

APPLICATION OF LANDSAT DATA FOR  
THE MANAGEMENT OF FOREST RESOURCES

Yukio Mukai, Sataro Tanaka, Shoji Takeuchi

Remote Sensing Technology Center of Japan  
Uni-Roppongi Bldg., 7-15-17, Roppongi, Minato-ku, Tokyo

Iwao Nakajima, Itsuhito Ohnuki

Forestry and Forest Products Research Institute Experiment  
1, Matsunosato, Kukizaki-mura, Inashiki-gun, Ibaragi Pref.

Hiroshi Watanabe, Ryoji Hatamura

Japan Forest Technical Association  
7, 6-bancho, Chiyoda-ku, Tokyo

ABSTRACT

This is a research paper which investigated the availability of Landsat data for forest type classification, timber volume estimation, yearly growth estimation and deforested area monitoring. Two test areas, one is about 15 km by 15 km and the other about 30 km by 25 km, were selected as study areas. A forest area extending in the west and south slope of Mt. Fuji, there being wide artificial plantations and ground truth data of their timber volumes and yearly growths being available, is used for the evaluation of timber volume and yearly growth estimation by Landsat data. As for the study of deforested areas monitoring, another test area where proper aerial photographs for its evaluation were available is selected.

The forest type of the test area can be classified into three age-classes (young, middle, old) of cedar and cypress, broad-leaved trees and needle-leaved trees in a high mountain area such as fir or spruce using two temporal overlapped Landsat data of May and December. Landsat data about 16 points in the artificial cypress plantations where timber volume and yearly growth data were examined on the ground were taken and using those paired data of Landsat data and timber volume or yearly growth, regression analysis were made. Landsat MSS Band 5 shows highest and negative correlation with timber volume and yearly growth, and multiple correlation coefficient was about 0.8 for timber volume and about 0.7 for yearly growth.

Two Landsat image obtained at an interval of several years were overlapped for the test area and a difference image was generated by subtracting the older image from the later one.

Areas composed of pixels more than a certain threshold level in the difference image were extracted as deforested areas and they were examined using two aerial photographs covering the test area obtained at an interval of several years. Cutted areas between two Landsat observation's time could be detected by an accuracy more than 90% and an deforested area as small as the size of one hectare, 100 m by 100 m, was discernible.

1. INTRODUCTION

Forest land covers large part of the land about its thirty percent, in the world, therefore remote sensing technology can be expected to be applicable in the various fields of forestry. Forest type classification, timber volume and yearly growth estimation and deforested areas monitoring might be important subjects for the management of forestry. In order to study the

usefulness of Landsat data for the above subjects, two test site were selected where timely Landsat data and ground truth data were obtainable.

A forest land (named "Fuji" in this paper), about 15 km by 15 km extending in the south and west slope of Mt. Fuji was selected as a test area for the study of forest type classification and timber volume and yearly growth estimation.

As the elevations of the test area cover a wide range from, 400 to 2500 m, there are various kinds of trees, which may be a good test area for forest types classification study. At lower elevation less than 1000 m, artificial plantations of Japanese cedar and cypress are dominant, and in the middle elevation, from 1000 to 1500 m, artificial plantations of Japanese cedar and cypress are extending but mixed with broadleaf trees, and in the higher elevation upper than 1500 m, there are needle-leaved trees such as fir. As artificial plantations are dominant in the test area, data on tree species distribution, age-classes of trees, timber volume and yearly growth are well prepared, which is the reason why it is selected as the test area.

A forested area (named "Ohme" in this paper), about 30 km by 25 km, where deforestations are likely to occur because it is near the big city, Tokyo and, its forested parts are apt to be converted to residential areas or agricultural fields.

## 2. STUDY PROCEDURES

Figure 1 shows the flow diagram of the procedures taken in this study. Test site Fuji and Ohme are included in one scene of Landsat data "Fujisan", identified by Path 116 Row 35 in Landsat WRS (World Reference System). Following four 116-35 Landsat data were gathered and used for this research.

Date of Observation	Dec. 15 '72, Feb. 25 '73
	Mar. 29 '79, May 22 '79

Ten or more GCP's (Ground Control Points) are selected in each gathered Landsat image and a new geometrically corrected Landsat image (called Landsat Map) covering only the test areas is generated from each original Landsat data by nearest neighbour resampling using 1st order affine Transformation introduced from GCP's data. Multi-temporal overlapped image covering the test area can be generated by overlapping each Landsat Map registering pixel by pixel.

An investigation tour for ground truth was made and the ground truth data indicated in Figure 1 were collected. The authors carried pictures photographing Landsat Map images being used for analysis afterwards and various kinds of informations obtained through the investigation tour were written in them, which were very useful for the coming analysis.

A forest type classification was made using two temporal Landsat data of Dec. '72 and May '79 by a supervised maximum likelihood method. Landsat data of 16 points where timber volume and yearly growth data are known by the ground truth investigation were taken in the multi-temporal image of Feb. '72 and Mar. '79.

Next, relationships between Landsat data and timber volume and yearly growth were examined by a regression analysis and their estimation images for the test area were generated using multiple regression equations.

As for deforested areas monitoring, a multi-temporal Landsat image of Feb. '72 and Mar. '79 was used. An image was generated by subtracting the older image from the later image of Band 5 and patches whose pixel values are higher than a certain threshold level in the subtraction image were extracted as deforested areas, and it was examined using aerial photographs taking the test area whether those extracted patches were deforested areas.

### 3. FOREST TYPE CLASSIFICATION AND TIMBER VOLUME AND YEARLY GROWTH ESTIMATION

#### 3.1 OUTLINES OF THE TEST AREA FUJI

Outlines of the test area Fuji are shown in Figure 2.

