THE USE OF REMOTE SENSING IN THE EVALUATION OF NATURAL REGENERATION POTENTIAL, EROSION RISK AND DESERTIFICATION RISK, AFTER FOREST FIRES

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ABSTRACT

Deforestation, caused by wild forest fires, is a leading factor contributing to soil degradation. The investigation of areas with low potential for natural regeneration and high risk for soil erosion and thus of serious desertification threat, is of critical importance for reliable and effective decision making for the protection of forest environment. The capability of Remote Sensing to investigate the natural regeneration and other relevant processes and to evaluate the status of the vegetation, after forest fires, is studied in this research. Four forest areas in the prefecture of Attica (Greece), which have been repeatedly burned during the recent years, have been selected as study areas. LANDSAT TM, SPOT and ERS-1 images were acquired and field operations were carried out, for all the study areas. A significant number of special transformations of the satellite images were carried out. Statistical analysis of the brightness values of the various bands and some selected transformations of the remotely sensed images were carried out, to investigate correlations with relevant field data. This statistical analysis guided the selection of the appropriate bands and transformations which were used during the classification and reclassification procedures. The final output of this research project was the production of natural regeneration potential, risk of soil erosion, desertification risk and vegetation maps.

1. INTRODUCTION

Forest fires are a major problem of the Mediterranean countries especially in the summertime. During the last two decades, forest areas of Greece and especially those of the Prefecture of Attica, have repeatedly suffered wild forest fires. The deforestation, caused by the forest fires, is a leading factor contributing to soil degradation. The determination of the areas with low potential for natural regeneration and high risk of soil erosion and thus of serious desertification threat, is of critical importance for reliable and effective decision making for the protection of forest environment. The investigation of the natural regeneration potential and the risk of soil erosion using satellite remotely sensed data, was the main task of this research, which is a part of the project: "A GIS Decision Support System for the Prevention of Desertification Resulting from Forest Fires" - Environment Research Programme, Contract No: EV5V-0025, C.E.C.

The parameters determining the risk of soil erosion are: rainfall erosivity, soil erodibility, slope gradient and slope length. For natural regeneration, the determining parameters are: rainfall, soil water storage capacity and aspect. A comprehensive set of rules based on physical modelling, which if used with field and remotely sensed data will yield the probabilities of occurrence of natural regeneration or soil erosion in the risk areas, has been generated by the forestry experts of the National Agricultural Research Foundation (NARF). Our main tasks were to investigate the relation of the ground data and the rules generated by NARF with satellite imagery and to produce maps for natural regeneration potential, risk of soil erosion and risk of desertification.

Another objective was the characterisation of existing vegetation within the test areas. After forest fires, and due to the different physical and other factors that affect each site, different types of vegetation appear. The aim of this task was to evaluate the possibility of distinguishing these different types of vegetation from satellite images and moreover the density and perhaps the height of new vegetation.

2. THE TEST AREAS

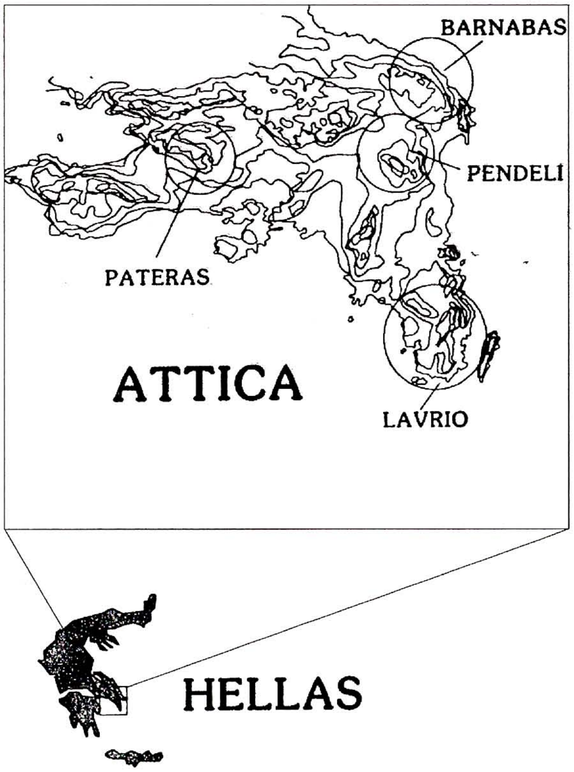

Figure 1 - Location of the test areas

Four areas, all of them located in the Prefecture of Attica, were selected as the test areas of this study. These areas are: Barnabas, Lavrio, Pendeli, and mountain Pateras (figure 1). The reason for selecting these areas was that they are located in one of the most disturbed areas hit by forest fires during the last twenty years and consequently, they are liable to a severe threat of land degradation. The choice of these test areas was mainly done by NARF (Nakos G., 1993b) and was controlled by the availability of relevant satellite data.

