EXTRACTION OF DAMAGED AREAS BY THE PINE BEETLE USING LANDSAT DATA

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ABSTRACT

Damaged areas by the pine beetle have been gradually expanding in Japan. The Forestry Agency of Japan have been promoting various undertakings against the damage by the pine beetle such as scattering chemicals and investigation of damaged volumes of pine.

A large area of about 110km by 110km covering a south part of Ibaragi prefecture and a north part of Chiba prefecture was selected as a study area. Landsat MSS images covering the study area were extracted from two Landsat data taken on November 26, 1972 and November 11, 1980 and those images were geometrically corrected to be overlapped each other rigorously. Pine areas (A) were extracted by a supervised maximum likelihood classification using multi-spectral data of the overlapped image of the study area. On the other hand, the areas (B) where Band 5 increased and the value of Band 6 decreased were extracted using the difference image of the overlapped image. The areas obtained through logical AND operation of the above areas A and B were extracted as the damaged areas by the pine beetle. The damaged areas were classified into three groups, slight middle and heavy according to the extent of Band 5 increase and Band 6 decrease.

There were about 120 local governments in the study area and the damaged volume by the pine beetle surveyed on the ground by the each local government office was gathered. It was found that there was a high correlation, correlation coefficient of 0.725, between the damaged voluem surveyed on the ground and the damaged area of each local governmental area computed from the results obtained from Landsat data. It was shown from this study that Landsat data were very useful for extracting damaged areas by the pine beetle.

1. INTRODUCTION

Pine is one of the typical forest types in Japan located in the Temperate Zones and much of it is seen on seasides or hilly regions in plains and it gives us a tasteful life by forming beatiful scenes. In recent years, the damage by the pine beetle has been spreading out all over the country in Japan and causing a serious problem in keeping pine woods. The Forestry Agency or local prefectures where the damage by the pine beetle are heavy have been promoting various undertakings against the damage by the pine beetle such as investigation of the damaged conditions and scattering chemicals. The investigation of the damaged conditions is a fundamental work in the undertakings against the damage and up to the present time aerial photo graphies have been mainly used for grasping the damaged conditions. The investigation using aerial photographies, however, for a large area such as a whole area covering a local prefecture may be very costly and time-consuming and moreover may be difficult to cover the whole area to be investigated at the same time.

The authors tried to investigate the damage conditions by the pine beetle using Landsat data selecting as a study area Ibaragi and Chiba Prefecture located in Kanto District where the damage by the pine beetle has been very heavy.

2. THE STUDY AREA AND LANDSAT DATA USED

The damage by the pine beetle in Ibaragi and Chiba Prefecture may be, at present, heaviest in Japan. A large area, about 110km square, comprising a south part of Ibaragi Prefecture and a north part of Chiba Prefecture and included within the coverage of the Landsat MSS scene of PATH-ROW No.115-35, is selected as a study area.

Outlines of the study area are shown in Figure 1. The damage by the pine beetle, in the study area, seems to have appeared at first in around 1972 near Mito City and afterward has been spreaded out around there and reached its peek in 1978 and 1979, when most of the pine in the plains in the study area were damaged by the pine beetle. The activity of the pine beetle becomes vigorous in summer when the temperature is high and the damaged pines are usually removed by cutting in winter. Therefore Landsat data obtained around November observing the pines damaged in summer of the year are considered to be suitable to be used for estimating the damage by the pine beetle.

Using the two Landsat MSS data taken on Nov.26, 1972 and Nov.11, 1980, the damage by the pine beetle of the study area which occurred during the period between the two years is estimated.

3. PROCEDURE

The first step of the data process employed in this study was to generate geometric corrected images of the study area from the two Landsat data obtained in 1972 and 1980, the beginning and the end of the period estimating the damage and to overlap the geometric corrected images exactly pixel by pixel.

On the other hand, ground investigations were conducted for the study area, by which the typical damaged areas whose degrees of the damage are heavy, middle, and slight are selected and the damaged volumes by the pine beetle surveyed on the ground by the local governmental offices in the study area were collected, and a existing vegetation map including the study area to be used later for the pine areas extraction was also collected.

