Study of forest vegetation regeneration based upon Landsat TM images analysis: preliminary results

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ABSTRACT

The Aleppo pine forests of Greece and in particular those of the prefecture of Attika have been burnt repeatedly during the last twenty years. Deforestation by forest fire is often the most important basic cause of soil erosion. Hence states of deforestation or the presence or absence of various types of vegetation cover may imply states of soil erosion risk and hence desertification threat. To monitor forest regeneration processes, remotely sensed data have been acquired for two different dates and image analysis techniques are being developed and evaluated for the identification of possible states of forest regeneration. A number of colour composites, ratio images, and normalized difference indices were constructed and evaluated for their potential in separating forest vegetation regeneration levels. Geometric corrections were made to register the satellite images into the Hellenic Geodetic Reference Datum of 1987. Unsupervised and supervised maximum likelihood classification techniques were implemented in order to extract various levels of forest regeneration classes.

1. INTRODUCTION

Traditionally, Landsat image classification has focused on land cover maps which show different homogeneous vegetation species. From a perspective of forest vegetation regeneration monitoring in burnt areas, it is desirable not only to know vegetation species but also to be able to discriminate the different stand densities and heights or level of regeneration (Benson and DeGloria, 1985; Chuvieco and Congalton, 1989; Coleman *et al.*, 1990; Jakubauskas *et al.*, 1990; Lopez Garcia and Caselles, 1991; Rokos *et al.*, 1993).

In this research effort, multidate Landsat TM images were acquired and processed to evaluate their potential in differentiating forest vegetation regeneration levels after forest fires. The study was conducted in the prefecture of Attika (Greece). The aim is to develop procedures for monitoring vegetation recovery over burnt areas based on the use of multidate satellite data and thus to assist forest managers in planning and management operations. While four test areas have been selected for study within Attika, this paper addresses the methodology and results obtained from the test area of Lavrio for which field test data were available.

The specific objectives of this study were:

1. Characterization of the spectral response of different forest vegetation regeneration classes and burnt surfaces, and
2. Investigation of the potential of the remote sensing data and techniques to be used for discriminating the degree of natural vegetation regeneration after forest fires.

To achieve the objectives, processing and evaluation of Landsat TM images took place by different digital image analysis techniques, such as training site statistics analysis and evaluation, TM band colour composites, band ratios, unsupervised classification, and supervised classification by the maximum likelihood algorithm.

2. THE STUDY AREA

The study area is located near Athens, the capital of Greece, in the prefecture of Attika **(Figure 1)**, one of the areas most disturbed by forest fires, with potential erosion risk and desertification threat. Attika is on the Greek Mediterranean coast almost at the centre of Greece.

Figure 1 - Prefecture of ATTIKA with the four (4) test areas (Lavrio, Pateras, Pendeli, and Varnavas)

From a climatic point of view, Attika is characterized as semi-arid. As a result, the vegetation is adapted to aridity and there is a high risk of fire. Each summer a great number of forest fires destroy a large part of the forest area of Attika. Forest fires are becoming one of the main environmental problems. The relative humidity of the area is typically very low during July and August, while strong winds facilitate the spread of the fire once it starts. The few but relatively intense rainfalls contribute to increased erosion of bare soils.

The study area has the typical characteristics of a Mediterranean forest ecosystem. The primary vegetation is composed of conifers, mainly Aleppo pine (Pinus halepensis), and a variety of shrub species. The surface geology is characterized by limestone and metamorphic rocks. The topography of the area is complex due to excessive relief diversity. The slopes tend to be medium to steep which would notably complicate the digital image classification process.

In the province of Attika, four test areas have been selected because there were forest fires in each of these areas within the last ten years (**Figure 1**). The test areas are located around 50-70 kilometres north east (test areas of Pendeli and Barnabas), west (test area of Pateras) and southeast of Athens (test area of Lavrio). The results reported in this paper concern the Lavrio test area.

Lavrio is located in southeast Attika about 70 km from Athens (**Figure 1**). The area has no major streams, and no significant water supply. It is characterized by hilly terrain and two major mountain ranges with a NS direction. North wind patterns are predominant.

The major fire that affected the test area of Lavrio was in 1985. The two Landsat TM images were acquired on June 26th, 1987 and July, 4th, 1990, hence two and five years after the fire of 1985.