The vegetation types of these areas comprise closed stands of Aleppo Pine (Pinus halepensis), as well as phrygana or maquis. The prevailing surface geology of the study areas consists of Metamorphic Rocks (Lavrio), Hard Limestones (Pateras) and Schist (Pendeli, Barnabas). The size of these mainly hilly or mountainous areas, varies from 500 ha up to 11000 ha. Animal grazing is significant, especially in the Pateras test area. Inside these test areas, 39 training and 14 test sites were selected and the necessary field data were collected and archived. The main criterion of training site selection was to reliably represent the variability and spatial diversity of the four test areas. The test sites have been used to test the accuracy of the results of our methods and techniques.

3. DATA ACQUISITION

3.1 Satellite Data

A series of LANDSAT TM, SPOT and ERS-1 images have been acquired (or were available from previous research projects) and were used in this project.

LANDSAT TM :
04/08/1984, Path 183, Row 34
26/06/1987, Path 183, Row 34
14/09/1987, Path 183, Row 34
28/01/1988, Path 183, Row 34
04/07/1990, Floating Scene
14/09/1993, Floating Scene

From the above list, the images of 1984 and 1987 are the best for identifying and defining the burned areas and for estimating the vegetation loss, since most forest fires within the four test areas took place in 1985. The scene of 1993 is the closest to the training site data acquisition (which took place within the year 1993) and thus the most useful for the production of the regeneration / erosion / desertification and vegetation maps. The 1987, 1990 and 1993 scenes were used for multitemporal analysis of the natural regeneration process.

SPOT:
Panchromatic :
22/04/1989, Path 274, Row 92
XS:
16/05/1986, Path 274, Row 92

both covering only Lavrio and Pendeli areas.

ERS-1 :
16/06/1993, Centre +38.57/23.49 - Asc.
16/06/1993, Centre +37.69/23.73 - Asc.
12/07/1993, Centre +38.27/23.39 - Desc.
23/06/1993, Centre +38.24/24.09 - Desc.
23/06/1993, Centre +37.36/23.87 - Desc.

All these images were necessary to cover the four test areas both in ascending and descending orbit. Multitemporal analysis is not possible with these ERS-1 images as there are only two images for each test area, very close in terms of time, one in ascending and one in descending orbit. Only some preliminary results should be expected from their use.

3.2 Field Data

Training sites data have been collected for all the test areas by NARF. The data refer to a series of physical parameters that characterise each site. The data collected for each site are the following (Nakos G., 1993a): Elevation (m), Surface Geology, Relief, Physiography, Aspect, Slope (%), Soil Depth (cm), Surface Soil Color (Munsell), Surface Soil Texture Class (type), Surface Stoniness (covering [%] - size of stones [cm]), Surface Rockiness, Date of Fire, Severity and Extent of Fire (%), Presence or Absence of Burned Trees, Prevailing Weather Condition (precipitation three years after the fire), Density, Mean Height and Color (Munsell) of New Vegetation (for the three major vegetation types of the study area: Aleppo Pine, Maquis and Phrygana), Human Influence(s) on the vegetation after the fire (mainly animal grazing), Desertification Hazard, Main Woody Species on the Test Site, Characteristics of the Area Surrounding the Test Sites.

These data were collected for 39 training and 14 test sites. Moreover, height and canopy closure for Aleppo Pine and undergrowth vegetation have been measured in 35 pure forest areas.

The training and test sites and the forest areas were marked on black and white airphotos at a scale of 1:20000, while on field trip, and were referenced to satellite remote sensing data by digitizing them directly over the satellite images. This was much easier for those areas covered by the SPOT panchromatic image.

