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USE OF LANDSAT IMAGERY FOR FOREST MANAGEMENT MAPPING;
a case study of the "Kobernausserwald" in Austria

by

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ABSTRACT

For European conditions the "Kobernausserwald" with an area of more than 10,000 ha is a rather large compact forest, mainly comprising pure spruce, patches of pure beech and also mixtures of spruce and beech. There is a normal age class distribution from regeneration to 120 years.
Landsat imagery (August 1979) in the form of CCT print-outs of individual bands and Principal Component calculations were compared with data from orthophoto maps (1974) and recent aerial photography (1979). The comparisons indicated that from Landsat imagery important data might be obtained, such as the separation of non-forest types from forest types and pure spruce from pure beech.
However, age class differentiation in forest types is impossible. In this case study area, due to the patchy distribution of forest types, area accuracy is questionable. For management mapping of this kind of forest the use of Landsat MSS is restricted.

Introduction

For forest management purposes, it is important to determine with the required accuracy the location and area of the main forest types and, if present, of the non-forest types. It will be necessary to differentiate between the dominant species, pure or in mixtures, according to age classes. Additional information which may be important might include details on felling activities, the presence of insect or disease attacks, forest fires, damage by wind, or features like new extraction roads.
To test the use of Landsat imagery for forest management mapping, a case study area was selected with the following favourable conditions:

- a rather large compact forest area under management for timber production;
- homogeneous, one main conifer and one main broadleaf species;
- a low percentage of non-forest vegetation inside the forest which can be differentiated from the forest types;
- cloudfree Landsat imagery of the four bands (4, 5, 6 and 7) with computer-compatible tape containing the MSS data;
- up-to-date aerial photography, recent orthophoto map and management map;
- field data and knowledge of the local past and present silvicultural treatments like systems of regeneration, thinning and felling.

For this article it is assumed that the reader has a basic knowledge of handling the Landsat imagery and the computer analysis of the data (Donker and Mulder, 1977).

Description of the case study area

The area selected for this study is the Kobernausserwald, situated about 40 km northeast of Salzburg, Austria. The terrain is hilly with elevations from 500-750 m above sea level. The state-owned forest, sub-divided into three districts: Mattighofen, Friedburg and Schneegattern, is a rather large compact forest of 10,250 ha and is situated between patches of non-state forest. The boundary between the state-owned forest and other forests is irregular in form. The main conifer species is Norway spruce (Picea abies); silver fir (Abies alba) is present in small groups or as individual trees and some small stands of pine (Pinus strobus) are present. The main broadleaf species is beech (Fagus silvatica). The spruce, the most important species in the area, as regards economic value, is usually in pure stands or in mixtures with fir and beech; the pure stands are found mainly in the lower parts. At higher elevations the more shade tolerant beech occurs in pure stands where the natural regeneration of the light-demanding spruce has failed.
To assure the natural regeneration of the spruce the felling in the age class 81-120 years is actually carried out in small strips. The opening up of the forest is done by successive fellings, leaving a number of seed trees. In former days the regeneration system was group-selection cutting. The aerial photograph at scale 1:30,000 (fig. 1) shows the rather heterogeneous distribution of age classes over the forest area. The non-forest areas comprise meadows along the main roads.
For the total state-owned Kobernausserwald a record of the distribution of forest types according to 40 years age classes was made in 1974 (orthophoto map):

	ha	%
a) Pure spruce and spruce mixed with beech		
81-120 years	3260	32.1
41-80 years	3471	34.2
b) 0-40 years (all species) including gaps larger than 0.25 ha	2922	28.8
c) Pure beech (41-120 years)	391	3.9
d) Roads and meadows	106	1.0
	10150	100.0

These data represent a normal age class distribution.

Material

The computer-compatible tapes (CCT) of the four MSS bands (4, 5, 6 and 7) of Landsat 2 were obtained from Telespazio Image Processing Facility in Fucino near Rome, Italy. The date is 2nd of August 1979. Up-to-date infra-red (black and white) aerial photography, taken in September 1979 at scale 1:30,000 is also available. An orthophoto, scale 1:30,000, was made from the August 1974 infra-red photography. On this orthophoto the above mentioned forest types were delineated according to the age classes. An orthophoto map of the 1979-imagery is in preparation.
The following steps were taken:
With the help of a quick-look print a window was selected of 520 (x-axis) by 200 (y-axis) pixels with a total of 104000 pixels, covering an area of 46800 ha around the three forest districts. For this window the data for the levels of radiance for the four bands are:

band	minimum	maximum	range	mean
4	9	38	30	13.45
5	6	56	51	12.17
6	11	74	64	37.71
7	4	89	86	42.43