3. METHODOLOGY AND RESULTS OBTAINED

A number of digital image analysis techniques for assessing forest vegetation regeneration in burnt areas from Landsat TM images have been applied, such as

1. Training site statistics analysis and evaluation
2. Creation of colour composites,
3. Formulation of band ratios and their false colour composition,
4. Unsupervised classification, and
5. Supervised maximum likelihood classification.

3.1 Description and evaluation of the training site data

The training site data used in this effort were collected by the Institute of Mediterranean Forest Ecosystem – National Agricultural Research Foundation (NARF) (Nakos, 1993) for evaluating the potential forest vegetation regeneration, risk of erosion and the risk of desertification. There are a number of factors contributing to land degradation after a forest fire such as absence of forest vegetation regeneration, soils found on impermeable rock surfaces, lack of significant soil cover, high slopes, and others. The distribution of the training sites was thus designed in order to represent the variability of these factors. These training data were also used as ground truth data for digital analysis of Landsat TM images to assess forest vegetation regeneration in the burnt areas and as such are being evaluated in this paper. The results of this study may help to determine the need for additional or different ground truth data.

The collected ground truth data of the six training sites pertained to various levels of forest vegetation regeneration. Ground field data have not been collected, at this time, to describe other land cover classes such as agriculture, urban, water, and others. Initial attempts for visual image interpretation and digital classification of the greater Lavrio area proved to be difficult without the valuable assistance of ground truth field data corresponding to each possible land cover class of the region. An unsupervised classification by the ISOCLASS algorithm was carried out for the 1990 image and resulted in many spectral classes, which could not easily be assigned to a land cover class. If additional field data were to be made available so that each and every land cover class possible in the region is represented, then an unsupervised or supervised classification for those land cover classes would have been successful. Thus, it was decided to restrict the remote sensing digital image analysis study to a more reduced area where we would not anticipate the presence of land cover classes for which we did not have ground truth information. This was achieved in a straightforward manner by restricting the study area into a portion of it for which it was known that the predominant land use prior to the fire was a variety of forest vegetation species. This knowledge concerning the pre-fire land use was obtained from the Forest Maps provided by the Institute of Mediterranean Forest Ecosystems. These maps have been digitized and georeferenced within the Desertification GIS constructed for the parallel efforts of desertification assessment (Rokos *et al.*, 1993). The *mask* was defined to include the following classes: forest, shrubs and bushes, barren and grazing land. The Forest Map classes excluded from further analysis were agriculture and urban. This simplification was in accordance with the objectives of this research effort which focuses on the evaluation of forest vegetation regeneration taking place within previously burnt forest land. It is not of concern to this effort what is happening outside the designated forest lands. Thus, most of the following digital image analysis techniques have been applied only to the area designated as the masked study area. Incidentally, the masked study area ended up with a very odd geometric shape.

3.1.1 Field Data Analysis And Evaluation

The field collected data describe, besides the degree of overall natural and Aleppo pine regeneration of each site, a number of other relevant landscape and ecological parameters such as surface geology, slope, relief, aspect, soil depth, etc. **Table 1** shows some of the landscape and ecological characteristics of the training sites represented by the field collected data. It is observed that all sites are on hilly terrain and thus they are characterized by steep slopes (usually between 21-40 %) and elevation less than 300 m. Hence, relief does not differentiate these sites. All sites, except site L5 (worst regeneration), which is on hard limestone are located on metamorphic rocks. Surface rockiness varies from slightly rocky for the L6 site (best regeneration) to very rocky for the L5 site (worst regeneration). The *natural vegetation except Aleppo pines* is *closed phrygana* for all sites, except for sites L4 and L5 with *open phrygana*. Soil depth attains almost 30 cm or more for all sites, except site L5 where it is less than 5 cm.

The six field test sites may be considered as representing six different forest vegetation regeneration classes, each having its own unique characteristics. At a first level of generalization, however, based primarily on the *Density of (Aleppo) Pine Seedlings* and secondarily on the *Density of Other New Vegetation*, the six training sites can be grouped, at this stage of analysis **(Table 1)**, to four forest vegetation regeneration classes **(Table 2)**:

1. low represented by L5,
2. low-medium represented by L4,
3. medium represented by L1, L2, and L3, and
4. high represented by L6.