4. DATA PROCESSING

4.1 Satellite Data Preprocessing

Meteorological data for the satellite images acquisition dates have been provided by the Hellenic Meteorological Service to the Remote Sensing Laboratory of the National Technical University of Athens (Na.T.U.Re'S Lab.). The meteorological data included: Temperature, Visibility and Rainfall Data.

Topographic maps at a scale of 1:50000 have been digitized and DEMs have been produced for the four test areas by the Institut fur Digitale Bildverarbeitung in Graz, Austria (DIBAG). Using the previously mentioned data as well as the field data of the forest areas, that were collected by NARF, the images were corrected for the influence of atmosphere and topographic relief and were geocoded according to the Hellenic Geodetic Reference System (EGSA87), which is a UTM projection based on GRS80 ellipsoid. All this work has been carried out by DIBAG.

All images were resampled to a spatial resolution of 20 metres. The atmospherically, radiometrically and geometrically corrected / geocoded images were supplied by DIBAG to the Na.T.U.Re'S Lab. for further processing.

4.2 Field data analysis

The field data provided by NARF, as well as the documented set of rules, generated by NARF (Nakos G., 1993b), compose the necessary infrastructure for predicting: the potential for natural regeneration after a forest fire, the risk of soil erosion and the desertification risk of a specific area. The first rule takes into consideration the soil depth class and the aspect class and gives five classes of natural regeneration potential. The second rule gives five classes of soil erosion risk considering the surface geology, soil depth class and the percentage of slope of each training site. The risk of desertification is considered as the sum of the previously generated classes (natural regeneration potential and risk of soil erosion). The two rules are shown in detail on Tables I and II.

Table I - Decision Table for Natural Regeneration Potential

Soil Depth	Aspect	Class	Class Description
Deep	North	1	No Limitation
Deep	South	2	Slight Limitation
Shallow	North	2	Slight Limitation
Shallow	South	3	Moderate Limitation
Bare	North	4	Strong Limitation
Bare	South	5	Severe Limitation

The first step was to statistically analyse the data and examine the correlation among some of the physical parameters, that have been measured on the field, as well as between those parameters and the results of the application of the NARF's model. This statistical analysis resulted in the following two interesting remarks.

Table II - Decision Table for Risk of Soil Erosion

Surface Geology	Soil Depth	Slope (%)	Class	Class Description
Permeable rocks	Deep	<20	1	No to Slight Risk
Permeable rocks	Deep	>21	2	Slight Risk
Permeable rocks	Shallow	<20	2	Slight Risk
Permeable rocks	Shallow	>21	3	Moderate Risk
Impermeable rocks	Deep	<20	2	Slight Risk
Impermeable rocks	Deep	21-40	3	Moderate Risk
Impermeable rocks	Deep	>41	4	High Risk
Impermeable rocks	Shallow	<20	4	High Risk
Impermeable rocks	Shallow	>21	5	Very High Risk
Bare rocks	-	-	1	No to Slight Risk

Soil Depth classes are: Deep: >30cm, Shallow: 5-30cm, Bare: <5cm

The regression of the abundance of natural regeneration versus the output classes of the natural regeneration potential rule, had a coefficient of determination R^2=0.38. This reveals that the above model is not sufficient to describe the regeneration process, possibly because some basic factors which disturb this process, like grazing or soil erosion, are not taken into consideration.
In this study, our effort is limited on producing thematic layers exclusively from satellite (and maybe DEM) data which could provide predictions, for natural regeneration potential and for risk of soil erosion, comparable to those of the supplied model.

The statistical analysis also showed that soil depth, which participates in both the above stated rules, explains 68% of the risk of soil erosion and 70% of natural regeneration potential. Thus, it would be very effective if we could create a soil depth thematic layer directly from the satellite imagery.