The next step of the data process was to extract the pine areas with a maximum likelihood classification method using the overlapped image of the study area. The Landsat data variation characteristics of the damaged area of each grade from the beginning to the end of the period estimating the damage were studies by examining the Landsat data of the typical damaged area of each grade selected through the ground investigation using the overlapped image.

The difference images of Band 5 and Band 6 showing Landsat data variations between the two times were respectively generated by subtracting the beginning image from the end image of the period estimating the damage. The areas (Landsat data variation areas) where Band 5 increased and Band 6 decreased in the study area were extracted being classified into three groups in proportion to the amounts of Band 5 increase and Band 6 decrease using the difference images of Band 5 and Band 6.

Finally the damaged areas by the pine beetle were obtained being graded into three ranks by taking logical AND operation between the Landsat data variation areas and the pine areas extracted before. The damaged area of each local governmental area within the study area was computed from the resultant image of the damaged area and correlated with the damaged volume surveyed on the ground by each local government.

4. GENERATION OF GEOMETRIC CORRECTED IMAGES OF THE STUDY AREA AND THEIR OVERLAPPING

About ten and more several Ground Control Points (GNP) whose geographical coordinates (latitude and longitude) are known have been selected to be used for the geometric correction for each Landsat scene covering the Land of Japan.

Image coordinates of the 11 standard GCPs selected for the scene PATH-ROW No.115-35 were measured for the original Landsat data 1 (26 Nov. 1972) and the original Landsat data 2 (11 Nov. 1980) and the resampling equations of 1st order affine transformation for the geometric correction were respectively derived from the relations between the geographical coordinates and the measured image coordinates of the standard GCPs.

A geomatric corrected image of 1972 (call T1) and 1980 (call T2) covering the study area were respectively generated from the original Landsat data 1 and data 2 using the above resampling equations. The resampling internal was selected in order that the 1:25000 scale map area having a size of 7.5' by 5' in longitudinal and latitudinal direction comprises 200 pixels by 200 lines, therefore the image T1 and T2 consist of 2000 pixels by 2400 lines because the study area have a size of $1^{o}30'$ and 1^{o} in longitudinal and latitudinal direction. The spatial size of one pixel is about 56 m by 46 m in longitudinal and latitudinal direction at the center of the study area, being strictly different according to the latitudinal position.

The image T1 and T2 were not yet exactly overlapped pixel by pixel owing to the largeness of their images size. About 50 GCPs for the purpose of the overlapping were selected in those geometric corrected images. The errors on the image coordinate of the GCPs selected for the overlapping between the image T1 and T2 were measured and a resampling equation for overlapping T1 onto T2 minimizing the squares of the errors of the GCPs was seeked.

A geometric corrected image (call T3) was generated by resampling the image T1 using the above resampling equation as which a 3rd order equation was employed. The image T3 (the geometric corrected image of 1972) and T2 (the geometric corrected image of 1980) were overlapped each other with the errors less than one pixel.

5. EXTRACTION OF THE PINE AREAS

Four bands data consisting of the Band 5 and 6 of the each image T3 and T2 were generated. The pine areas of the study area were extracted by a supervised maximum likelihood classification method using the above four bands data. Twelve categories including the pine and the needle leaved tree other than the pine etc. were set up and the training areas for those categories were selected using an interactive image processing system. It was very difficult to discriminate the pine from the needle leaved tree other than the pine because their spectral reflectance characteristics were very similar.

Landsat data of the damaged pine should be, strictly speaking, slightly changed at the time of 1980 owing to the damage, but the amounts of the change by the damage were not so much that the damaged pine was discriminated to the needle leaved tree other than the pine, whose spectral characteristic is the most similar to the pine, in the process of the classification.

6. GENERATION OF THE DIFFERENCE IMAGE BETWEEN THE TWO OVERLAPPED LANDSAT IMAGES OF THE STUDY AREA

Difference images between the two exactly overlapped image T3 and T2 were generated in order to extract the areas where Landsat data variated owing to the damage by the pine beetle. Before generating the difference image between T3 and T2, the grey values of T2 were equalized to those of T3.