Using two bands the best selection would be bands 5 and 7.
Print-outs of bands 5 and 7 at a scale of approximately 1:50,000 were made with the Gould plotter. The print-outs, which were adjusted for (skew)distortion, had an automatically built-in histogram equilisation of radiance levels for nine grey scale classes ranging from black to white.

band 5		grey class	band 7	
radiance levels	%		radiance levels	%
6-8	3.4	black	4-22	12.3
9-9	18.3	"	23-25	11.2
10-10	20.1	"	26-28	10.6
11-12	15.9	"	29-34	10.2
13-13	9.3	"	35-43	10.8
14-14	10.4	"	44-52	12.7
15-16	14.5	"	53-59	9.1
17-56	8.2	"	60-67	14.5
		white	68-89	10.7

Comparing these two print-outs with the orthophoto map (figures 1 and 2 as examples) it can be observed that band 7 gives more information on the forest types and band 5 on forest and non-forest types. With the Optronics a colour print at scale 1:110,000 was made of the combination of band 7 in green and band 5 in red. The conifer forest types

show a dark green, the young and broadleaf types a medium green, meadows a very light green and bare soil, villages and arable land a reddish colour.
The first step was to obtain a sample set of the radiance levels for all of the four bands for the different types assumed to be separable. The available orthophoto map, the up-to-date aerial photographs and the knowledge of the forest composition made a field visit unnecessary.

First sample set

The print-outs of bands 5 and 7 were used for the sampling procedure and taped onto the X-, Y-tablet of the Tectronix. Individual pixels were selected using the orthophoto map with age class delineation and the colour enhanced print of the combined bands 5 and 7 as a guide to obtain the location of the different types. The feature space plot of band 5 (x-axis) and band 7 (y-axis) on the television screen enabled a direct control of the sampling procedure with the possibility of rejecting incorrectly selected pixels.
The following non-forest and forest types were sampled:

symbol	description	no. of sample units (pixel)
G	meadow and grassland	9
U	village, bare soil and arable land	16
S	spruce, pure, age class 41-120	13
B	beech, pure, age class 41-120	8
Y	young, mixed, age class 0-40	11

From the feature space plot of band 5 (x-axis) and band 7 (y-axis) it was obvious that the non-forest types of G (in rather small cluster) and U (in very wide clusters) could be separated from the forest types. The narrow clusters belonging to S (spruce) are different from the clusters B (beech), which lie within the wider clusters of Y (young); meaning that pure beech older than 40 years can not be distinguished in young mixed forests of an age of less than 40 years.
The next step in the procedure was to subject the spectral intensities of the sample set of the four bands to a Principal Component analysis. The variance-covariance matrix calculated from the four spectral intensities of the sample set are:

MSS bands	4	5	6	7	
4	9.32				
5	15.40	28.81			
6	17.28	17.83	174.29		
7	13.54	6.53	232.58	327.85	
trace					540.27

The matrix of "eigenvectors" and "eigenvalues" are:

MSS bands	eigenvectors			
	1	2	3	4
4	0.044	0.443	0.082	0.891
5	0.035	0.830	-0.411	-0.377
6	0.586	0.243	0.741	-0.218
7	0.808	-0.237	-0.524	0.126
eigenvalues	497.48	40.40	1.89	0.49
percentage of total variance	92.08	7.48	0.35	0.09

The Principal Component 1 (PC 1) already contributes more than 92% of the total variance by its eigenvalue. It is doubtful whether these data can be improved by the addition of an other sample set for the same non-forest and forest types. The print-out of the PC 1 is comparable to that of band 7, and the one of PC 2 to band 5, due to the high values of the eigenvectors (0.808 and 0.830). An example of these print-outs is given in figure 2, which shows the same area as that covered in figure 1. Figure 3A gives the feature space plot for the PC 1 (x-axis) and the PC 2 (y-axis) and the same conclusions about the differentiation of types can be drawn as for the band 5/band 7 feature space:

1° The non-forest types U and G can be separated from the forest types S, B and Y.
2° The forest type S (mature, pure spruce) can be separated from the forest types B and Y.