This grouping of the six field test sites into four vegetation regeneration classes is further supported by the field data alone, as follows. Sites L1, L2, and L3 have the same level of medium natural regeneration, based on the medium *Density of (Aleppo) Pine Seedlings*. Test site L3 has a NW aspect and it should have been in shadow during the passage of the Landsat satellite. The presence of shadow during the pass of the Landsat satellite may in turn confuse the spectral signature of the class represented by this training site, e.g., the medium forest regeneration class **(Table 2)**. The effect of shadow is further discussed later on. Training site L4 has a low to medium level of regeneration. Training site L5 has a very low regeneration level because of (1) its surface material which is hard limestone, (2) its very rocky surface, and (3) its lack of significant soil cover (soil depth < 5 cm). In contrast, training site L6 has the highest level of regeneration.

An additional training site was selected by the Remote Sensing Laboratory team containing Aleppo pine forest cover which was not burnt. A Landsat TM image corresponding to a pre-fire date (1985) was not available at this time, and hence the signatures of unburnt forest and regenerating forest species could not be effectively compared. Therefore, an Aleppo pine vegetated control area (non-

Table I - Description and initial grouping of the six field training sites for the lavrio area

Density of other new generation	Sparse (< 25 %)	Moderately Dense(25 – 50 %)	Dense (> 50 %)
Dense (> 50 %)		MEDIUM: L1 Hilly Metamorphic Soil Depth 5-30 Aspect SE Slightly Rocky Closed Phrygana MEDIUM: L3 Hilly Metamorphic Soil Depth > 30 Aspect NW Stony Slightly Rocky Closed Phrygana	
Moderately Dense (25 – 50 %)	LOW-MEDIUM: L4 Hilly Metamorphic Soil Depth > 30 Aspect E Moderately rocky Open phrygana	MEDIUM: L2 Hilly Metamorphic Soil Depth > 30 Aspect S Moderately Rocky Closed Phrygana	
Sparse (< 25 %)	LOW: L5 Hilly Hard Limestone Soil Depth < 5 Aspect N Very Rocky Open Phrygana		HIGH: L6 Hilly Metamorphic Soil Depth > 30 Aspect NE Slightly Rocky Closed Phrygana

Density of (Aleppo) Pine Seedlings

Table 2 - Grouping of the training sites based on three sources: field data, spectral data and prediction

Field Training Sites Collected by NARF	L5	L4	L1	L2	L3	L6
Field Based Regeneration Class	Low	Low-medium	Medium	Medium	Medium (under shadow)	High
Spectrally Separable Class	Low	Medium	Medium	Medium	Medium-high	High
Predicted Potential Regeneration Class (1=Best, 5=Worst)	4	1	2	2	2	1

burnt forest), "the forest reference area", has been selected and used as a training site, so that the existing differences between the unburnt forest and the various levels of forest vegetation regeneration may be studied.

Furthermore, the Remote Sensing Laboratory has collected fourteen *test sites* for evaluating the results of forest vegetation regeneration classification. These fourteen test sites were selected as follows: 2 for low, 4 for medium, 6 for high, and 2 for the forest class.

3.1.2 Analysis and Evaluation of the Spectral Signatures of the Training Sites

Prerequisite of computer assisted classification is the generation, presentation, and analysis of ground truth data statistics. It is only after the examination of the spectral characteristics of the six training sites that a final decision will be made on the way to use them during the classification.

Figure 2 shows plots of the mean brightness values for each training site for each Landsat TM band and for each constructed normalized difference index, for both dates 1987 and 1990. The mean brightness value curves may be considered as representing the spectral signatures of the training classes and their corresponding classes. A comparison of the multispectral statistics of the six training sites and an evaluation of their spectral separability follows.

