AN ASSESSMENT OF MERGED SPOT(P+XS) IMAGERY FOR DETECTION OF DISTURBED HILL FOREST SITES IN PENINSULAR MALAYSIA

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Large and small-scale logging activity is becoming an increasing problem in tropical forests and requires faster and more accurate detection and monitoring. The usefulness of digitally enhanced merged SPOT(P+XS) data in comparison with conventional 1:40 000 panchromatic aerial photography for the identification and quantification of logging roads/forest disturbance was made in a hill forest of northern Pahang, Malaysia. The results indicate that at least six levels of logging road/disturbed site can easily be identified and mapped with a high accuracy when compared with the ground survey. By reference to maps of licensing applications and grants, legal and illegal logging activity can be well separated.

Key Words: SPOT, detection, site disturbance, hill forest

INTRODUCTION

Large and small scale legal and illegal logging activity is becoming a major problem in Peninsular Malaysia and other tropical countries. The problem is particularly acute in the hill forest lands where high rainfall intensities of short duration and susceptibility of the soils to compaction and erosion have accelerated and magnified soil losses, consequently reducing timber and crop yield potentials.

The amount and degree of soil disturbance has increased dramatically with the rise in mechanised and sometimes uncontrolled logging activity for log production and clearing forest land for conversion to agricultural production and urbanization. A study by Kamaruzaman (1988) showed that serious soil compaction occurred on more than 40% of the logged area, mostly along skid trails, secondary forest roads and at logging yards (log landings).

It would therefore be extremely useful to identify, quantify and record such activity especially to help forest managers estimate natural regeneration and enrichment rates or plan compensatory planting with indigenous or fast-growing species to rehabilitate disturbed hill forest areas.

The collection of reliable data to survey and map logging disturbance in the hill forest is difficult. Any estimation by ground survey is confounded by the very large areas involved, difficult terrain, uncomfortable climate and the near-impenetrable nature of the tropical hill forest. The use of satellite image data for forest monitoring seems more promising.

Several studies have used satellite imagery for the delineation and classification of forest areas (see for example Danson, 1987; Hopkins *et al.*, 1988; and Karteris, 1988), some by digital classification and others by visual interpretation techniques.

While most of the studies concerned with delineating forest area or condition have found Landsat TM imagery particularly useful, work aimed at the detection of linear features such as logging roads has mainly utilised SPOT (P+XS) imagery, the increased spatial resolution making a great deal of difference to the successful delineation of these narrow linear features (Rivereau and Pousse, 1988). Occasionally, high spatial resolution SPOT(P) imagery has been used with other lower spatial resolution (but higher spectral resolution) data to obtain the best of both systems.

Jaakkola *et al.* (1988) found that merged SPOT(P+XS) imagery was very well suited for forestry work, especially if visual interpretaion rather than digital techniques classification were employed.The merging of SPOT(XS) data with aerial photography also provides a powerful tool for forest type delineation (Jaakkola and Hagner, 1988).

In terms of identifying linear features, Rivereau and Pousse (1988) found a high degree of success with both SPOT(P+XS) data. Accuracies of over 88% for detection of logging roads were obtained by Jaakkola *et al.*(1988) when using a combination of SPOT(P+XS) imagery.

Most of these studies seemed to indicate greater accuracy when visual interpretation techniques were employed, although some sophisticated digital process such as advanced filtering did show some promise (eg. Jaakkola and Hagner, 1988 and Hagner, 1987).

Satellite data then offers much promise for identifying forest area parameters, in particular logging road activity, but most of the work has previously concentrated on well-managed forest environments where the stands were often of a single tree species type and mostly of coniferous tree forests.

The objective of this study was to examine the usefulness of merged SPOT(P+XS) imagery for the detection, classification and quantification of forest disturbance sites in a natural tropical hill forest area in central Malaysia.