A comparison was made between the area and location of the mature spruce forest (40-120 years) according to the photo-interpretation delineation on the orthophoto map of 1974 and the assumed area of pure spruce according to the print-outs based on the sample set. First of all the co-ordinates of a point on the orthophoto map has to be correlated with the pixel number (x- and y-direction) of the print-out. At the edge of the forest area 8 clearly identified pixels were selected and the centre of each was pricked at the corresponding position on the orthophoto map. The accuracy of a point location has been calculated to be 0.62 pixel units (x- and y-direction) for the print-out and the centre of a pixel as 40 m and 45 m (east- and north-direction) for the map co-ordinates at scale 1:30,000.
In the forest area 26 blocks of 225 ha (nearly 500 pixel units) were systematically selected on the orthophoto map. The cornerpoint locations of these blocks were calculated for the band 7 print-out. The area of spruce forest according to the orthophoto map is 3353 ha or 57.3% out of 5880 ha (26x225 ha). The corresponding data for the print-out with three levels of assumed radiance ranges for pure mature spruce forest are:

Band 7 radiance range	area in ha	% of 5880 ha	difference with ortho-photo map %	standard deviation for individual block of 225 ha compared with orthophoto map %
4-26	2828	48.3	-9.0	19.1
4-27	3133	53.6	-3.7	19.4
4-28	3612	61.7	+5.4	19.6

Manipulation of the radiance range of band 7 can result in a print-out of the pure spruce forest type with an area for the total Kobernausserwald comparable with ± 5% of the area according to the orthophoto map. However, when considering the smaller 225 ha blocks these data are not accurate enough for management purposes.
Also it is possible that the mature spruce forest type photo-delineation used for the 1974 orthophoto map is not comparable with the computer print-out because:
a. pure spruce with an age less than 40 years can have the same radiance as mature spruce;
b. mature spruce mixed with beech has a lower radiance level than pure spruce;
c. presence of mixed pixels at boundaries of stands of pure mature spruce with stands of pure beech (mature or young), and with non-

forest areas like meadows, roads and gaps;

d. information on the orthophoto map of 1974 is not up-to-date because of more recent fellings in mature spruce forest and thinnings of beech in young mixed forest stands.

To obtain information about the above mentioned possibilities a second sample set for the forest types only was obtained.

Second sample set

The sampling was carried out on the orthophoto map placed on the X- Y-tablet of the Tectronix. For a smaller window of 420 pixels in x- and 200 pixels in y-direction the corresponding corner co-ordinates were calculated for the orthophoto map; the smaller window was used because the 520x200 pixel size was too large to fit the corresponding 1:30,000 co-ordinates of the orthophoto map inside the X- Y-tablet.
To ensure that the co-ordinates of a point on the orthophoto map will give the correct corresponding x- and y-pixel number from the tape data, the original eight control points were tested. The accuracy was within one pixel. To ensure a good sample set with the up-to-date forest composition the sample plots were interpreted according to species on the 1979 aerial photographs of scale 1:30,000. The plot size was 180m x 240m corresponding to a 9 pixel size. The centre point of these plots were stereoscopically transferred from the orthophoto map with age class delineation onto the 1979 photographs. Sampling these points at the orthophoto map on the X- Y-tablet the computer data of the pixel is assured to be of a pure pixel of the forest type in question according to species composition and age class.
The following forest types were sampled:

symbol	description	no. of sample units
A	spruce, pure, age class 81-120 years	10
B	spruce, pure, age class 41-80 years	10
C	spruce, pure, younger than 40 years	10
D	beech, pure, age class 81-120 years	5
E	beech, pure, younger than 40 years	5
F	mixed (10-90%), age class 81-120 years	5
G	mixed (10-90%), younger than 40 years	5

A trial was made to include the recent fellings of 0-5 years (1979-1974) as a type in the sample. Due to its small size (strip cutting) plots of a 9 pixel size could not be obtained, and therefore plots of 1 pixel were used. The data were scattered in the feature space of bands 5 and 7 over the non-forest and forest type clusters. Recent fellings as a type was excluded from the sample set.
The variance-covariance matrix calculated from the four spectral intensities of the sample set are:

MSS bands	4	5	6	7
4	0.54			
5	0.22	0.88		
6	2.57	4.82	53.76	
7	3.93	7.43	82.98	130.92

trace 186.10

The matrix of eigenvectors and eigenvalues are:

MSS bands	eigenvectors			
	1	2	3	4
4	0.026	0.120	-0.460	0.880
5	0.048	0.149	0.884	0.440
6	0.537	0.822	-0.083	0.171
7	0.818	-0.536	0.016	0.057
eigenvalues	184.40	0.85	0.45	0.41
percentage of total variance	99.08	0.46	0.24	0.22

In figure 3B the feature space plot for the PC 1 (x-axis) and the PC 2 (y-axis) is given. The conclusions are:

1° Pure spruce (A, B and C) can be distinguished from the mixed and beech forest types, but differentiation according to age classes is impossible.