4.3 Data Transformations

Taking into consideration previous experience based on our experimental research work and on the relevant international literature as well as the needs of our research, the following image transformations have been carried out:

LANDSAT TM:
For LANDSAT TM images the following series of transformations have been carried out: the sum TM1+TM3 (Ardo J., 1992), one Chromaticity Index: TM4/(TM2+TM4+TM7) (Ardo J., 1992), the Structural Index (SI=TM4/TM5) (Fiorella M. et al 1993), the NDVI and the MIR corrected NDVI (NDVIc) (Nenami R. et al 1993), the Tasselled Cap Transformation's Brightness, Greenness and Wetness Indices (Crist P. et al 1984), and the first three Principal Components. These transformations have been carried out for all LANDSAT TM images. Thermal Band 6 has been ignored during the principal component analysis. Moreover, multitemporal NDVI and TM1+TM3 colour composites have been created using the images of 1987, 1990 and 1993 as Red, Green and Blue respectively. The colour composite images were split to Hue, Saturation and Intensity images to make statistical analysis possible.

SPOT :
Transformations have been carried out only for the Panchromatic image. The XS image has been used only for visual interpretation of the burned areas. Textural transformations have been carried out, based on first order statistics (Standard Deviation and Absolute Difference algorithms) and moreover one adapted Haralick method, which has been developed by the Na.T.U.Re'S Laboratory (Iossifidis C., 1993). All these transformations didn't give satisfying results for our application.

DEMs:
The DEMs for the four test areas have been produced by DIBAG. Slope and Aspect images have been generated using the DEM data, for all test areas.

ERS-1:
All four study areas could be characterised as hilly to mountainous. Well known problems of ERS-1 images

over such areas are shadows, foreshortening and layover (FAO/ESA, 1993). Shadows are provoked by slopes, away from the radar illumination, with an angle that is steeper than the sensor depression angle. No particular shadows appear on our images. Foreshortening is the across-track compression of the radiometric information back scattered from foreslope areas of mountains. The foreshortening effect may be eliminated by the geocoding (using DEM data) process. Layover, which is an extreme form of foreshortening, occurs when the angle of the slope facing the radar is greater than the angle of the incidence radar beam. Then the ordering of the surface elements is the reverse of the actual ground order (e.g. top of mountains are displaced - "laid over") and layover zones appear as bright features on the image. In layover zones, the radiometric information is the result of the superimposition of the response of many objects. Unfortunately this is a major problem on our images which cannot be resolved by the geocoding process. The only way to retrieve information for the layover areas is to combine both ascending and descending orbit images. Two simple ways of combining the two, different orbit, images have been tested at this point. The transformations that have been carried out are the minimum image: min (Asc.,Desc.) and the combination of the two images (Ascending and Descending) due to the aspect of each pixel (as this has been calculated from the DEM).

4.4 Colour Composites

Various combinations of LANDSAT TM bands or transformations were used to produce colour composites and evaluate their capability for discerning the exposed soil surface of the burned areas as well as the various levels of forest vegetation regeneration. Among them the most interesting composites were those having the Far or Middle Infrared TM band on RED, Near Infrared band on GREEN and a Visual band on BLUE (e.g. 7,4,1 on R,G,B). The Saturation factor of such colour composite is the one that mainly reveals the regeneration status of the burnt areas. Composites of the Tasselled Cap Indices (TCB, TCG, TCW on R,G,B), as well as of the multitemporal images that were created were also proven satisfactory. Replacement of the Intensity of any of the above composites by ERS-1 intensity produces interesting images. Using the "minimum" or the "aspect merged" image, the influence of topographic relief is eliminated, while texture information is added.

5. MAP MAKING PROCESS

For the production of the risk of soil erosion and natural regeneration potential maps standard classification techniques as well as hybrid rule based methods were used.

The density of the new vegetation on the test areas few years after the fire as well as surface rockiness provide evidence for natural regeneration potential. This means that assessing natural regeneration potential directly by image classification theoretically would be possible. This approach does not seem very helpful for investigating the risk of soil erosion, but it has been tested.

Another way for assessing natural regeneration potential and risk of soil erosion would be to produce, by image classification, the proper thematic layers (soil depth, surface geology) which if reclassified according to the expert's rules, could give a better estimation for both the above mentioned attributes. This would be an indirect (hybrid) and perhaps a better method to be used especially in the case of soil erosion risk assessment.

5.1 Statistical Analysis of Field Data versus Satellite Data

The statistical analysis that was carried out had two major aims. The first one was to investigate the relations of the factors, which contribute to natural regeneration potential and risk of soil erosion, with the satellite imagery and determine which bands or transformations of the satellite images should be used in the classification procedure towards natural regeneration potential and risk of soil erosion estimation, or for the production of any other thematic layer, like soil depth and surface geology. The second was to find the most appropriate bands or transformations to be used for classification towards vegetation type identification.