THE STUDY AREA

The study area selected was a 10 x 10 km area in Ulu Tembeling, north Pahang, roughly between longitudes 102° 35' and 103° 47' East and latitudes 4° 20' and 4° 25' North and about 240 km north-east of the Federal capital of Malaysia, Kuala Lumpur (Figure 1). In this area, the forest is composed of mixed hill dipterocarp forest and located mostly over 600 m above sea level. The slope gradient ranges from nearly level to 45°. Annual precipitation in the area is approximately 210cm. Precipitation occurs in two seasons, mainly in April to May and November to December. The relative humidity is high, with a daily mean of 85.7% and ranging from 62.3 to 97.0%. Mean annual temperature ranges from 20 to 31°C.

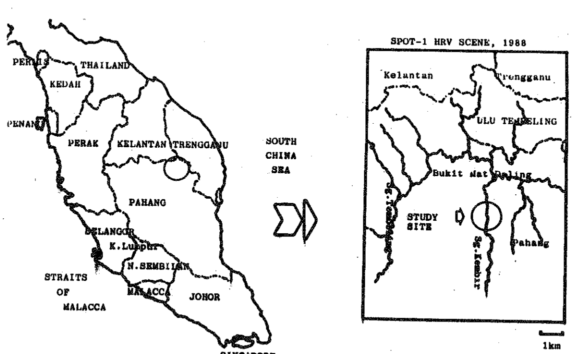

Fig. 1. A map of Peninsular Malaysia showing the study site.

DEFINITION OF DISTURBED SITES

For the purpose of this paper disturbed sites are taken to mean sites which have experienced any direct movement or compression of soil or surface litter as an inevitable consequence of timber harvesting or logging operation. These sites which includes forest roads, decking (log landings) and skid trails are degraded to compacted soil structures resulting in poor regrowth of trees. They can be brought under vegetative/tree cover with reasonable effort and are currently underutilized or areas which are deteriorating due to lack of appropriate water and soil management.

DESIGNING A CLASSIFICATION SYSTEM FOR DISTURBED SITES

A classification system was used to group the different disturbed site categories that need to be identified and quantified.

The classification system used in this study was based on the existing classification system for definitions of forest roads being used by the Malaysian Forestry Department Headquarters, Kuala Lumpur; and the surface soil disturbance category classified by Kamaruzaman (1988). The disturbed sites were grouped and defined into six classes as shown in Table 1.

Soil Disturbance Class	Definitions
1. Primary forest road (PFR)	permanent; connective lines from primary landing to public/access road; road use is for truck, pick-up; road width carriage way including shoulders is about 8 m; road surface is unpaved and very seriously compacted
2. Secondary forest road (SFR)	temporary, connective lines from secondary landing to primary landing/PFR; used by winch-lorry and accessible by truck only under dry condition; road width carriage way including shoulders is about 6 m; road surface is partly unpaved and seriously compacted
3. Skidding road (SR)	used by skidders/crawler tractors; links from the skid trails to secondary landings; forest cover is only cut and some earth is removed; road surface is not prepared; road width carriage way including shoulder is about 5 m; soil surface is moderately compacted
4. Skidding trail (ST)	used by crawler tractor; links from the felling site to SR; forest cover is only cut and no earth is removed; road surface is not prepared; road width carriage way including shoulders is about 3 m; soil surface is compacted
5. Primary log landing (PL)	a cleared area in the forest normally close to the PFR where logs are hauled by a winch-lorry and gathered preparatory to further transportation by the timber jinkers or trucks
6. Secondary log landing (SL)	a cleared area in the forest smaller in size compared to the PL; temporarily located close to SFR where logs are skidded by crawler tractors and gathered preparatory to further transportation by the winch-lorry to a PL

Table 1. A classification system for disturbed sites

MATERIALS AND METHODS

SPOT Data and Aerial Photographs

A selected SPOT High Resolution Visible (HRV) imaging instrument-(P+XS) mode image with spatial resolution of 10 and 20 m, respectively was obtained for the study area (path/row K27/J341, 13 October 1988). The south and east quadrants of the image were covered to some degree by haze and cloud, and cloud shadow. Medium scale (1:40000) black-and-white aerial photographs from August, 1986 (L44S F706) were available and obtained for the study. These photographs served as the baseline information and were used for comparison and analysis, to establish the situation during August 1986, to locate field plots accurately and to assist in the verification of disturbed forest site categories.