The elevations of the test area, extending along the slope of Mt. Fuji, the highest mountain in Japan, cover a wide range from about 400 m to 2500 m.

Forest types of the lower forest and the higher forest separated by an elevation line of about 1000 m are pretty different. Most of the lower forest are managed by private owners and rich in artificial plantations of middle or old age-classed Japanese cedar or cypress characterized by relatively high timber volume and yearly growth. Higher forest areas, on the other hand, are under the management by the Government and in its lower part whose elevations are between about 1000 m and 1500 m, artificial plantations of Japanese cypress, pretty part of which are in young age-class, are dominant but broadleaf trees whose leave fall in winter, can also be seen here and there. In the highest area, where the elevations are more than 1500 m, there are semi-alpine plants such as fir, spruce and larch.

#### 3.2 FOREST TYPE CLASSIFICATION

Two temporal Landsat data, Dec. 12 '72 and May 22 '79, when spectral characteristics of vegetation are very different each other, are used for the forest type classification. Those two geometrically corrected Landsat Map are overlapped pixel by pixel and Band 5 and 7 data are extracted from each Landsat Map and they were merged to form a multi-temporal data composed of four bands, Band 5, 7, 5 and 7. Using this data a forest type classification was carried out by a supervised maximum likelihood method. Supervised method needs a training area which is a sample area representing a forest type to be classified and training areas for each forest type are designated at the time of classification using the forest type distribution data collected through the ground investigation.

The classification categories for forest type are as follows:

1. Japanese cypress-1 (Young age, very low timber volume)
2. Veitch fir-2, 3. Japanese cypress-2 (Middle age, low timber volume),
4. Japanese cypress-1 (Old age, high timber volume), 5. Larch,
6. Broadleaf tree, 7. Veitch fir-1.

Figure 3 shows the characteristics of multi-temporal Landsat data of training areas for each forest type and Figure 9 and 10 respectively show the false color image and the forest type classification image for the test area Fuji. The old, middle and young age-classes of Japanese cypress, in this classification, mean respectively more than about 40, 40-15 and 15-0 years old.

According to Figure 3, the old and middle age-classes show similar characteristics in Dec. data but different in May data and young age-class of Japanese cypress, which appears as grass land because grasses on the ground are exposed as young trees are still very small, shows similar in May data but different in Dec. characteristic with broadleaf trees. In this manner, the use of two temporal Landsat data, summer and winter, increases the capability of forest type classification. It can be read from the classified image that forest types are roughly classified into three classes, in accordance with the elevations, which are very similar to the features as delineated in Figure 2.

It is found that artificial plantations of Japanese cypress can be classified into three age-classes using two temporal Landsat data if the

proper training areas for the classification can be set up, and the availability of tree age classification will suggest the possibility of the estimation of timber volume and yearly growth by Landsat data.

### 3.3 ESTIMATION OF TIMBER VOLUME AND YEARLY GROWTH

Forest areas are usually managed by the unit of a small area called "Rinpan" as big as several hundreds meter square established for convenience of forest management and various kinds of data concerning the forest management such as forest type, tree age, timber volume and yearly growth are collected and arranged by the unit of Rinpan. Those data of typical Rinpans, mainly of artificial plantations of Japanese cypress, and relatively as large as to be recognizable on the image at the time of analysis are gathered through the ground investigations.

Three kinds of temporal Landsat data, Feb. 25 '73, Mar. 29 '79 and May 22 '79 and Band 5 and 7 of each same as the forest type classification case are used for this analysis. Landsat data of spots where timber volume and yearly growth data are known by the ground investigation are taken on the image of the test area produced on the CRT of a image processor. Finally, 16 pairs of data relating Landsat data with timber volume and yearly growth were obtained and they were put forth for the regression analysis resulting to find some relationships between them.

16 pairs of data used for the regression analysis are shown in Table 1 and Table 2 and 3 are resultant correlation tables. Equations obtained for timber volume and yearly growth estimations using Landsat data are as follows;

$$\begin{aligned} V &= -30.5 X_1 - 16.2 X_3 - 9.1 X_4 + 955.5 \\ G &= -0.30 X_1 - 0.16 X_2 - 0.60 X_3 + 0.15 X_4 + 16.4 \\ V: & \text{timber volume m}^3/\text{ha}, \quad G: \text{yearly growth m}^3/\text{ha}\cdot\text{year} \\ X_1: & \text{'73 2/25 B5}, \quad X_2: \text{'73 2/25 B7}, \quad X_3: \text{'79 3/29 B5} \\ X_4: & \text{'79 3/29 B7}. \end{aligned}$$

Figure 5 and 6 show respectively correlations of timber volume and yearly growth between estimated values from Landsat data and ground surveyed data.

Estimation images of timber volume and yearly growth from Landsat data using the above equations are shown in Figure 11 and 12. In Figure 11, timber volume is sliced at 50 m<sup>3</sup>/ha interval and in Figure 12 yearly growth at 2 m<sup>3</sup>/ha·year. According to Table 2 and 3, it is found that both Band 5 and 7 show negative correlations with both timber volume and yearly growth and that Band 5 shows higher correlation than Band 7, and the use of multi-temporal data increases the multiple correlation coefficient up to 0.822 for timber volume and 0.736 for yearly growth. Moreover it can be said from Table 2 that Feb. or Mar. data are better than May data for timber volume estimation because the correlation coefficient, in the case of using both Band 5 and 7, of Feb. or Mar. is higher than that of May.