First, means and standard deviations of T2 and T3 were computed and an image (call T2') whose mean and standard deviation are equal to those of T3 was generated from T2. Next a difference image T2'-T3 was generated by subtracting T3 from T2' and a regression equation of the first order between the image data of T2 and T3 was derived using only the pixels lying within the range of plus and minus one standard deviation from the mean of the difference image T2'-T3, by which only the image data of the pixels not changing so much between T2 and T3 could be used in deriving the regression equation. An regression image (call T2") of T2 toward T3, whose grey values are corrected to equalize to those of T3, was generated using the above regression equation. Finally a difference image T2"-T3, which is considered to show more correctly the difference between the two overlapped Landsat image of T2 and T3 than the direct difference image T2-T3, was generated by subtracting T3 from T2".

As difference values between two images generally variate within a small range with zero as the center, the difference image was generated shifting zero to 127 and being normalized with σ_E , residual standard deviation obtained in generating the regression image T2", so that $+5\,\sigma_E$ corresponds to 255 and $-5\,\sigma_E$ to 0, which results in a contrast stretch of the difference image.

Regression coefficients and the residual standard deviations obtained in the regression analysis when the image T2 was regressed toward the image T3 are shown in Table 1.

7. EXAMINATION OF LANDSAT DATA VARIATION DUE TO THE DAMAGE BY THE PINE BEETLE

As leaves of the pine tend to become red and its vitality tends to decrease when it is damaged by the pine beetle, the Band 5 and 6 of Landsat MSS are considered to be sensitive to the variation due to the damage. Band 5 and 6 data of test points of the damage of the regression image T2" and T3, the beginning image of the period extracting the damage, were examined. The test points of the damage are typical damaged point found through the ground survey, and at least one typical damaged point is selected for each class of slight, middle and heavy damage.

A pine area inside GR1, GR2, GR3 in the test area TA01 and TA02 shown in Figure 1 was selected as each typical damaged point of slight, middle and heavy damage. Views of typical slightly, middlingly and heavily damaged areas are shown in Figure 5 and rough definitions of each class of the damage are as follows: (1) Slight damage: A damaged pine is independently and sparsely located. (2) Middle damage: A range of damaged pines is sparsely located. (3) Ranges of damaged pines are located here and there.

Means of Band 5 and 6 data of 2 x 2 pixels (about 100m x 100m) areas around the selected tests points of the damage in the test area TA01 and TA02 of the image T2" and T3 were examined using an interactive image processor and the variations due to the damage by the pine beetle were computed by subtracting the means of image T3 from those of image T2". The means and the variations are respectively shown in Table 2 and Figure 2.

It can be read from Figure 3 that Band 5 tends to increase and Band 6 tends to decrease as the damage by the pine beetle advances and Band 6 may be more sensitive than Band 5. GR2 of TA01 shows a singular tendency, which grey values of the selected test point as the middle damage may not be exactly taken because the true size of the damaged pines is usually pretty small.

8. EXTRACTION OF THE DAMAGED AREAS BY THE PINE BEETLE USING THE DIFFERENCE IMAGE OF BAND 5 AND 6

As it has a tendency that Band 5 increases and Band 6 decreases as the damage advances, areas where Landsat Band 5 and 6 data changed due to the damage by the pine beetle can be extracted by slicing the difference images of Band 5 and 6.

Furthermore, to extract finally the damaged areas by the pine beetle, the areas Band 5 increased and Band 6 decreased should be taken logical AND operation with the pine areas extracted before by the multi-spectral classification.

As the difference images were generated being normalized with the residual standard deviation σ_E, their slicing boundaries can be designated using σ_E. Several cases of slicing boundaries were setted in the upper from the center for the difference image of Band 5 and in the lower from the center for that of Band 6 as the damage class goes on to the slight, middle, heavy class, and the damaged areas for the cases with the test area TA01 were obtained by taking logical AND operation between the sliced output areas and the pine areas. The slicing boundaries grading the damaged area into three classes considered to be most suitable were decided estimating the output results for the cases with the informations of the distributions of the damaged areas by the pine beetle of the test area TA01 collected through the ground survey.