The LANDSAT TM images of 1987 (the nearest to and after the time of most forest fires) and 1993 (the nearest to the time of field data collection), and the ERS-1 images have been linearly regressed versus natural regeneration potential, risk of soil erosion, abundance of natural regeneration, surface rockiness and stoniness, surface geology, soil depth and the percentage area of phrygana, maquis, aleppo pine and bare rocks on each site.

In this paper only the 1993 LANDSAT TM image statistical analysis results will be reported, as this was the only one used until now.

According to the regressions, the LANDSAT TM visual bands have the highest correlation ($R^2 \cong 0.50$) with natural regeneration potential. Also significantly correlated with this attribute are LANDSAT TM band 7, Principal Component 1 and Tasselled Cap Brightness and Greenness Indices ($R^2 \cong 0.45$).

Highest R^2 values (a little higher than 0.40) for risk of soil erosion are achieved by Tasselled Cap Brightness, Principal Component 1 and LANDSAT TM bands 5 and 4. Lower R^2 values, in comparison with those achieved for natural regeneration potential, indicate that the results of a direct classification towards risk of soil erosion estimation will not be accurate enough.

For the field data attributes, that were regressed versus satellite digital values, the following conclusions were obtained.

Abundance of natural regeneration is mostly correlated (R^2=0.57) with NDVI and Tasselled Cap Greenness while R^2 values around 0.50 were achieved with LANDSAT TM visual bands.
Surface geology has a high correlation (R^2=0.57) with LANDSAT TM band 4 and about 10% less with any other band or transformation. This reveals that there is a strong relation between surface geology and the existing vegetation.

Soil depth according to the forestry experts of NARF should follow a linear relation with vegetation density. A presupposition for this would be that the maximum possible amount of vegetation for certain soil conditions respectively is present, which may not be true for regenerating areas. The highest R^2 values for soil depth are 0.24 and 0.23 for Tasselled Cap Greenness and LANDSAT TM band 1 respectively. These R^2 values, which are quite low, indicate that it will be difficult to produce a reliable thematic layer concerning soil depth directly from satellite imagery. On the other hand it was noted that the combination (as defined by the rule for the risk of soil erosion) of surface geology and soil depth, which can be obtained if the slope class (also as defined by the same rule) is subtracted from the risk of soil erosion class, had a much better correlation with satellite data than this of soil depth and of risk of soil erosion. This possibly occurs because the density but also the type of the existing vegetation depends on the combination of the surface geology and the soil depth of each site. The R^2 values for this combined attribute are 0.10 to 0.40 higher than those for soil depth, and highest values are achieved by LANDSAT TM band 4 (R^2=0.53), Tasselled Cap Brightness index (R^2=0.52) and LANDSAT TM band 3 (R^2=0.50). Thus, the production of a layer concerning the soil depth and surface geology combined attribute should be more reliable than that of just soil depth. After the production of this thematic layer a reclassification based on slope will produce the erosion risk map. Special care should be taken in the case of *bare* soils (meaning the soil depth class - see Table II).

For the vegetation type percentage area covering (phrygana, maquis, aleppo pine) low values of R^2 were expected, since almost all the training sites have a mixture of different vegetation types. The Principal Components 2 and 3, which did not have any correlation with the previously discussed attributes, were those to describe the vegetation cover in the best way. PC3 had the highest correlation with % phrygana and % maquis, while PC2 had a notable correlation with % Aleppo pine. Tasselled Cap Greenness and NDVI were enough correlated with % Aleppo pine, % maquis and had a good correlation with % Rockiness and Stoniness. R^2 values were low as expected, ranging from 0.15 to 0.53, but indicative enough. For all the other bands or transformations of LANDSAT TM data R^2 values were almost zero.

5.2 Classifications

For the production of the risk maps only the 1993 LANDSAT TM image was used up to now. The maximum likelihood classifier was used in all cases. Urban and agriculture areas were masked out (blanked) and each test area was classified using all the 39 training sites. The selection of the bands, that were used for classification, was made taking under consideration the regression analysis results and the correlation matrix of the 1993 LANDSAT TM image (covering the four test areas) which is shown on Table III (Negative values indicate an inverse correlation of the two bands).