Timber volume and yearly growth estimation image, Figure 11 and 12, are very similar, which suggests there are much relations between the two. It can be read from those estimation images that forests of high timber volume and yearly growth are extending in the lower areas than 1000 m elevation line, and forested areas in the middle elevations between 1000 m and 1500 m show very low timber volume but some value in yearly growth, whose reason is because timber volume of the young age trees in a forest area is considered to be very little but their yearly growth to be pretty high. These images generated from Landsat data are considered to be pretty applicable for estimating timber volume or yearly growth of artificial plantations.

#### 4. DEFORESTED AREAS MONITORING

A forest area "Ohme" in Tama hill about 30 km by 25 km where deforestations are likely to occur because it is located near to a megalopolis, Tokyo, is selected as a test area for study of Landsat data availability for deforested areas monitoring. Two Landsat data, Feb. 25 '73 and Mar. 29 '79 covering the test area at the interval of several years were collected.

Spectral characteristics of deforested areas usually become higher, as shown in Figure 4, in all Bands of Landsat data than forested areas because grasses there were under trees are exposed to surface owing to deforestation and they usually show higher spectral reflectance than trees. Therefore deforested areas can be monitored by subtracting Landsat data before deforestation from that after deforestation. Band 5 is considered to show the most difference between after and before deforestation because Band 5 reflectance by trees decrease as they grow. A subtraction method of Landsat data before and after deforestation was examined in this study for deforested areas monitoring.

##### 4.1 PROCEDURES OF DEFORESTED AREAS EXTRACTION

Procedures of deforested areas extraction by subtraction methods are shown in Figure 7. Landsat images should be geometrically corrected and overlapped pixel by pixel before subtracting a image from the other image. Landsat Map  $T_1$ ,  $T_2$  are geometrically corrected images covering the test area of Landsat data taken at different time  $T_1$ ,  $T_2$  and they are already adjusted to overlap pixel by pixel. Next they should be radiometrically corrected because the two Landsat data are not taken under the same radiometric conditions, for conditions affecting the radiometric intensity such as attenuation by atmosphere, sun irradiance and senser sensitivity are different at each observation time of those Landsat data.

The radiometric correction was made by a method of using a training area which is a basis between the two Landsat images. Urban areas or bare soils may be a good training area as their reflectivities are considered to be not so changeable at any observation time of Landsat data. An urban area within the Landsat Map is used as a training area for the radiometric condition in this study.

Regression coefficients were computed via the regression analysis between the two Band 5 image data of pixels within the training area and Band 5 image data of Landsat Map  $T_1$  were converted using the regression coefficients obtained. A first order regression equation was used in this case.

A subtraction image was generated by subtracting Landsat Map  $T_2$  from  $T_1'$ , the converted image of  $T_1$ , using the regression coefficients. Subtracted values will vary in both positive and negative sides centering around zero and in a small range within several counts. Therefore the subtraction image was generated being normalized with the standard deviation of the errors by the regression, which act as a contrast stretch, and given a offset to get rid of negative image data.

Incidentally, some statistical data obtained in the process of the generation of the subtraction image are as follows;

Regression: Band 5 of Mar. 29 '79  $\rightarrow$  Band 5 of Feb. 25 '73

Regression equation:  $y = 0.85584X - 6.12221$

Standard deviation of the errors: 4.66, F-value: 17568

Correlation between Band 5 data of two Landsat data: 0.88291

As the older image data were subtracted from the later one, deforested areas will show higher values and areas trees have growed, to the contrary, will show lower values in the subtraction image. It is convenient for

understanding to slice the subtraction image at the interval of the standard deviation as the subtraction image is generated being normalized with the standard deviation. Finally, the patches whose pixel values are higher than 2.0 sigma are extracted to be probable deforested areas.

Figure 13 shows the extracted areas obtained via the process mentioned above for the test area Ohme.

#### 4.2 EXAMINATION OF THE EXTRACTED AREAS BY THE SUBTRACTION METHOD

Extracted areas by the subtraction method using Landsat data were examined if they were deforested areas using the aerial photographs. Observation times of Landsat data and aerial photographs used for this study are as shown in Figure 8 and their timings are not exactly synchronous.

LT<sub>1</sub>, LT<sub>2</sub>: Older and later time of Landsat data, Feb. 25 '73 and Mar. 29 '79

AT<sub>1</sub>, AT<sub>2</sub>: Older and later time of aerial photographs, the end of '67 and the end of '76

Figure 14 shows the mosaic photograph of the test area Ohme made by pasting aerial photographs together and red colored patches in it are deforested areas identified by comparing two aerial photographs taken at AT<sub>1</sub> and AT<sub>2</sub> with human-eyes. Extracted areas by Landsat data and aerial photographs, Figure 13 and 14, are carefully compared each other and the results of the comparison of the two image are shown in Table 4.

According to Table 4, 116 points in total were detected by Landsat data or aerial photographs and 74 points of them were coincident in both data. 13 points were detected by Landsat data and not by aerial photographs, but 12 points of them, being identified by examining carefully aerial photographs, were the areas where their land use had changed from agricultural fields to residential areas and the last one point is also a deforested area cutted between AT<sub>2</sub> and LT<sub>2</sub> in Figure 8, which is the reason why it is detected by Landsat data but not by aerial photographs.

As the observation times of Landsat data are winter, in the case agricultural fields changed into residential areas, their reflectivities of Band 5 are considered to become higher. 25 points were detected by aerial photographs and not by Landsat data, but 19 points of them are deforested areas cutted between AT<sub>1</sub> and LT<sub>1</sub> in Figure 8, being unrecognizable by Landsat data but recognizable by aerial photographs, and 5 points of the remaining 6 points were in shadows of Landsat image, which is the reason why they are not detected by Landsat data, and the last one point was not detected by unexplained reason.

