampy tall secondary vegetation dominated by *Melaleuca* sp.
  9. Swampy shrubby vegetation
 10. Swampy grassland dominated by Cyperaceae
 11. Rubber estate
 12. Coffee gardens, often overtopped by fruit trees, mixed with food crop fields
 13. Pepper gardens
 14. Orchards, fruit trees
 15. Newly opened field for rubber and oil palm estate
 16. Dry fields, food crops, mixed with secondary regrowth
 17. Village, habitat and fruit trees
 18. Rice field

B. *Digital classification*

The analysis of visual displays of SPOT data provided the selection of thirty two SPOT spectral classes. Computer screen displays of enhanced SPOT data and SPOT photographic products at a 1/100 000 scale of bands XS1, XS2 and XS3 allowed the identification of most of them. However, some classes (20 to 31) could be distinguished only during digital processing stages (density slicing, image enhancement, etc.). They were not detected with conventional photo-interpretation, and the question of their real existence also arises since, unfortunately, most of these classes could not be identified properly. However, qualitative values of the density of their biomass were tentatively assessed with the aid of techniques developed for extracting information on soil and leaf area indices (Rouse *et al.* 1973; Richardson & Wiegand 1977; Tucker 1977). They can be classified as "sparse vegetation" (29, 30, 31), "rather sparse vegetation" (26, 27, 28), "vegetation" (22, 23, 24, 25) and "green vegetation" (20, 21).

The 32 classes and their characteristics are presented below (Gastellu-Etche-gorry 1988): They are grouped per land cover type and according to their relative position on the "vegetation axis".

Forest

   (1) Primary Forest: tall trees up to 45 - 55 m. Compared to other classes, it is characterized by the smallest XS1 and XS2 radiometric values; i.e. highest absorption by vegetation.

(2) Very depleted forest: result of former exploitation of primary forest followed by local depletion.

(3) Remnant primary forest and secondary growth: external features (roads, etc.) reveal some degradation. Radiometries in bands XSI and XS2 are slightly larger than those of (1).

(4) Remnant primary forest and secondary growth. The proportion of primary forest is less important than that of (3).

(5) Swamp vegetation: Small XS3 radiometric values: XSI and XS2 radio-metric values are larger than those of dry land forests. A "spotted" textural pattern may reveal the presence of the swampy areas.

Secondary Forest

(6) Old tall secondary forest: compared to (7), the trees and texture are similar but the vegetation index (i.e. leaf area index and/or biomass density) is larger.

(7) Tall secondary forest: taller and older than (8); texture may be similar to that of (10).

(8) Low secondary forest: compared to primary forest, the XSI and XS2 radiometric values are larger and the XS3 radiometric values are similar.

(9) Low secondary forest: successional stage before (8), younger and smaller.

Rubber Plantation

(10) Rubber plantation: homogeneous aspect on XSI and XS2 imageries. It is identified thanks to the presence of roads that usually display a geometric pattern.

(11) Young rubber plantation: successional stage after (12).

(12) Newly planted rubber trees: XSI radiometric values are between those of rubber plantation and secondary forest growth, whereas its XS3 radiometric values are smaller than those of rubber plantation, primary forest and secondary forest.

Settlements and mixed gardens

(13) Fruit tree gardens: close to settlements; should be verified in the field.

(14) Gardens and sparse vegetation cover (alang-alang grasses).

Shrubs, herbaceous vegetation and bare soil

(15) Herbaceous vegetation: vegetational stage after (17), it is more densely vegetated (larger vegetation index).

(16) Shrubs and thicket vegetation.
(17) Sparse vegetation cover: bare soil and more or less sparse herbaceous vegetation.
(18) Recently opened area: vegetational stage before (17).
(19) Bare soil.

Non-identified land cover units (assessed through their respective vegetation index; leaf area! index/biomass):

(20), (21) Green vegetation
(22), (23), (24), (25) Vegetation
(26), (27), (28) Rather sparse vegetation
(29), (30), (31) Sparse vegetation.

Water (32)

Moreover, Figure 2 shows that some spectral classes which share similar spectral characteristics cannot be reliably discriminated by spectral analyses only
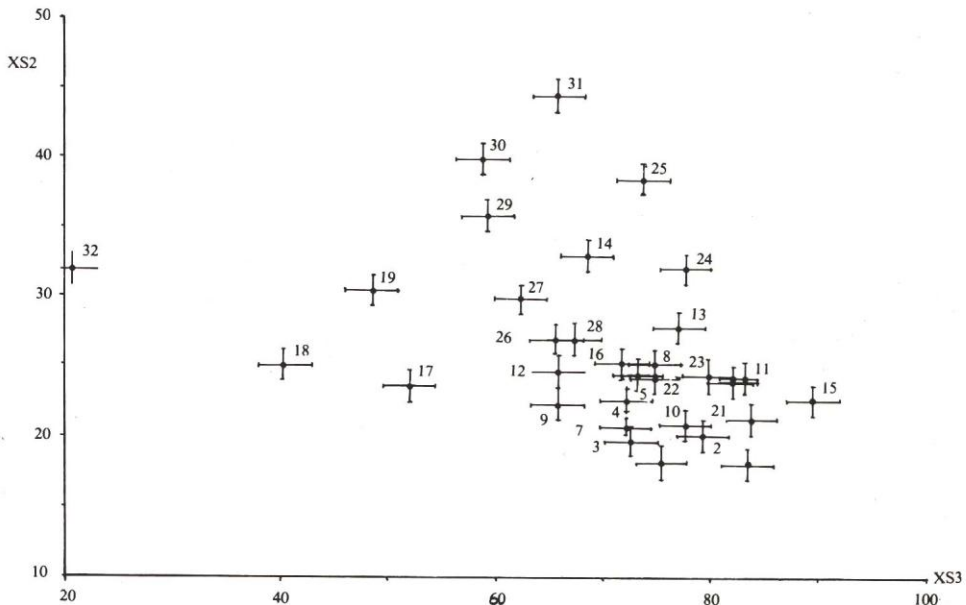