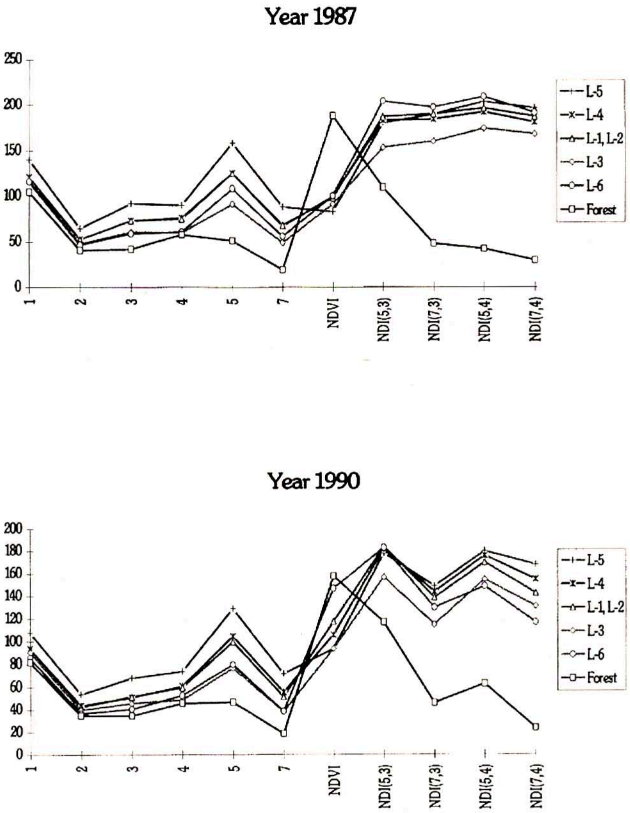

Figure 2 - Mean Brightness Values Diagrams of the Six Training Sites for all the Landsat TM Bands (except the thermal) and selected normalized difference indices for the 1987 and 1990 Images

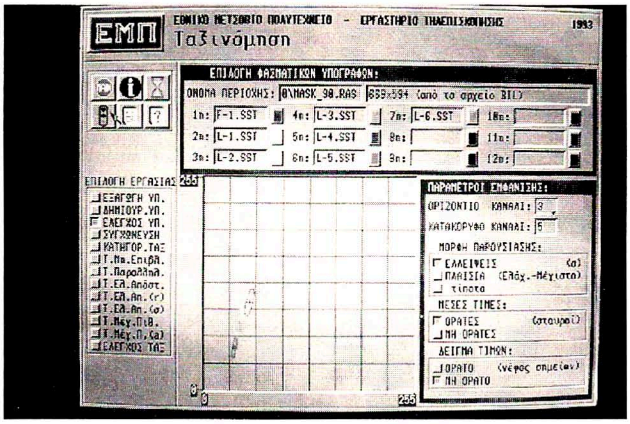

Figure 3 - Scattergram between TM bands 3 (in the horizontal axis) and 5 (in the vertical axis) showing all six training sites. It is noticeable that the ellipse of training site L-3 is very near to that of L-6

Sites L1 and L2. The mean brightness values of the training sites L1 and L2 were very close **(Figure 2)**. This is also indicated in **Table 3**. Thus training sites L1 and L2 have been spectrally grouped together under the medium level regeneration class (**Table 2**).

Table 3 - Mean brightness values from all Landsat TM bands for training sites L1 and L2 for 1987 and 1990

SITE	TM1	TM2	TM3	TM4	TM5	TM7
L1 – 1987	120	52	71	72	122	68
L2 – 1987	118	53	74	77	128	68
L1 – 1990	91	41	49	58	96	49
L2 – 1990	94	44	54	62	104	54

Site L4. Site L4 according to the earlier analysis of the field data (Table 1), is located between the low regeneration class L5 and the medium regeneration class (L1 & L2). However, according to Figure 2, the brightness values of site L4 almost coincides with those of sites L1 and L2. This is also observed in the constructed scattergrams. **Figure 3** is an example of the scattergram between bands 3 and 5 showing in ellipses the two dimensional distribution of the brightness values of all test sites. In all the scattergrams the same relationship was observed. Therefore, based on its spectral properties, site L4 should be placed in the class of medium forest vegetation regeneration together with sites L1 and L2.

Sites L3 and L6. It is also observed in Figure 2 that training sites L3 and L6 are very close spectrally. This was also observed in all the scattergrams. For example, in the scattergram between bands 3 and 5, shown in Figure 3, training site L3 is located closer to the high forest vegetation regeneration class, represented by site L6, instead of being located near the medium regeneration class, represented by sites L1 and L2. Site L3 according to the field data fits into the medium regeneration class. Spectrally, it is closer to the high regeneration class. The reason for this discrepancy is that site L3 is under shadow as it was explained earlier because of its NW aspect **(Table 1)**. Thus, it is anticipated some confusion during classification between the class of high regeneration represented by site L6 and the medium regeneration class represented by training site L3.