Counting out the numbers of the deforested areas where the points detected by both Landsat data and aerial photographs did not coincide owing to the asynchronism of their observation times, an accuracy of detecting deforested areas by Landsat data can be computed as follows:

$$\frac{74}{74+6} \times 100 = 93 \text{ percent}$$

Incidentally, the space of the smallest deforested area detectable by Landsat data was about one hectare, 100 m by 100 m.

#### 5. CONCLUSION

1. A forested area can be classified into several kinds of forest types using two temporal Landsat of Dec. and May, and especially artificial plantations of Japanese cypress can be classified into three age-classes, young, middle and old.

2. Multiple regression analysis on relationships between Landsat Band 5 and 7 data and timber volume or yearly growth of artificial plantations of Japanese cypress using 16 pairs of sample data were made, and it is found from the analysis that Band 5 and 7 show negative correlation with timber volume or yearly growth and Band 5 is more correlative. Correlation coefficients of Band 5 with timber volume and yearly growth were respectively about -0.7 and -0.6, and multiple correlation coefficients were respectively 0.822 and 0.736. Estimation images of timber volume and yearly growth for a test area were generated and they were very similar.

3. Deforested areas of a forested area were detected by a method of taking differences of Landsat Band 5 data taken at the interval of several years and they were examined using aerial photographs and deforested areas could be detected with an accuracy of more than 90 percent.

#### 6. ACKNOWLEDGEMENTS

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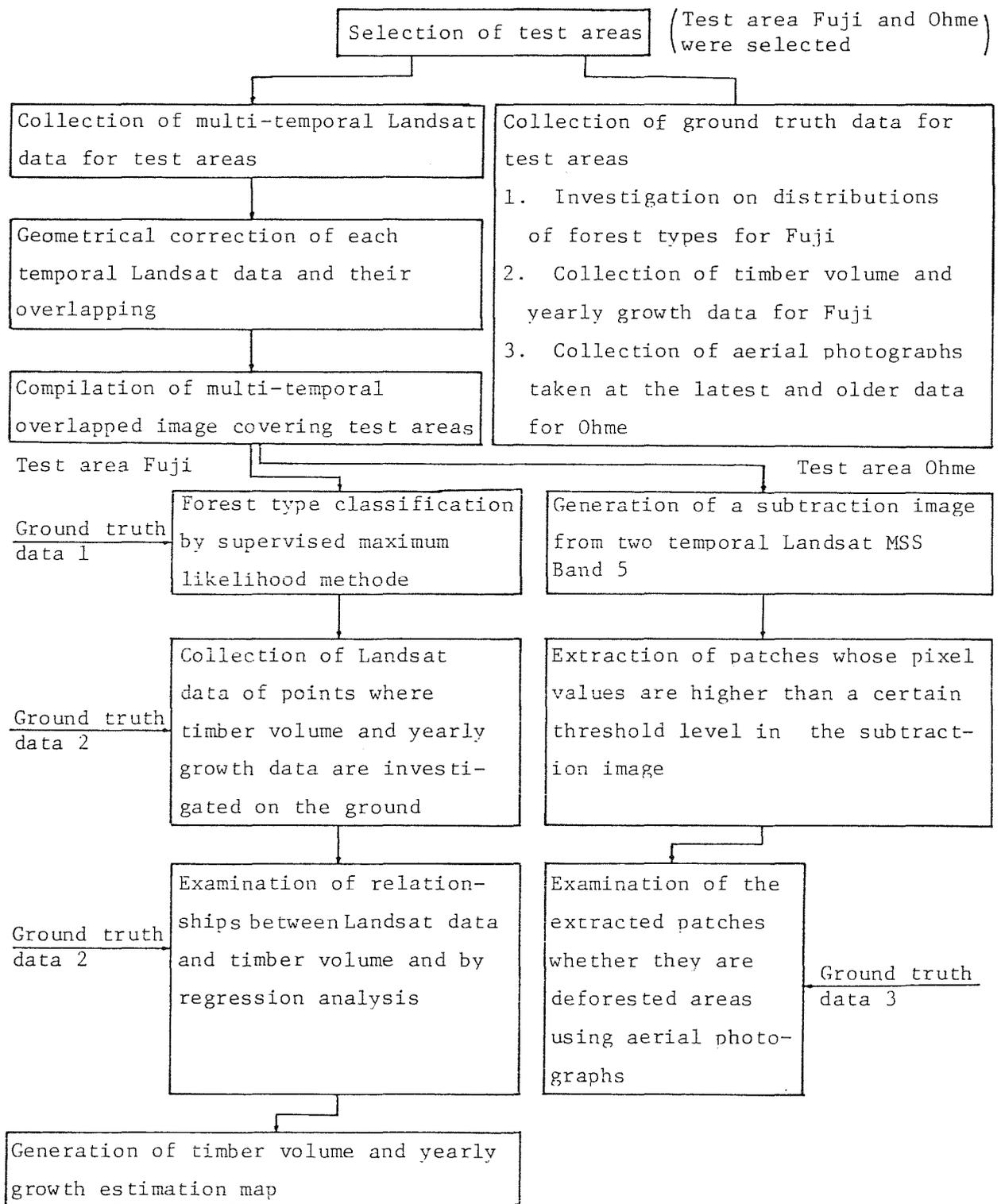