• Direct approach

For both classifications, towards natural regeneration potential and risk of soil erosion estimation, two different selections were made. The first one was based on LANDSAT TM bands themselves and the second one on their transformations. Based on the regression statistics and the correlation matrix of the 1993 LANDSAT TM image, LANDSAT TM bands 1,4,5 and 7 were selected to participate in both classifications, for natural regeneration potential and risk of soil erosion estimation. Moreover, the three Tasselled Cap Transformation indices, which are not much correlated each other, proved to have a good behaviour versus all training site attributes. Thus, classification procedure towards natural regeneration potential and risk of soil erosion estimation was repeated, based on these three indices.

No matter whether we used the LANDSAT TM bands themselves or the Tasselled Cap Transformation indices, the classification results were very similar. The classifications based on Tasselled Cap Transformation indices proved to be more accurate.

For the vegetation type identification things were more clear. According to the statistical analysis results there were three transformations that were related with the percentage area covering of the different vegetation types. These were Principal Components 2 and 3 and NDVI which are not correlated (see Table III).

Table III - Correlation Matrix of the 1993 LANDSAT TM image

	TM 1	TM 2	TM 3	TM 4	TM 5	TM 7	TM1 + TM3	NDVI	TCB	TCG	TCW	PC1	PC2	PC3
TM 1	1	0,96	0,91	0,71	0,84	0,80	0,97	-0,76	0,90	-0,84	-0,69	0,89	-0,29	-0,35
TM 2	0,96	1	0,96	0,79	0,86	0,82	0,98	-0,73	0,93	-0,80	-0,70	0,91	-0,30	-0,22
TM 3	0,91	0,96	1	0,85	0,89	0,89	0,98	-0,74	0,95	-0,76	-0,75	0,94	-0,22	-0,08
TM 4	0,71	0,79	0,85	1	0,79	0,80	0,80	-0,35	0,86	-0,33	-0,65	0,83	-0,20	0,35
TM 5	0,84	0,86	0,89	0,79	1	0,92	0,88	-0,66	0,96	-0,63	-0,95	0,97	0,18	-0,04
TM 7	0,80	0,82	0,89	0,80	0,92	1	0,87	-0,67	0,94	-0,64	-0,91	0,95	0,09	0,12
TM1+TM3	0,97	0,98	0,98	0,80	0,88	0,87	1	-0,77	0,95	-0,81	-0,74	0,94	-0,26	-0,20
NDVI	-0,76	-0,73	-0,74	-0,35	-0,66	-0,67	-0,77	1	-0,68	0,91	0,62	-0,70	0,08	0,47
TCB	0,90	0,93	0,95	0,86	0,96	0,94	0,95	-0,68	1	-0,68	-0,87	1,00	-0,06	0,00
TCG	-0,84	-0,80	-0,76	-0,33	-0,63	-0,64	-0,81	0,91	-0,68	1	0,56	-0,69	0,21	0,61
TCW	-0,69	-0,70	-0,75	-0,65	-0,95	-0,91	-0,74	0,62	-0,87	0,56	1	-0,91	-0,43	0,00
PC1	0,89	0,91	0,94	0,83	0,97	0,95	0,94	-0,70	1,00	-0,69	-0,91	1	0,02	-0,02
PC2	-0,29	-0,30	-0,22	-0,20	0,18	0,09	-0,26	0,08	-0,06	0,21	-0,43	0,02	1	0,10
PC3	-0,35	-0,22	-0,08	0,35	-0,04	0,12	-0,20	0,47	0,00	0,61	0,00	-0,02	0,10	1

• Indirect approach

For the risk of soil erosion estimation the indirect method was also used. At first, for the 39 training sites, the slope class of each site was subtracted from its *risk of soil erosion class*, producing three classes describing the combination of surface geology and soil depth. These three classes actually represent:

Class value	Combined attribute class
1	Bare rocks Permeable rocks & Deep soil
2	Permeable rocks & Shallow soil Impermeable rocks & Deep soil
4	Impermeable rocks & Shallow soil

The satellite image was then classified based on these three classes and the output classification wass reclassified based on the slope class of each pixel as follows:

Initial class value + 0: for ≤ 20% slope
Initial class value + 1: for 21%-40% slope
Initial class value + 2: for ≥ 41% slope

The result is a new classified image with five classes (any result higher than 5 is truncated to 5). This reclassification will cause an overestimation in the case of bare rocks (see Table II), therefore the new classified image is again reclassified based on the vegetation classification and the soil erosion risk class is reduced to 1 for the rocky areas (since the vegetation classification is not 100% accurate this last reclassification will cause some underestimation in some cases).