Site L5 is characterized as low forest vegetation regeneration.

3.2 Geometric correction

The geometric correction of the Landsat TM images was made with an affine transformation. The whole eastern part of Attika, including the test areas of Lavrio, Pendeli, and Barnabas was corrected as a whole and thus facilitated the selection of control points. Eight control points were used, the majority of which were located relatively easily using the Attika coastline and were matched to the correspon-ding locations of the Hellenic Army Geographic Service (HAGS) 1/50,000 scale topographic maps. Resampling took place by linear interpolation to avoid excessive modification of the image values. The RMS error was much less than the 30 m resolution of the Landsat TM.

3.3 Radiometric correction

The two Landsat TM scenes of June 26, 1987 and July 4th, 1990 employed in this study were both taken almost at the same time of the summer. Since meteorological data have not been collected as yet for the two dates of the scenes, it was not possible to carry out a radiometric correction which would have taken into account such data. It has therefore been assumed that since the two scenes have been acquired under relatively similar weather conditions which do not usually change from year to year, a simple shift of the histogram of the 1987 scene in relation to that of the 1990 scene would be adequate for their normalization. The histogram shift took place separately for each band based on the mean brightness values of a specific water body. The radiometric correction was applied only prior to creating the normalized difference indices and was not applied before the classification which took place with the original data without any modification.

3.4 Colour composites

For a preliminary interpretation, the images were enhanced by various techniques and visually interpreted to recognize and discriminate various vegetation regeneration states. The visual interpretation was done through various colour composites and band ratios and was aided and checked by comparison with aerial photographs and field checking.

Various combinations of Landsat TM bands were used to design colour composites and evaluate their capability for discriminating the exposed soil surface of the burnt area or the various levels of forest vegetation regeneration. The selection criteria were based both on the visual appraisal of the colour composites and the analysis of the characteristics of the brightness values of the training sites. The Landsat TM infrared bands 4, 5, and 7 are typically more sensitive to the healthy green vegetation than the visible bands, especially the red band (TM3) which is the less sensitive. Vegetation reflects the most in the Landsat TM band 4 and thus it is desirable for band 4 to be included in a color composite which would aim at assisting discrimination of vegetation from burnt areas. It is also observed in **Figure 2** that the greater separation between the mean brightness curves occurs in TM bands 3, 4, 5, and 7.

Considering the above factors and upon extensive visual comparison of various colour composite images with the ground test data, it was concluded that the best colour composites were made of bands 7, 4, 3 (R, G, B) and 5, 4, 3 (R, G, B). The colour composites of bands 7, 4, 3 (R, G, B) are shown for both dates of 1987 and 1990 in **Figure 4**. In these images, natural vegetation appears in dark green while the burnt soil surface appears in bluish red. In the 1990 scene of this figure, there is a very bright red spot in the northwest of our study area, and it is suggested that it might have been a rather recent fire. Band combination 4, 3, 2 (R, G, B) was also a relatively good colour composite where vegetation appears deep brown while the soil surface of the burnt area appears in gray-green tones.

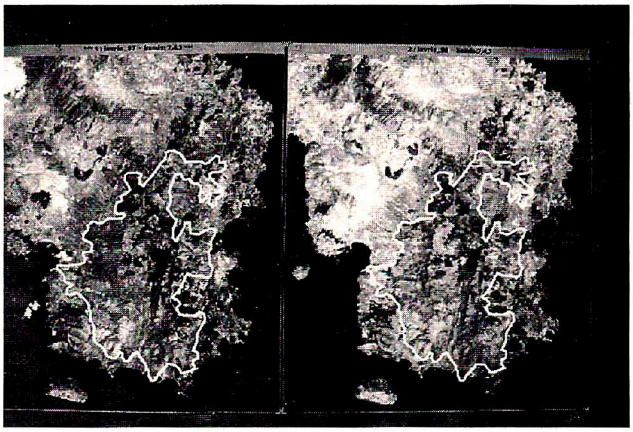

Figure 4 - Colour composite [7,4,3] presented as (R, G, B) of geo-coded Landsat TM scene of 26 June 1987 and of 4 July 1990. In the 1987 image the burnt areas appear in bluish red color while the vegetation appears in dark green. In the 1990 image the bluish red color has been reduced indicating the presence of forest vegetation regeneration

3.5 Normalized difference indices

A number of normalized difference indices were constructed and were evaluated for their significance in discriminating forest vegetation regeneration levels and the burnt area. Each index was defined by the standard algebra of such indices, e.g., NDVI(4,3) = (TM4-TM3)/(TM4+TM3).