Secondary Data

Other material and reference data acquired to support the satellite imagery were Jerantut District Forest Operational Plan Map (scale 1: 63360), Kuala Sat and Sungai Tekai topographic maps (scale 1: 63360), and Forest Resource Map 1981-82 of P. Malaysia obtained from the Forestry Department Headquarters, Kuala Lumpur.

The boundary of each disturbed site was delineated on the aerial photographs and satellite imagery based on features such as pattern, elevation, topography, shape/form and tone/texture, shadow, site/location and homogeneity. Delineation into disturbed site categories were carried out by using aerial photgraphs based on tone, texture and homogeneity. Also, the expected dendritic nature of the hierarchical PFR/SFR/SR/ST networks were relied on for the interpretation phase. Delineation of disturbed sites using satellite imagery were based on differences in the image contrast by visual interpretation of the amount of barren sites that were found in the study area.

The areal extent and distribution of the disturbed sites such as forest roads and log landings were determined from the 1986 aerial photography and 1988 SPOT imagery taken over the same area. It is much easier to establish site disturbance data from aerial photograph and satellite data than by ground survey or from collation of documentation in the forestry departments. A cartometer and a planimeter were used to measure the amount and areal extent of disturbed sites, respectively.

Ground Data

In this study, ground data verification was conducted from April to August 1990 which was about two and four years from the date of the SPOT imagery and aerial photograph, respectively. Due to the slow rate (more than 15 years) of soil recovery in tropical hill forest of Malaysia (Kamaruzaman, 1988), it is assumed that there is no significant difference in the objects observed between the date of imagery/aerial photograph and the time when the ground verificatiion was done.

Image Interpretation Analysis and Mapping

The base map is in the form of clear acetate prepared from Ulu Sat and Sg. Tekai topographic map sheets. The scale is 1:24854 to facilitate direct tracing on the merged SPOT image having the same scale as the base map. Details on the map include boundaries of the study area, major rivers, and logging roads.

For this study, mapping from SPOT imagery is with reference supporting aerial photography. This method has been known to be the fastest and cheapest approach for someone who is not familiar with the area being mapped.

The clear base map was positioned to the SPOT image. Geometric correction of the imagery in this area of highly-varying terrain with many areas without clearly identifiable features such as roads or rivers, and old small-scale topographic maps were difficult so interpretation was carried out with the help of a zoom transfer scope. Interpretation of the image was completed when all the objects (disturbed sites) on the image had been delineated based on the classification system being used.

Field Verification/Ground Truthing

For testing of mapping accuracy, sampling points for each disturbed site category were chosen after careful examination of the SPOT images and aerial photographs. Special emphasis was given where a disturbed site type possessed different spectral responses and where different disturbed site categories possessed similar spectral responses. During the field work, the reasons for such phenomena were investigated.

A total of 300 sampling points for ground truthing were located from the aerial photograph and SPOT imagery. They were selected to represent all categories of disturbed sites classified earlier. The categories of the 300 sample points are distributed among the defined disturbed site classes used (Table 2).

Soil Disturbance Class	1986 Aerial Photo	1988 SPOT Image	Total
1. Primary forest road	23	22	45
2. Secondary forest road	42	38	80
3. Skid road	40	46	86
4. Skid trail	13	8	21
5. Primary landing	2	1	3
6. Secondary landing	5	5	10
7. Forest cover (control)	25	30	55
Total	150	150	300

Table 2. Distribution of total number of samples among classification objects

A stratification system point sampling was used because it was neither possible nor desirable to check everything. A total of 300 reference points were selected for field survey by stratified random sampling within strata. At each field check point, 10 x 10 m square plot was laid out. The general characteristics of this plot such as disturbed site category, slope, aspect, elevation, soil properties and vegetation cover were assessed and correlated with stratified aerial photographs and preliminary image classification of the SPOT data. Slide photographs were taken at such reference point location to demonstrate the forest regrowth and physical properties of disturbed soils. In the field work, classes that appeared in the preliminary classification were identified and located.