6. EVALUATION OF THE CLASSIFICATION RESULTS - CONCLUSIONS

NARF has gathered field information for 39 training sites and 14 test sites. The sample could be characterised as "poor" for our four test areas, which cover about 200 km^2 of forest land (the satellite images cover a total area of 510 km^2), and thus, the expected classification accuracy is obviously of the same value.

The testing of the classifications that have been carried out was done based on the data of the 14 test sites. For the classification for vegetation type identification, more sites could be used to test its accuracy since only 15 of the 39 training sites, which were characterised as "pure", were actually used for training. The predicted values for the 14 test sites, according to the classifications that have been carried out, are summarised on Table IV. The field measured values are also shown in parentheses.
The previous results, for risk of soil erosion and for natural regeneration potential, may seem disappointing but if we assume that a mis-classification between adjacent classes is acceptable (± 1 Class), which would be equivalent to reducing the 5 risk classes to 3, then the accuracy level becomes reasonable (Table IV). According to the forestry expert's directions it is better to group the five classes into three under the following schemes:

Initial "Risk of Soil Erosion" or "Natural Regeneration Potential"

class:		Final class:
1	→	1
2 to 3	→	2
4 to 5	→	3

Initial "Risk of Desertification"

class:		Final class:
1 to 2	→	1
3 to 4	→	2
5 to 6	→	3

According to the previous grouping Table IV changes as shown on Table V.

Table IV - Predicted values for the Test Sites (5 classes)

Site	Natural Regeneration Potential	Risk of Soil Erosion (Direct Approach)	Risk of Soil Erosion (Indirect Approach)	Risk of Desertification Direct	Risk of Desertification Indirect	Vegetation Type (majority only)
TB-1	2 (2)	5 (3)	4 (3)	4 (3)	3 (3)	Maquis (Maquis)
TB-2	2 (1)	5 (3)	4 (3)	4 (2)	3 (2)	Maquis (Maquis)
TL-1	2 (3)	4 (5)	4 (5)	3 (4)	3 (4)	Aleppo Pine (Aleppo)
TL-2	2 (2)	4 (3)	5 (3)	3 (3)	4 (3)	Aleppo Pine (Aleppo)
TP-1	1 (1)	4 (1)	4 (1)	3 (1)	3 (1)	Phrygana (mixture)
TP-2	3 (2)	4 (2)	5 (2)	4 (2)	4 (2)	Maquis (Maquis)
TP-3	1 (2)	4 (3)	5 (3)	3 (3)	3 (3)	Maquis (Maquis)
TP-4	1 (1)	3 (2)	3 (2)	3 (2)	2 (2)	Phrygana (Aleppo)
TP-5	5 (2)	1 (3)	1 (3)	3 (3)	3 (3)	Rock outcrops (Rocks)
TP-6	5 (3)	1 (3)	2 (3)	3 (3)	4 (3)	Rock outcrops (Rocks)
TPD1-1	2 (3)	5 (5)	4 (5)	4 (4)	3 (4)	Aleppo Pine (mixture)
TPD1-2	1 (3)	4 (5)	5 (5)	3 (4)	3 (4)	Aleppo Pine (Aleppo)
TPD1-3	3 (3)	3 (5)	5 (5)	3 (4)	4 (4)	Phrygana (Rocks)
TPD2-1	2 (2)	4 (3)	5 (3)	3 (3)	4 (3)	Aleppo Pine (Aleppo)
Accuracy	43%	7%	14%	43%	36%	86%
± 1 Class	79%	50%	57%	78%	86%	

Table V - Predicted values for the Test Sites (3 Classes)