2° Mixed spruce/beech forest of mature age class (F) can be separated from pure mature beech forest (D), but not from young mixed forest (G).

3° Pure mature beech forest (D) cannot be separated from young mixed forest (G) and only with difficulty from young beech forest (E).

In addition there is firstly the problem of mixed pixels located partly in one of the pure forest types (A, B, C, G and E) and partly in the mixed forest types (F and G), gaps and recent felling areas and all the forest types partly mixed in location with the non-forest type of meadows (roads) within the forest are.
Secondly, how can such a mixed pixel in the field be assessed to obtain the accuracy in area of the forest types? Instead of a field check, photo-interpretation data were used.
To obtain tentative data about this accuracy, 100 points in the forest area were sampled on the orthophoto map. For each point the radiance level of each corresponding pixel of band 7 was divided into three classes according to the data of the second sample set, as follows: pure spruce (60), pure beech (10) and mixed (30). By photo-interpretation using the 1979 photographs at scale 1:30,000, each point was classified according to pure spruce, pure beech and mixed, using three different sizes: circular plot of 0.05 ha, pixel size of 0.45 ha and 9 pixel size of 4.05 ha.
The classification of mixed (10-90%) is not only done according to species but also included gaps larger than 0.25 ha, meadow and roads. No separation was made for age class.
The results for the 100 points are as follows:

	band 7											
photo species	spruce			mixed			beech			total		
size of plot	1	2	3	1	2	3	1	2	3	1	2	3
spruce	48	34	27	16	7	1	3	2	-			
mixed	10	25	33	11	21	29	2	5	9			
beech	2	1	-	3	2	-	5	3	1			
total	60	60	60	30	30	30	10	10	10	100	100	100
correct	80%	57%	45%	37%	70%	97%	50%	30%	10%	64%	58%	57%

Apparently the individual pixels of the forest types can be best assessed by "spot" (0.05 ha) location. Even with such a simple classification of three forest types about one out of three pixels (36%) are wrongly classified.
The classification of mixed forest with limits of 25-75% did not give a significant improvement in the overall accuracy (33% incorrect).