To encode the ratio values in a standard 8-bit format a normalizing function was applied. In particular, the following indices were constructed and evaluated NDVI(4,3), NDI(5,3), NDI(7,3), NDI(5,4) and NDI(7,4). These indices were only applied to the masked area of Lavrio to facilitate comparison with the field training and test data.

The best indices were selected by looking at the brightness curves of **Figure 2**. As seen in **Figure 2**, all these indices provide relatively good separation between the indicated training sites except the NDI(5,3). The best ratios appear to be the NDI(5,4) and NDI(7,4). The selected indices were evaluated by visual appraisal of the images as well as by determining to what degree each training and test site class came to fall onto the corresponding class of the normalized difference index image. The match was satisfactory for all the training site data and all the indices.

A colour palette has been constructed for the presentation of the indices in pseudo colour and for the visual comparison of the 1987 and 1990 normalized difference indices for evaluation of the forest vegetation regeneration change that took place between the two dates. **Figure 5** shows the pseudocolour NDI(7,4) of 26 June 1987 and of 4 July 1990. From low to high level of biomass the colour palette varies as: dark blue, light blue, dark green, light green, orange, red, pink.

Evaluation of the forest vegetation regeneration change between 1987 and 1990 was also made by subtracting the corresponding normalized difference indices. The forest vegetation regeneration as computed by the NDI(7,4) index agreed with that which was indicated by the training site data. A colour composite image of three of the indices [NDVI(4,3), NDI(5,4), NDI(7,4)] was also made and it separated satisfactorily the forest vegetation regeneration levels.

3.6 Unsupervised and supervised classification

At first, an unsupervised classification by the ISOCLASS algorithm was carried out for the 1990 image of the whole Lavrio area, with an initial value for the number of classes set to 20. Relating these spectral classes to meaningful land cover classes proved to be very difficult. Thus it was decided to perform all subsequent classifications within the masked area which has been defined earlier.

The subsequent classification experiments have all been constructed with the maximum likelihood classifier. Based on the earlier discussion on the training class statistics, the decision was made to classify the images using 6 distinct training sets and then to evaluate the results after first merging the classes together into only four aggregate classes: forest, high, medium, and low regeneration. Class merging took place with the following criteria (1) the class corresponding to site L4 was merged with the medium level regeneration (L1 & L2), and (2) the class corresponding to site L3 was merged either with the medium regeneration class (L1, L2, L4) or the high regeneration class L6. The later gave the highest classification accuracy since L4 spectrally resembles L6 because it is under shadow.

The six classes and their training sites are indicated in **Table 4**. In the last two classification experiments, indicated by numbers 7 and 8 in **Table 5**, only four classes were used for training the classifier. This was achieved by merging the training sites before classification in the manner indicated in **Table 5**.

The first supervised classification using the maximum likelihood classifier was carried out using TM bands 2, 3, 4, 5, and 7 since these bands offer a good separation among the training sites **(Figure 2)**. The overall classification accuracy was 69 % **(Table 5)**. The second supervised clas-