Conclusively the slicing boundaries for the three damaged classes were decided as follows:

	Band 5 increase "OR" Band 6 decrease
Slight damage	0.5 - 1.0 σ_B
Middle damage	1.0 - 1.5 σ_B
Heavy damage	1.5 - 4.8 σ_B

Figure 3 shows the above slicing boundaries in a two dimensional space composed of the Band 5 increase axis and the Band 6 decrease axis.

Finally the damaged areas by the pine beetle of the study area were extracted being graded into three classes by taking logical AND operation between the areas obtained by the above slicing boundaries from the difference image of Band 5 and 6 and the pine areas extracted before.

The extracted damaged areas of the three classes and the remaining pine areas were expressed by respectively distinct colors and they were superposed on the natural pseudo color generated from Landsat data, which was a final output image. The output image of the test area TA01 is shown in Figure 6.

9. EXAMINATION OF THE OUTPUT RESULT

The damaged areas by the pine beetle obtained from Landsat data were examined using the damaged volumes data surveyed on the ground by the local governments of the study area. There are about 120 local governments inside the study area whose boundary lines are shown in Figure 1. The damaged volume by the pine beetle of a local governmental area is examined every year by visual inspection on the ground by the each local government office.

The accumulated damaged volume surveyed on the ground from 1972 to 1980 of the each local government of the study area was computed from the yearly surveyed data. Furthermore the damaged area of the each local governmental area inside the study area was computed from the output result obtained from Landsat data. As the damaged area from Landsat were extracted being graded into three classes, the damaged area of each local government was computed for two cases, the pixel count of the each damage class was added in non weighting mode (call Non weighting case) and weighting mode (call Weighting case). Weighting factor for the slight, middle and heavy damage were set to respectively 1.0, 5.0, 20.0.

A regression analysis was carried out using the damaged volume surveyed on the ground and the damaged areas extracted from Landsat data computed by each local governmental area of the study area, which is carried out by the group of local governments within only Ibaragi Pref., only Chiba Pref. and the both.

Table 3 shows the correlation coefficients of the regression analysis and Figure 4 shows the correlation graph for the group of Ibaragi and Chiba Pref. and non weighting case. The analysis shows that there are high correlation between the two data, and weighting case shows relatively higher correlation than non weighting case. It can be said from this examination that damaged areas by the pine beetle can be extracted being into three classes from Landsat data.

10. CONCLUSION

The results obtained from this study can be summarized as follows;

(1) Two Landsat MSS data obtained at the beginning and end of the period extracting the damage by the pine beetle were overlapped and firstly pine areas were extracted by a multi-spectral classification using the four bands data composed of Band 5 and 6 of the each Landsat MSS.

(2) Damaged areas by the pine beetle could be extracted by taking logical AND operation between the areas where Band 5 increased and Band 6 decreased and the pine areas.

(3) The damaged areas could be graded into three classes using the tendency that Band 5 increase and Band 6 decrease as the damage advances.

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Table 1 Regression coefficients and residual standard deviations obtained in the regression analysis when the image T2 was regressed toward the image T3.

Band	Reg. Coef. y = ax + b		Residual S.D.
	a	b	
Band 5	0.830	1.463	1.062
Band 6	0.864	1.567	1.081

Table 2 Means and variations of Band 5 and 6 data of 2 x 2 pixel areas around the selected test points of the damage in the test area TA01 and TA02 of the image T2" and T3.
Figures in ( ) mean the amounts of variation.

Case	Damage Grade	Image T3		Image T2"	
		Band 5	Band 6	Band 5	Band 6
TA01	GR1	12.0	20.0	10.7(-1.3)	19.7(-0.3)
	GR2	12.0	16.7	10.0(-2.0)	17.0(+0.3)
	GR3	10.4	19.2	10.2(-0.2)	15.0(-4.2)
TA02	GR1	9.8	19.7	10.4(+0.6)	21.0(+1.3)
	GR2	12.1	20.1	11.1(-1.0)	19.7(-0.4)
	GR3	8.9	19.6	10.0(+1.1)	16.4(-3.2)

Table 3 Correlation coefficients between the pixel counts of the damaged areas estimated from Landsat data and the damaged volume examined on the ground for non weighting and weigthing case, being computed by each local government of the study area.