Observations were recorded on a ground check data sheet for every location/site visited and were particularly rigorous for those disturbed site category with uncertainities or confusions as detected by the aerial photographs and satellite imagery. All of the data collected from ground truth were used for correcting the primary map to make the disturbed site map showing existing disturbed sites in the study area. The author and two assistants spent 10 days each month for five consequtive month (April to August, 1990) in the field visiting 280 of the sample points.

RESULTS AND DISCUSSION

As a result of development, the natural primary hill dipterocarp forests were disturbed to meet the needs of timber demand. Disturbed sites are quite easily recognized because of their linear shapes and light colour against the dark background. Generally, the disturbed forest sites due to roading and logging activities may be identified and classified as follows: (1) PFR, (2) SFR, (3) SR, (4) ST, (5) PL, and (6) SL.

During the identification of different disturbed site classes, it was found that the spectral differences among them were not always clear. The basic reason to this identification problem is the dominance of mixed pixels in the area. Each pixel corresponded not only to one disturbed site cover type, but in some cases it contained two or more types (mixed site disturbance). The identification accuracy check by sample points is summarized in Table 3.

Soil Disturbance Class	Total Number of sample points		Total Number of sample points correct		Total number of sample points wrong		Overall total points AP+SPOT correct	Overall total points AP+SPOT wrong
	1986 AP	1988 SPOT	1986 AP	1988 SPOT	1986 AP	1988 SPOT		
1. Primary forest road	23	22	23	22	0	0	45	0
2. Secondary forest road	42	38	40	34	2	4	74	6
3. Skid road	40	46	37	42	3	4	79	7
4. Skid trail	13	8	13	7	0	1	20	1
5. Primary landing	2	1	1	1	1	0	2	1
6. Secondary landing	5	5	3	3	2	2	6	4
7. Forest cover	25	30	25	30	0	0	55	0
Overall Total	150	150	142 (94.7%)	139 (92.7%)	8 (5.3%)	11 (7.3%)	281 (93.7%)	19 (6.3%)

Table 3. Accuracy check by sample points of visually interpreted 1986 aerial photograph and 1988 merged SPOT image.

Identification of the SR had the highest number of points incorrectly identified. Three of the sample points mapped as SR were actually ST and the other four were SFR. On the image, these areas appeared identical. More attention to the topography of these areas would have assisted in reducing these errors. Similarly, the sample points mapped as SFR were not correct since they were actually SR. Generally, 93 % of the total number of sample points visually mapped was accurate.

Disturbed forest sites especially the eroded PFR were well identified in the scene at sample points E1 and E2 (Figure 2). In the SPOT 1988 image, visual interpretation was limited by the haze(H) and cloud shadow(CS), particularly in the central part of the scene. Logged-over disturbed forest sites were easily identified at reference points LOX and LOY. New PFR(NP), SFR(NS) and SL(NL) were observed in the image where no logging licences were permitted by the Pahang State Forestry Department to log in the area.

From the delineation of the SPOT imagery and aerial photographs and with some ground checks, it was found that new disturbed sites, particularly the PFR of the study area have been constructed at a rate of 19.4% in two years. This is due to its construction leading to Kg. Bukit Mat Daling in 1988. Detailed results are given in Table 4. Except for the skid trails, the other category of disturbed sites showed an increase of more than 100% within two years.

The image-to-image registration of visual aerial photograph (1986) and SPOT (1988) image (scale 1: 24 854) accentuated changes. For instance, the recovered areas and PFR, SFR, SR, ST and SL that have been illegally constructed from 1986 to 1988, can be detected and monitored. Omissions of some of the SFR, SR, ST and SL in the 1988 SPOT image were due almost entirely to the presence of

Soil Disturbance Class	1986 Aerial Photograph	1988 SPOT Imagery	Percent Change (%)	1990 Ground Check
1. Primary forest road (km)	5.2	6.2	19.4	6.7
2. Secondary forest road (km)	*13.4* 5.4	*8.6* 10.9	*-36.0* 102.6	*3.7* 6.1
3. Skid road (km)	*4.8* 3.6	*3.5* 9.2	*-27.5* 155.6	*2.1* 7.8
4. Skid trail (km)	*1.4* 1.3	*0.3* 1.1	*-92.1* -12.5	*0.0* 0.9
5. Primary landing (ha)	N.A	N.A	N.A	*0.0* 0.1
6. Secondary landing (ha)	N.A	N.A	N.A	*0.1* 0.2

Italicized figures showing the amount of disturbed areas on the left portion of the primary forest roads

Bold figures showing the amount of disturbed areas on the right portion of the primary forest road

N.A - Areal size too small for manual analysis

Table 4. The areal extent of new disturbed sites established in 1988

regeneration and over-hanging trees which obscured the logged-over disturbed sites.