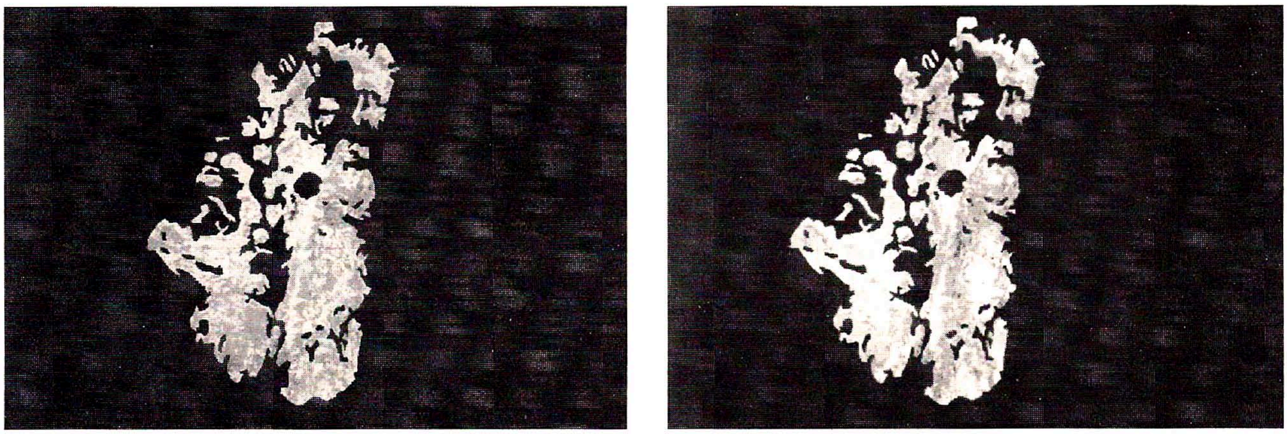

Figure 5 - Pseudocolor NDI(7,4) of 26 June 1987 and of 4 July 1990. From low to high level of biomass the colour palette varies as: dark blue, light blue, dark green, light green, orange, red, pink

sification used only bands 3, 4, and 5. Bands 2 and 7 were dropped for two reasons. The first was that they were correlated with bands 3 and 5, respectively. The second was that bands 2 and 7 are not as good in separating the training sites as the bands 3, 4, and 5. The overall classification accuracy of this run has increased to 71 % (**Table 5**).

Table 4 - The six classes and their training sites

CLASS	Training site	Description
Class-1	Forest	Not burnt forest
Class-2	L6	High forest vegetation regeneration
Class-3	L3	Medium regeneration in shadow
Class-4	L1 & L2	Medium forest vegetation regeneration
Class-5	L4	Medium to low regeneration
Class-6	L5	Low forest vegetation regeneration

The next effort was directed towards the use of the normalized difference indices for classification. The most discriminating ones are the NDVI(4,3), NDI(5,4), and NDI(7,4) (**Figure 2**). The overall classification accuracy for this run was 72 % (**Table 5**). The next classification effort employed the combination of TM bands 3, 5, 7 and indices NDI(7,3) and NDI (7,4) which resulted in an overall accuracy of 77 % (**Table 5**). The results of this classification are shown in **Figure 6**. During this trial, and while site L3 was merged with the medium regeneration class instead of the high regeneration class the overall accuracy dropped to 73 % because site L3 was spectrally closer to the high regeneration class while *de facto* it was closer to the medium regeneration class (**Figures 2 and 3**).

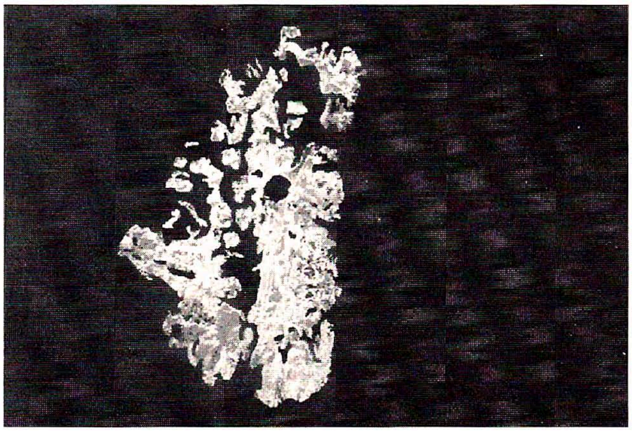

Figure 6 - Results of the supervised classification for the 1990 Landsat TM image using the maximum likelihood classifier with six training classes: Forest, L-6, L-3, L-2 & L-1, L-4, L-5 and five bands: 3, 5, 7, NDI(7,3), NDI(7,4). The overall accuracy of this classification was 77 %

Table 5 - Results of maximum likelihood supervised image classification of the 1990 Landsat TM image (masked area) for various forest vegetation regeneration classes