	Ibaragi pref.	Chiba pref.	Ibaragi and Chiba pref.
No. of local governments	76	50	126
Non weighting case	0.819	0.860	0.776
Weighting case	0.826	0.847	0.825

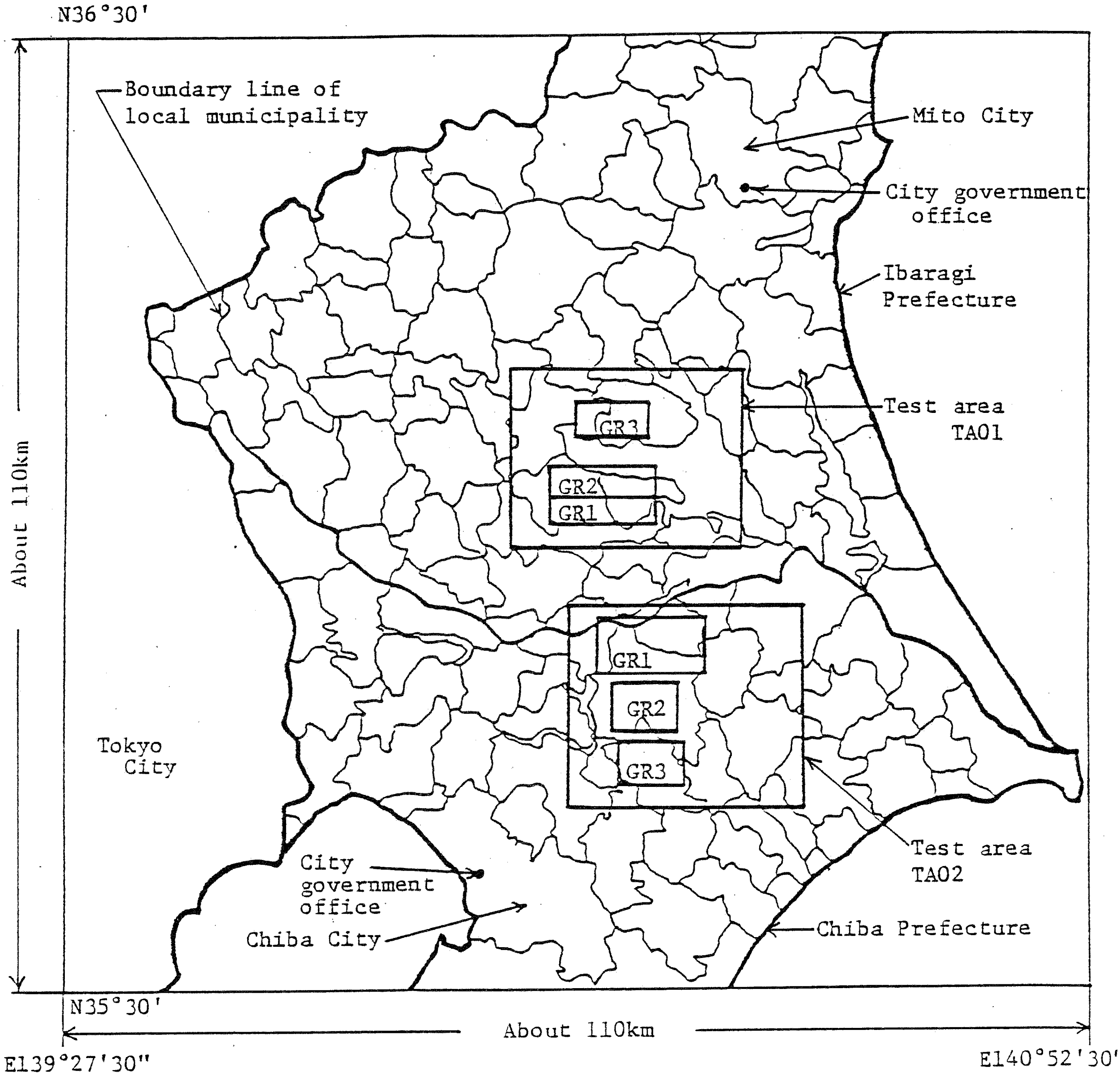


Fig. 1 The outline of the study area. TA01 and TA02 are the test areas the ground survey were conducted in this study.
GR1, GR2 and GR3 are the areas respectively regared as the slightly, middlingly and heavily damaged area through the ground survey.