Figure 1 Flow diagram of study procedures

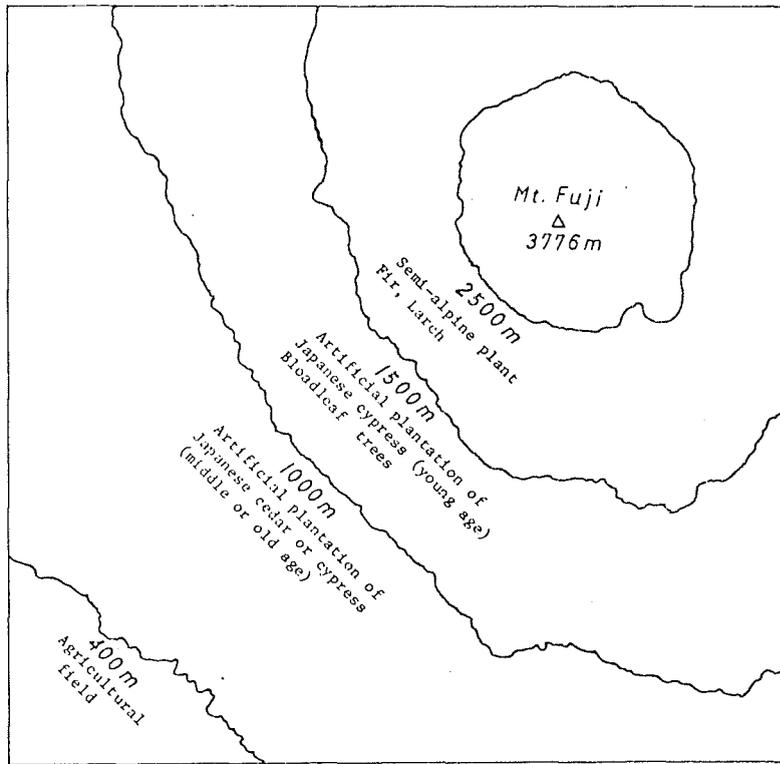


Figure 2 Outline of the Test area Fuji

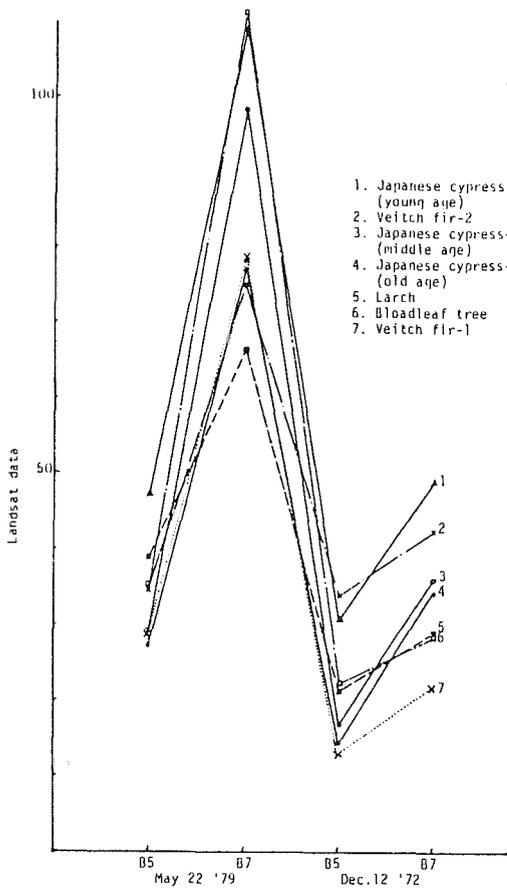


Figure 3 The characteristics of multi-temporal landsat data of training areas for forest types

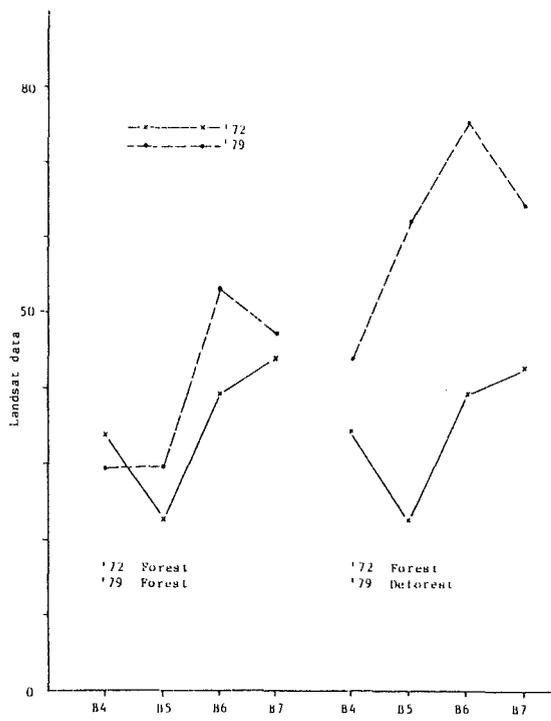


Figure 4 The characteristics of Landsat data of a forested area at '72 and '79, and a deforested area between '72 and '79

No.	Rinpan	Landsat data						Timber volume (m <sup>3</sup> /ha)	Yearly growth (m <sup>3</sup> /ha·year)	Tree age (year)
		'73 B5	2/25 B7	'79 B5	3/29 B7	'79 B5	5/22 B7			
1	5	12.4	35.8	14.7	35.0	16.8	50.3	20	3.2	18
2	36	11.2	25.5	14.6	30.3	16.0	59.5	50	4.78	24
3	38	9.2	23.5	13.2	31.0	14.0	42.8	270	8.42	50
4	261	8.8	22.3	12.5	29.5	13.2	41.3	220	6.97	48
5	263	8.7	21.5	12.7	27.0	13.1	38.7	207	6.51	48
6	251	9.9	23.6	13.3	28.1	13.6	45.7	180	5.42	46
7	257	9.3	24.5	13.5	29.0	14.2	44.6	170	6.09	44
8	255	10.9	23.6	13.7	28.6	15.3	53.4	160	5.74	44
9	258	12.7	25.4	13.7	31.5	15.0	47.8	50	4.77	24
10	259	11.7	25.1	13.5	31.8	14.5	48.2	50	4.77	24
11	260	10.3	25.4	13.8	33.8	14.4	44.6	50	4.75	24
12	291	11.7	22.4	14.7	27.5	14.9	49.4	140	5.12	42
13	299	11.3	24.7	13.8	29.5	14.6	44.8	120	5.46	39
14	164	10.5	25.7	13.9	31.3	14.3	41.6	197	3.65	59
15	153	12.2	30.9	13.9	37.6	14.6	49.1	60	6.12	23
16	210	10.2	26.6	13.6	33.7	14.3	43.0	60	5.70	25