No	Bands Used	Training Sites Employed	Post-Classification Grouping	Overall Classification Accuracy
1	TM 2, 3, 4, 5, 7	Forest L6 L3 L1&L2 L4 L5	Forest L6 & L3 L1 & L2 & L4 L5	69 %
2	TM 3, 4, 5	As above	Forest L6 & L3 L1 & L2 & L4 L5	70 %
3	NDVI(4,3) NDVI(5,4) NDVI(7,4)	As above	Forest **L6 & L3** L1 & L2 & L4 L5	72 %
4	NDVI(4,3) NDI(5,4) NDI(7,4)	As above	Forest L6 L1 & L2 & L4 & **L3** L5	69 %
5	3, 5, 7, NDI(7,4) NDI(7,3)	As above	Forest L6 & **L3** L1 & L2 & L4 L5	77 %
6	3, 5, 7, NDI(7,3) NDI(7,4)	As above	Forest L6 L1 & L2 & L4 & **L3** L5	73 %
7	3, 5, 7, NDI(7,3) NDI(7,4)	Forest L6 L1 & L2 & L3 & L4 L5	Forest L6 L1 & L2 & L3 & L4 L5	66 %
8	3, 5, 7, NDI(7,4) NDI(7,3)	Forest L6 & L3 L1 & L2 & L4 L5	Forest L6 & L3 L1 & L2 & L4 L5	80 %

Another effort was made by using the same bands as in the previous classification, however, merging the training sites before classification into four classes (Forest, L5, L1-L2-L3-L4, L6) resulting in an accuracy of 66 % (**Table 5**). In the last effort, when the training sites were merged before classification into the four classes(Forest, L5, L1-L2-L4, L3-L6) an overall accuracy of 80 % was attained (**Table 5**. Every time training site L3 was placed in the medium regeneration class (where, it belongs based on the field data) the classification accuracy was lower than when it was placed in the high regeneration class (where it spectrally belongs).

4. DISCUSSION OF RESULTS AND CONCLUSIONS

False colour combinations of the TM bands 7, 4, 3 (R, G, B) and 5, 4, 3 (R, G, B) have been shown to be informative for the recognition, and discrimination of the pine forest, and the low, medium, and high forest vegetation regeneration classes. The indices NDI(5,4) and NDI(7,4) have shown good discrimination between the potential regeneration classes. The false colour composite of the indices [NDVI(4,3), NDI(5,4), NDI(7,4)] (R, G, B) was found superior for recognition of forest vegetation regeneration. Band selection for the false colour composites and the normalized difference indices was done according to the statistical interband data, the properties of the mean brightness values curves of each test site, the scattergrams as well as by assessing the match of the overlay of the 6 training site data provided by NARF and the 14 test data collected on top of these image products.

The six training sites were used to train the maximum likelihood classification algorithm to classify the test areas by means of a supervised methodology. Based on confusion matrix analysis of the 14 test sites, the overall classification accuracy varied from 66 % to 80 %.

The heterogeneity of the training sites – due to variation in species composition, tree spacing, height, slope, aspect, etc. – may have contributed to the reduced classification accuracy. It is anticipated that the classification accuracy could significantly increase if one was to perform a study 7 to 10 years after the fire. In that case potential training sites could have been more homogeneous.

The natural regenerating forest vegetation shows some fragmentation caused by a frequent mixture between forest and shrub species with various densities and stand heights. As a consequence of this fragmentation, it was difficult to spectrally and spatially discriminate and map the various forest vegetation regeneration species for the Lavrio test site within the first 5 years after the fire. Again, if the study is repeated in another 3 to 5 years, there will not be so much fragmentation and mixture and a species separation will be more feasible.

At present, there was no effort involving field radiometry, experimental plots, or laboratory analysis, in order to establish absolute relationships between specific field data and their reflectance values. It is desirable to plan such efforts and to extend the present methodology in order to obtain correct radiometric values. For multitemporal monitoring it is also desirable that the images be normalized to account for the varying effects of the atmosphere. It is anticipated to do such corrections provided that "ground atmospheric" data will be available.

There is a need for more training sites in order to separate the medium class(es) of forest vegetation regeneration which at present appear to produce the greatest confusion during classification. It is also anticipated that a correction will be made to reduce the effect of the shadows when the DTM is available.

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