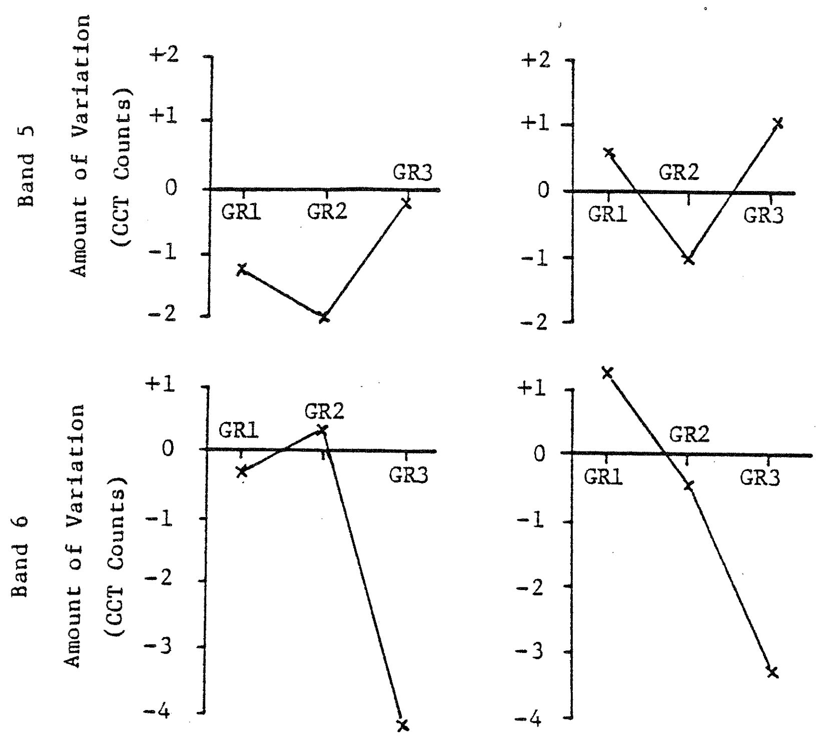


Fig. 2 Variations of Band 5 and 6 data due to the damage by the pine beetle examined from the data of the test points of the damage selected in the test area TA01 and TA02. GR1, GR2 and GR3 are respectively the slight, middle and heavy damage case.