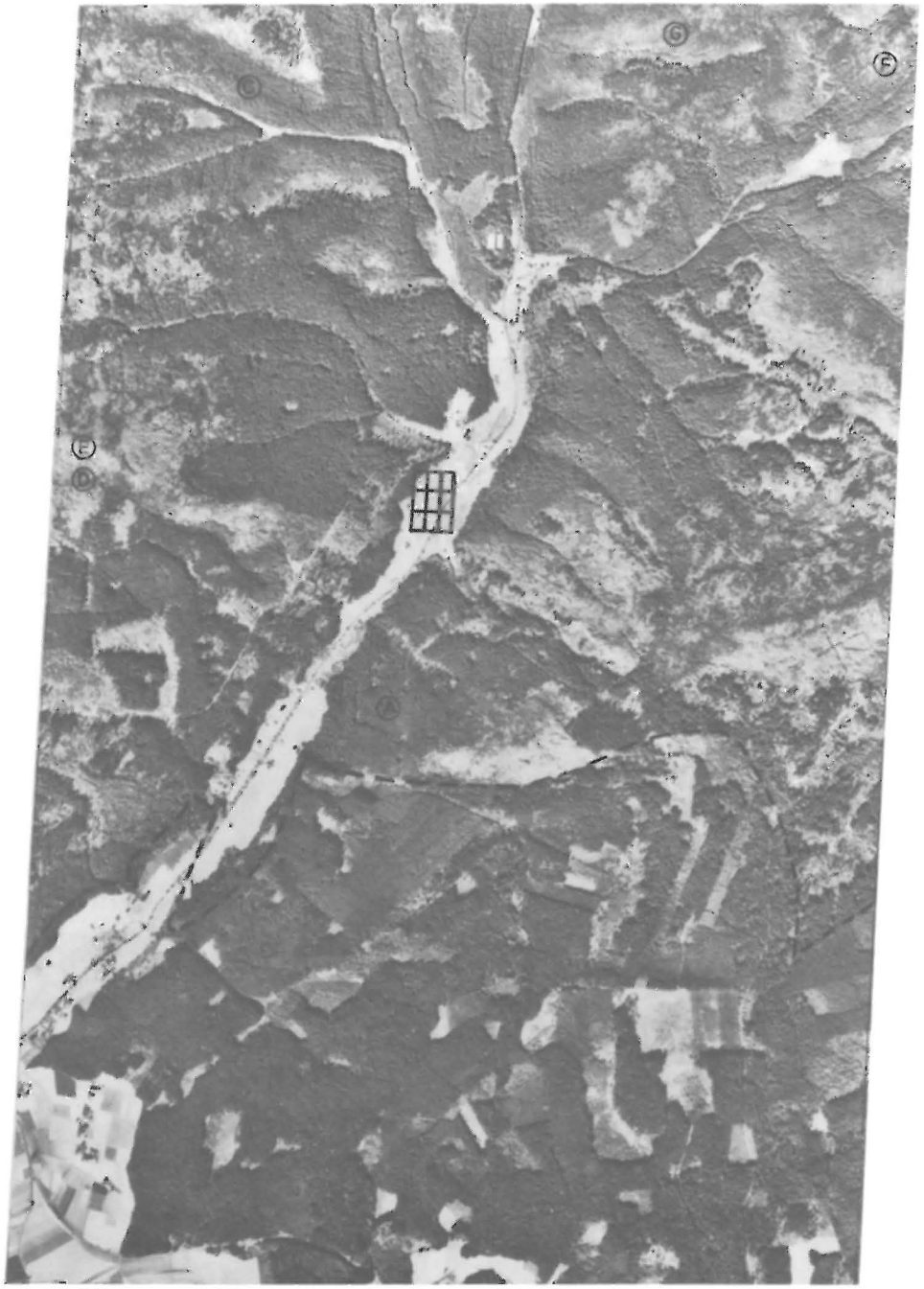
Conclusions

The silvicultural system of strip felling and group selection cutting enables a natural regeneration of the spruce and beech, resulting in a rather heterogeneous patchy distribution of forest types.
The use of Landsat MSS is rather restricted for management mapping of this kind of mapping because:

a. Recent fellings (0-5 years) are not accurate indicated on the Landsat imagery.
b. Age class differentiation is impossible.
c. Differentiation into only two forest types: 1) pure spruce and 2) mixed pruce/beech and pure beech is possible.
d. Area accuracy in the differentiation between three forest types: 1) pure spruce, 2) pure beech and 3) mixed is questionable.

Literature

DONKER N.H.W. and MULDER N.J. - Analysis of MSS digital imagery with the aid of Principal Component transform.
ITC Journal 1977-3.