Table 1 Sample pairs data relating Landsat data with timber volume and yearly growth

Date	Band	Correlation coe.	Multi-Corre.coe.	Multi-Corre.coe.
'73	B-5	-0.763	0.797	0.822
2/25	B-7	-0.641		
'79	B-5	-0.647	0.799	
3/29	B-7	-0.696		
'79	B-5	-0.664	0.664	0.810
5/22	B-7	-0.542		

Table 2 Correlations between Landsat data and timber volume

Date	Band	Correlation coe.	Multi-Corre.coe.	Multi-Corre.coe.
'73	B-5	-0.624	0.700	0.736
2/25	B-7	-0.521		
'79	B-5	-0.669	0.736	
3/29	B-7	-0.257		

Table 3 Correlations between Landsat data and yearly growth

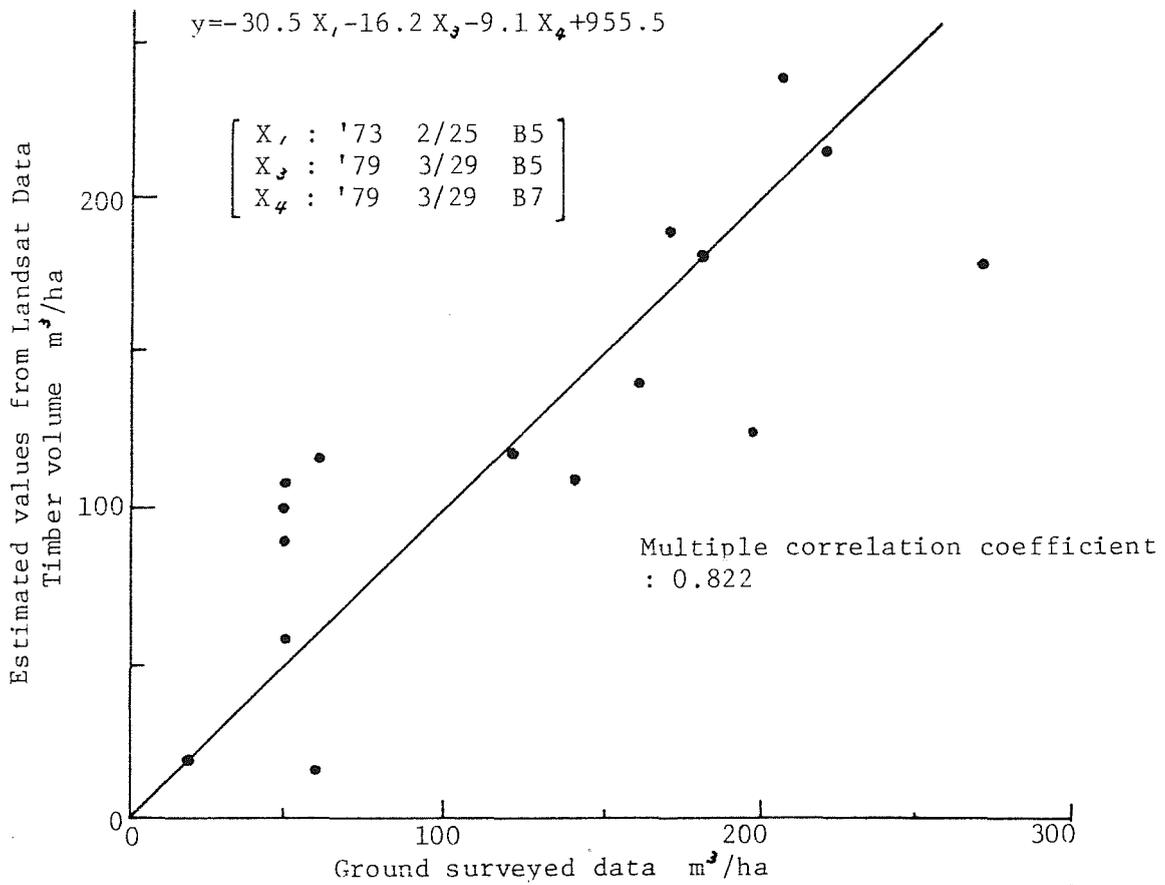


Figure 5 Correlation graph of timber volume between estimated and ground surveyed data