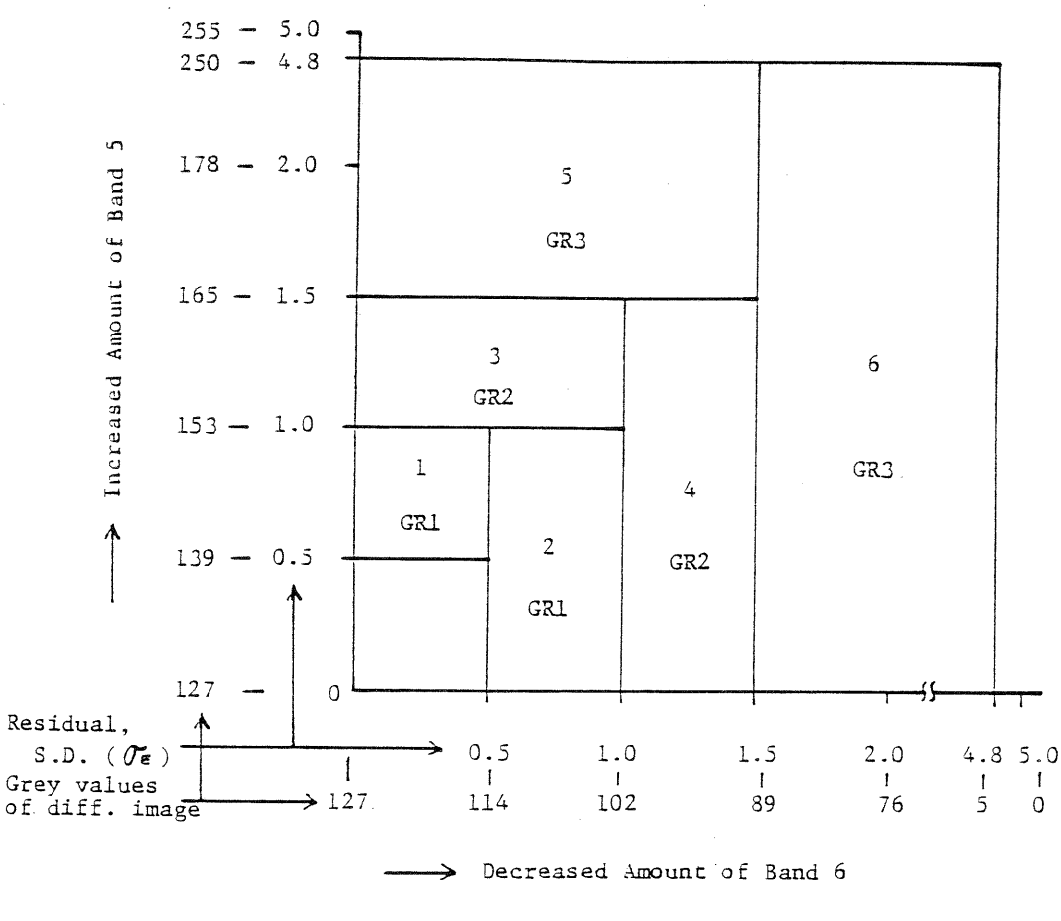


Fig. 3 Slicing boundaries for extracting the slightly(GR1), middlingly(GR2) and heavily(GR3) damaged areas from the difference imades of Band 5 and 6.