Figure 2. XS3/XS2 diagram of the 32 spectral classes selected in Martapura scene.

i.e. classes (26) and (28), (21) and (11), (8) and (22), etc. In this case, knowledge of the field (if any) and the spatial and textural information which can be extracted from simple photo interpretation of SPOT XS1, XS2 and XS3 imageries must also be inputed (Gastellu - Etchegorry 1988).

In this study, the identification of these classes obviously required additional field checks which were conducted in June 1988. Plate 1 and Table 3 give an example of the reformulation of the 32 classes for one "window of the Martapura scene", after field work. Only 13 classes (11 vegetation types) were actually identified for that particular area, which means that several spectral values correspond actually to one vegetation types. Classes 5,8,22,23,26 and 28 for instance, should be regrouped into class 7 e.g. grasslands, at least as far as identification of the types is concerned.

Table 3. Digital classification of window Batu Marta, Martapura

|	Vegetation types	Pixels	Surface (ha)	Percentage (%)	Colour
0	Unclassed and home-stated mixed gardens (settlement)	14926	597.04	4.8	black
3	Secondary forest mixed with rubber	40617	1624.68	13.2	whitish bright red
4	Low secondary forest and *Schima wallichii*	59524	2380.96	19.4	bright green
6	Shrub, secondary regrowth (newly felled)	4235	169.4	1.4	whitish grey
7	Grassland	52676	2107.04	17.1	yellow
8	Rubber tree estate	93328	3733.12	30.4	red
9	Swampy shrubby vegetation	10737	429.48	3.5	orange
11	Dry field, food crop, mixed with secondary regrowth	12398	495.92	4	dark green
12	Longtime burnt and slightly covered by regrowth	6900	276	2.3	dark grey
13	Recently burnt for estate area	7828	313.12	2.5	brown
14	Swampy area	2388	95.52	0.8	violet
17	River	811	32.44	0.3	blue
18	Sand sediment in the river	782	31.28	0.3	bright blue
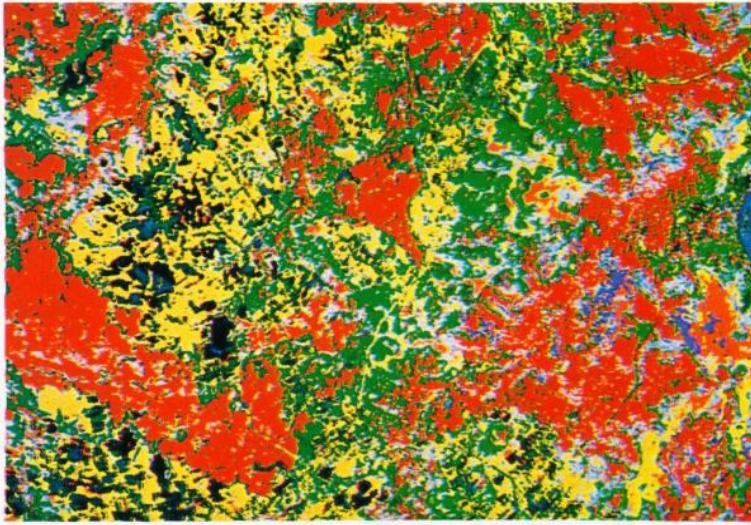
Plate 1. Digital classification of window Batu Marta, Martapura

2. Muarabungo - Pasirmayang

A very peculiar land-use feature is found there. Local people have grown rubber trees since 1910. After about two years of rice cropping, the field is planted
with rubber trees and it gradually becomes a secondary forest mixed with rubber which is rarely cleaned but still used for tapping. This leads to various stages of secondary forests mixed with rubber which are impossible to differentiate from pure serial stages on remote sensing documents. The area still harbours pieces of quite undisturbed forest and large tracks of logged over forests. The landscape is also characterized by large transmigration areas.

In that area, remote sensing encountered problems in identifying and classifying the following vegetation and land cover types:
- the mosaic nature of the primary lowland forest: the tropical forest is highly dynamic and grows in patches, a mosaic of higher and lower forest parts which have their origin in the natural fall of trees or part of the tree crowns.
- the locally depleted forest (local exploitation) and the really undisturbed ones (only industrial logging is recognizable but only indirectly through the visualization of the logging roads).
- low secondary forest types mixed with rubber tree cultivation (managed by local farmers) and pure serial stages without human interferences.

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