Table 5 shows the change in total disturbed forest sites of the study area based from 1986 aerial photograph and SPOT image at scales 1: 24 854. The amount of disturbances as measured from ground truth is also included for comparison purposes. Table 5 shows a decrease of 0.66 km of ST annualy. The decrease in areas classified as ST were attributed to the increase in residual forest cover due to secondary regrowth/vegetation after two years. On the other hand, there is an increase in roading activities, especially that of the PFR and SFR. As a result, there is a decrease of hill dipterocarp forest area which is probably due to the cutting of logs by the villagers and illegal logging since logging licences agreement have not been given since 1985 for this area. The decrease in areas classified as ST is due to those areas that have already been covered with grasses, herbaceous plants and shrubs. As seen from Table 5, the PFR disturbance category showed an increase of 8.2 % from 1988 to 1990 due to its increasing use by the villagers for transporting illegaly cut timber for personal use, such as boat making and house constructions.

Object/Soil Disturbance Class	1986 Aerial Photo (a)	1988 SPOT Image (b)	1990 Ground Check (c)	Annual Change (b-a)/2	Roading Density[1] (km/ha)	Percentage of logged-over concession forest area[2]
1. PFR (km)	5.2	6.2	6.7	0.5	0.0029	0.23
2. SFR (km)	18.8	19.5	9.8	0.4	0.0104	0.62
3. SR (km)	8.4	12.7	10.0	2.1	0.0046	0.23
4. ST (km)	2.7	1.4	0.9	-0.7	0.0015	0.04
5. PL (ha)	N.A	N.A	0.1	-	-	-
6. SL (ha)	N.A	N.A	0.4	-	-	-

[1] Based on a logged-over concession forest area in 1986 of 1 815 ha.

[2] Based on a logged-over concession forest area in 1986 of 1 815 ha and width of disturbed sites as defined in the classification system for disturbed sites.

N.A - Areal size too small for manual analysis.

Table 5. Site disturbance changes of the study area

Further ground validation and field checking of the initial interpretation further increases the accuracy of the interpretation. This is specially true for areas misinterpreted and classified as SR. After ground validation and field checking it was found that there were no more areas left as SR and the interpretation was changed from SR to ST. Areas classified as PFR have been visited during field checking and ground validation proved as such. This was further supported by the fact that these areas are still bare in 1990 and with a few sites being eroded.

Combining the 1988 SPOT and 1986 aerial photograph images provides valuable additional information. For example, the combined images can be used to map areas that need rehabilitative efforts for soil and water conservation in optimizing forest lands productivity.

CONCLUSIONS

The present study demonstrates that merged SPOT (P+XS) data is a valuable satellite remote sensing technique to identify, quantify, map and monitor six classes of disturbed sites in hilly terrain of the tropical hill dipterocarp forests of P. Malaysia with an accuracy of about 93%. Unpermitted logging on a small scale basis by the nearby villagers can be well separated with references to maps of licensing applications and grants. However, it is emphasized that interpreters should have prior knowledge on the topography and the soil disturbance pattern of a logged-over area to be mapped before actually begining with image interpretation.

This information when used along with information on other natural resources like soil, water, and geology, can be used as a data base for the decision maker, particularly for forest engineering operations, management, conservation and rehabilitation planning for the optimum utilization of hill forest sites and following purposes: (1) forest road construction planning, policy, strategy and timber harvesting guidelines, (2) selection of areas for rehabilitation - it is important that those areas disturbed be restored as productive forest areas. One of the solutions to achieve the desired target is by establishing forest compensatory plantation programme.

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