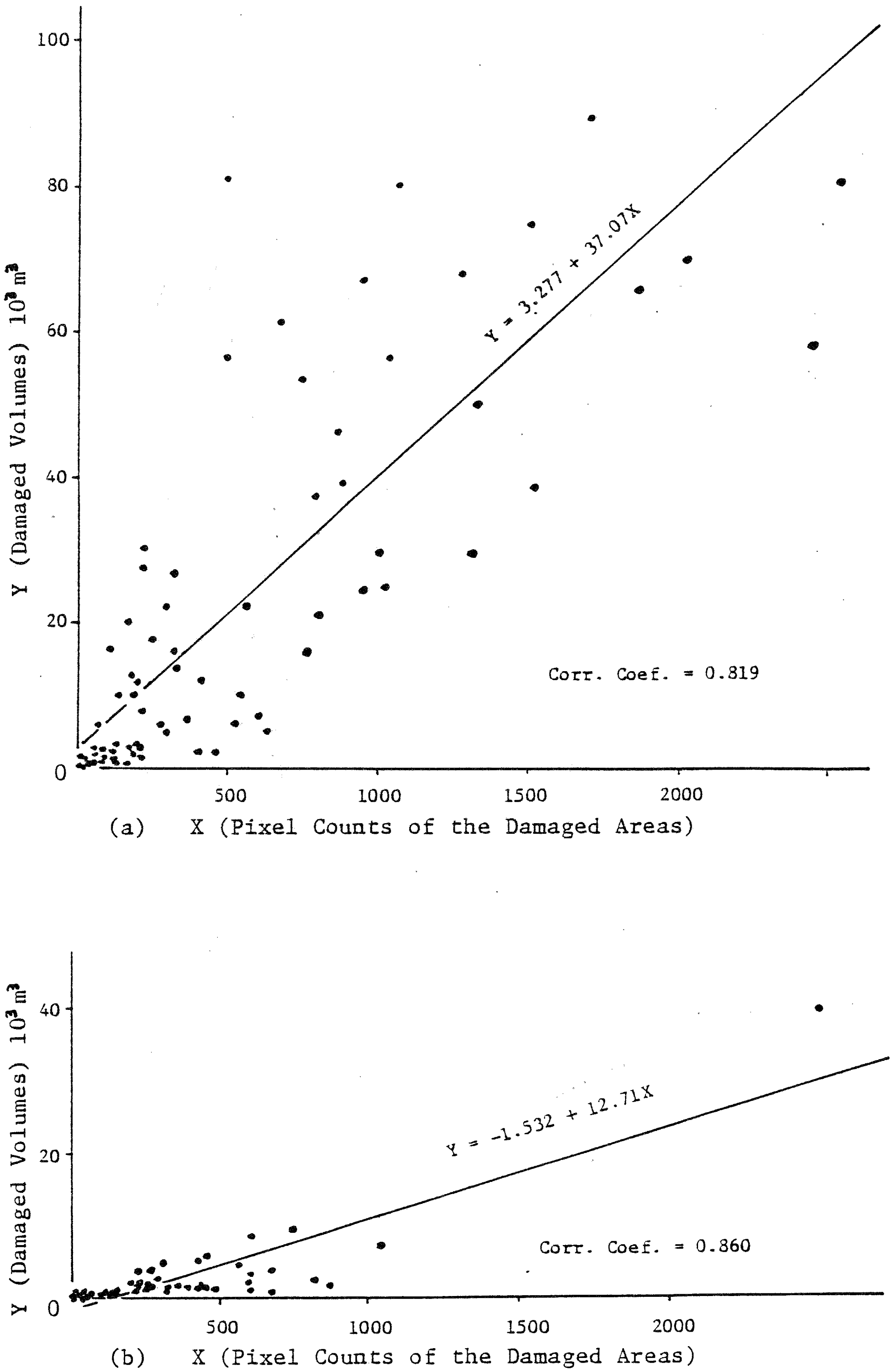


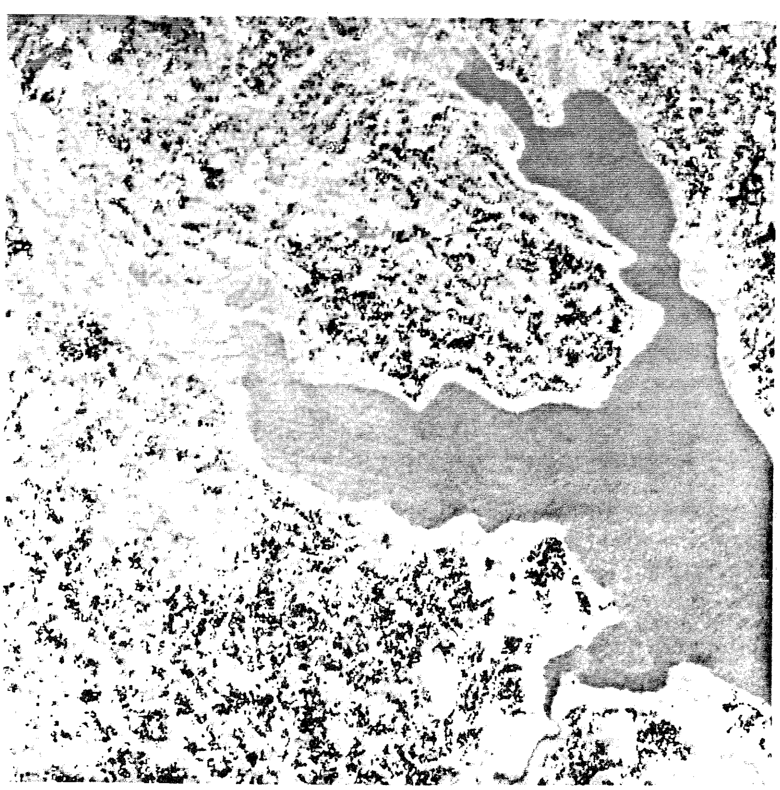
Fig. 4 Correlation graph between the pixel counts of the damaged areas estimated from Landsat data and the damaged volumes examined on the ground computed by each local government area within Ibaragi(a) and Chiba(b) prefecture(Non weighting case).

(a) Heavily damaged

(b) Middlingly damaged

(c) Slightly damaged

Fig. 5
Views of heavily, middlingly and slightly damaged areas by the pine beetle selected in the ground truth investigation.



Red ; Heavily damaged
Yellow ; Middlingly damaged
Cyan ; Slightly damaged
Black ; Pine area

Fig. 6 The damaged areas by the pine beetle of the test area TA01 extracted from Landsat data superposed on the background image.