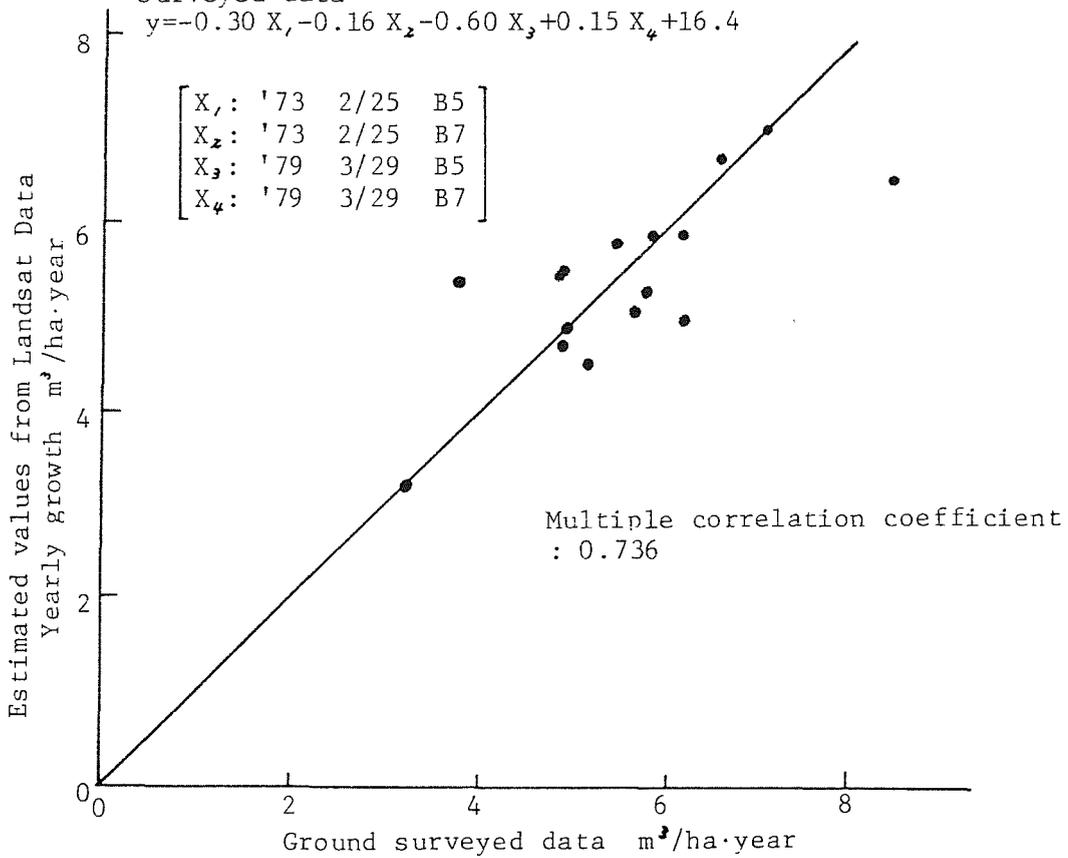


Figure 6 Correlation graph of yearly growth between estimated and ground surveyed data

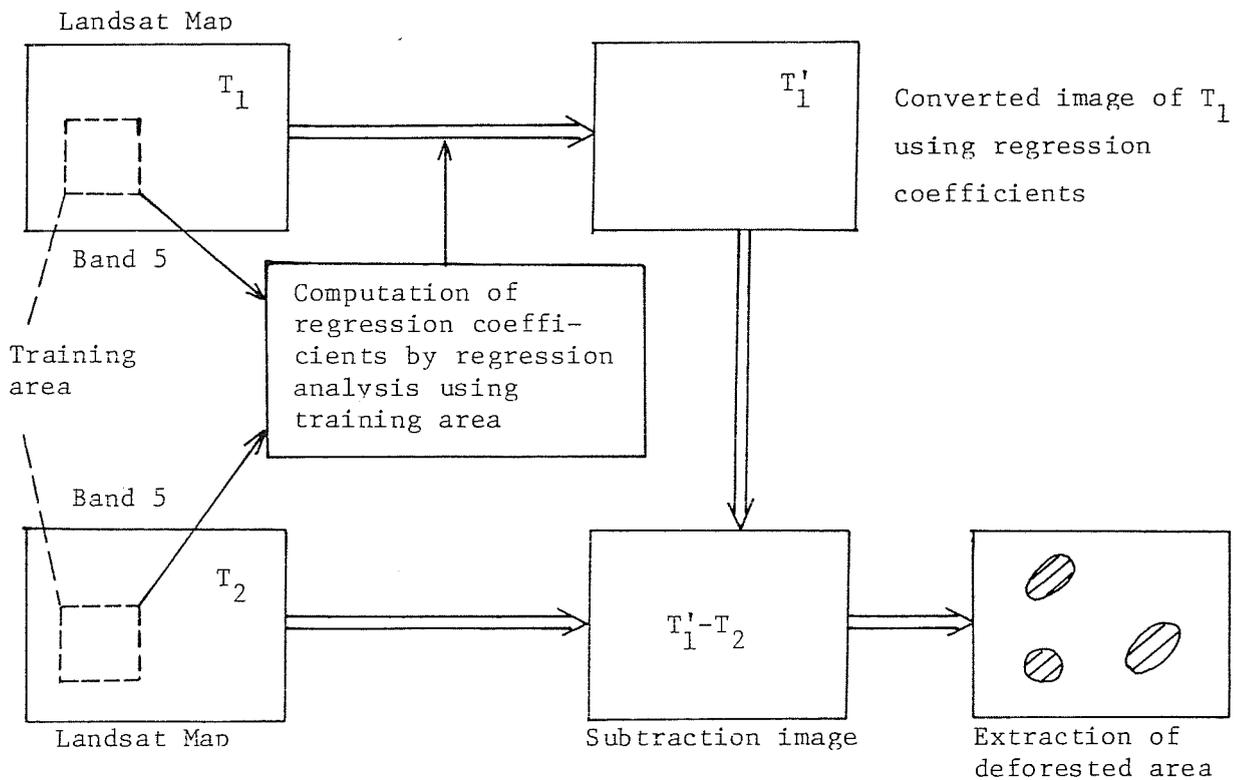
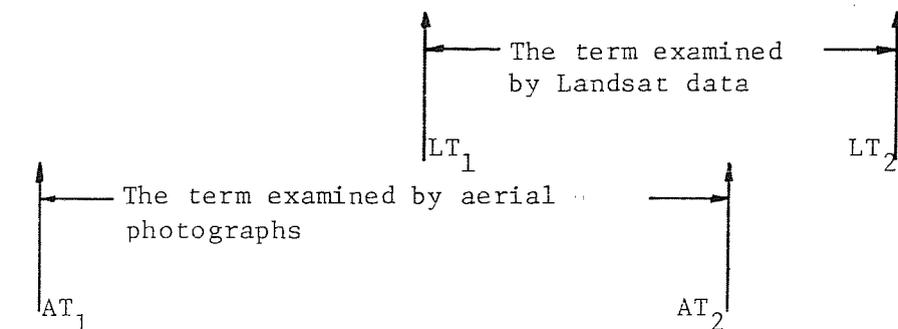