Aerial photograph scale 1: 30,000

A - Spruce (81 - 120)
B - Spruce (41 - 80)
C - Spruce < 40

D - Beech (81 - 120)
E - Beech < 40
F - Mixed (81 - 120)
G - Mixed < 40

Limit of State forest

Block of 9 pixels

FIG. 2

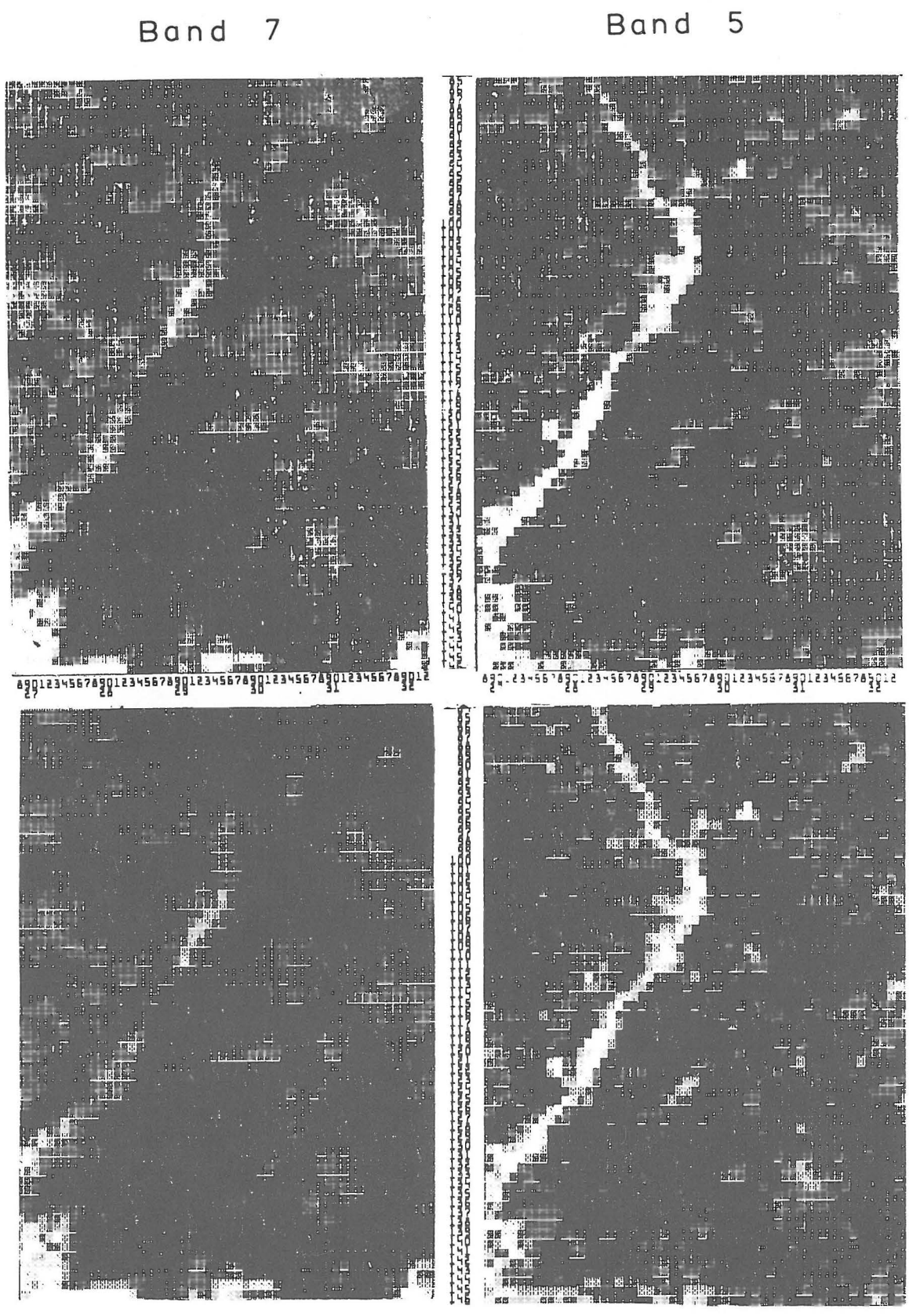
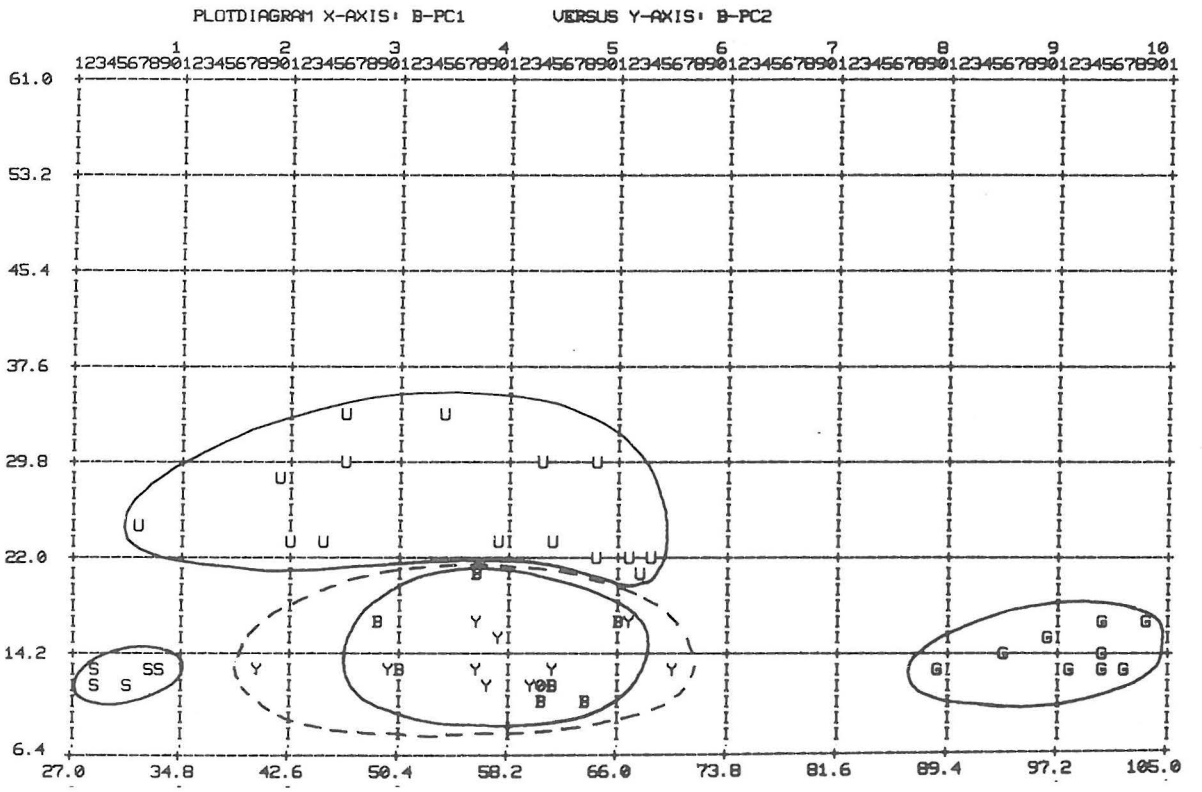
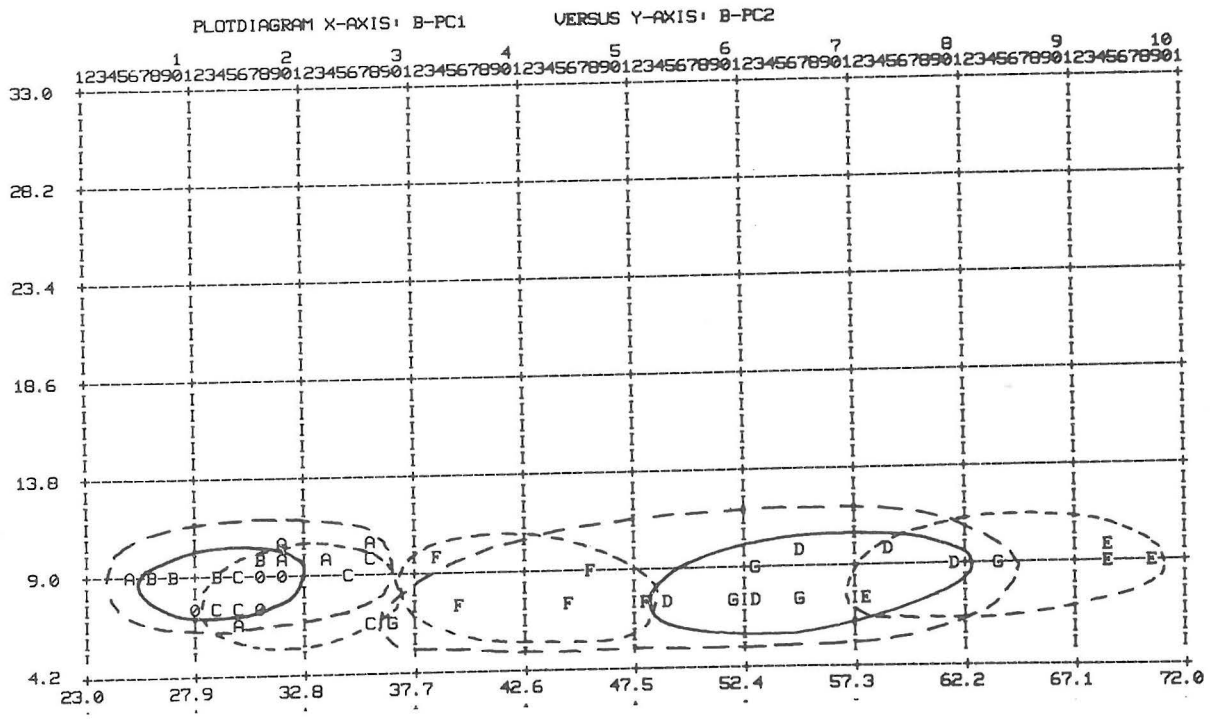


FIG. 3 Feature space plots PC1 _ PC2



A. 1st. sample set



B. 2nd. sample set