Figure 7 Procedures of deforested areas extraction by subtraction method

67 68 69 70 71 72 73 74 75 76 77 78 79



$LT_1, LT_2$ : Observation times of Landsat data No.1 and No.2

$AT_1, AT_2$ : Observation times of aerial photograph No.1 and No.2

Figure 8 Observation times of Landsat data and aerial photograph used for deforested areas monitoring

Deforested areas detected by Landsat data or AP (aerial photographs)	Number of points detected	Remarks
Detected by Landsat and AP	74	
Detected by Landsat and not by AP	13	12 points: Agricultural fields → Residential areas
Detected by AP and not by Landsat	25	19 points: Cutted between $AT_1$ and $LT_1$

Table 4 Results of the comparison of deforested areas detected by Landsat data and aerial photographs

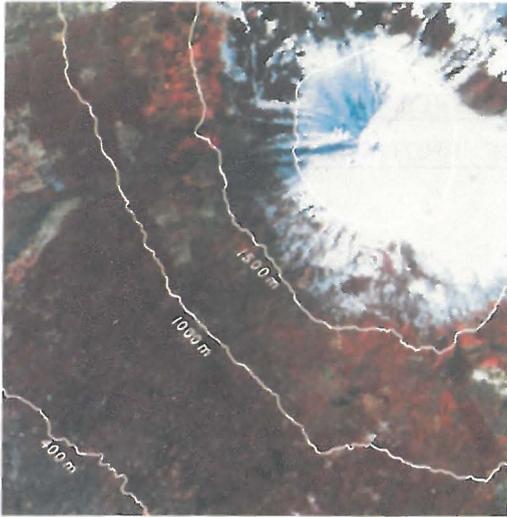


Figure 9 Landsat false color image of the test area Fuji

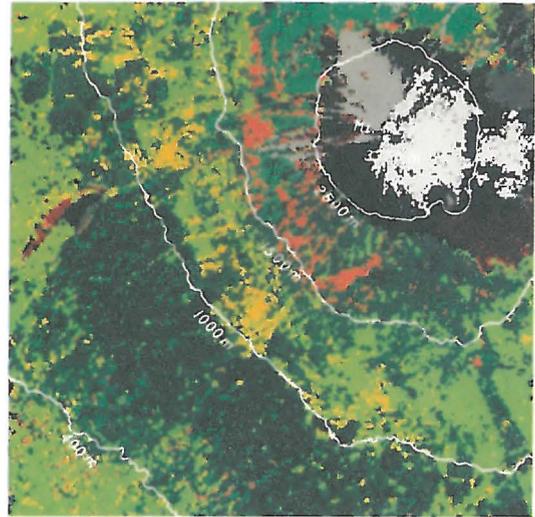


Figure 10 Forest type classification image by Landsat data

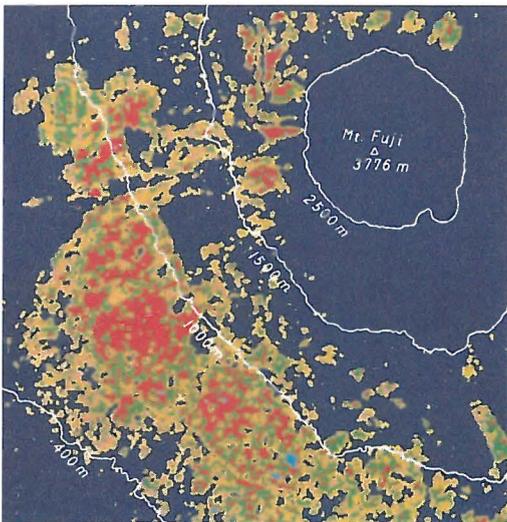


Figure 11 Timber volume estimation image from Landsat data

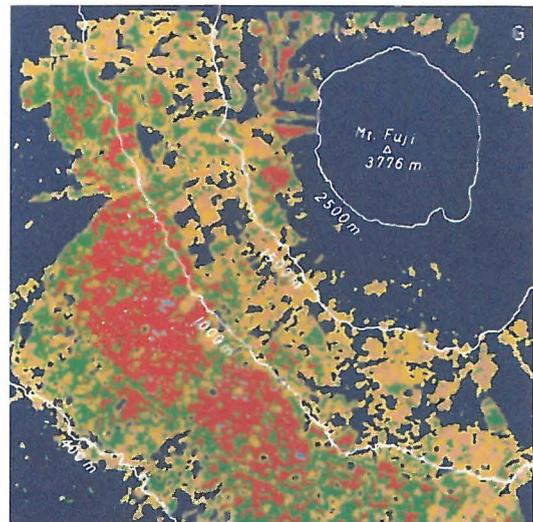


Figure 12 Yearly growth estimation image from Landsat data



Figure 13 Deforested areas detected by Landsat data of the test area Ohme



Figure 14 Deforested areas detected by aerial photographs