Site	Natural Regeneration Potential	Risk of Soil Erosion (Direct Approach)	Risk of Soil Erosion (Indirect Approach)	Risk of Desertification		Vegetation Type (majority only)
				Direct	Indirect	
TB-1	2 (2)	3 (2)	3 (2)	3 (2)	3 (2)	Maquis (Maquis)
TB-2	2 (1)	3 (2)	3 (2)	3 (2)	3 (2)	Maquis (Maquis)
TL-1	2 (2)	3 (3)	3 (3)	3 (3)	3 (3)	Aleppo Pine (Aleppo)
TL-2	2 (2)	3 (2)	3 (2)	3 (2)	3 (2)	Aleppo Pine (Aleppo)
TP-1	1 (1)	3 (1)	3 (1)	2 (1)	2 (1)	Phrygana (mixture)
TP-2	2 (2)	3 (2)	3 (2)	3 (2)	3 (2)	Maquis (Maquis)
TP-3	1 (2)	3 (2)	3 (2)	2 (2)	2 (2)	Maquis (Maquis)
TP-4	1 (1)	2 (2)	2 (2)	2 (2)	2 (2)	Phrygana (Aleppo)
TP-5	3 (2)	1 (2)	1 (2)	2 (2)	2 (2)	Rock outcrops (Rocks)
TP-6	3 (2)	1 (2)	2 (2)	2 (2)	3 (2)	Rock outcrops (Rocks)
TPD1-1	2 (2)	3 (3)	3 (3)	3 (3)	3 (3)	Aleppo Pine (mixture)
TPD1-2	1 (2)	3 (3)	3 (3)	2 (3)	2 (3)	Aleppo Pine (Aleppo)
TPD1-3	2 (2)	2 (3)	3 (3)	2 (3)	3 (3)	Phrygana (Rocks)
TPD2-1	2 (2)	3 (2)	3 (2)	3 (2)	3 (2)	Aleppo Pine (Aleppo)
Accuracy	64%	29%	43%	43%	43%	86%

It was expected that combining different thematic layers with serious level of uncertainty would not produce a reliable thematic layer for risk of soil erosion estimation and, although the indirect approach gives better results for than the direct one, it becomes clear (on both tables, IV and V) that the risk of soil erosion cannot be predicted, based only on satellite data, with an acceptable accuracy level. On the other hand, the prediction of three classes of natural regeneration potential seems to be possible, even with simple image classification.

As it is revealed from the classification results, the vegetation status of a forest area, which has been burnt, may be well estimated using remote sensing techniques, some years after the forest fire. Appart from the vegetation density estimation, which can be achieved in a good manner with any of the well known vegetation indices, the vegetation type identification is also possible.

7. FUTURE WORK

An attempt was made to include ERS-1 "minimum" image as another band during the classification procedure and the construction of the LANDSAT TM Principal Components but no better results were obtained. What was noted during the statistical analysis is that ERS-1 "minimum" image was very sensitive to the percentage of vegetation cover within an area having the same vegetation type ("pure" sites), but the sample was too small to give any acceptable results.

Texture analysis of the ERS-1 images will be one of the next steps of this research.

8. OUTPUT MAPS

On the next page indicative risk and vegetation maps for one of our four study areas (Pateras), which have been produced by image classification, are presented (figures 2,3,4,5). The maps were also tested on the field and were found to be as accurate as described on Tables IV an V.

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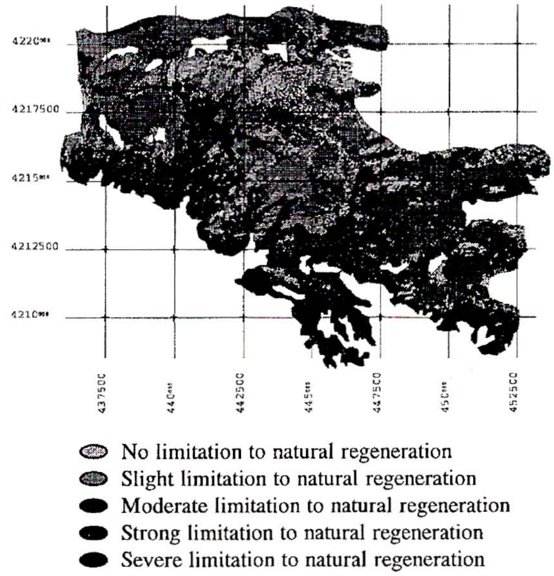

Figure 2 - Natural regeneration potential map

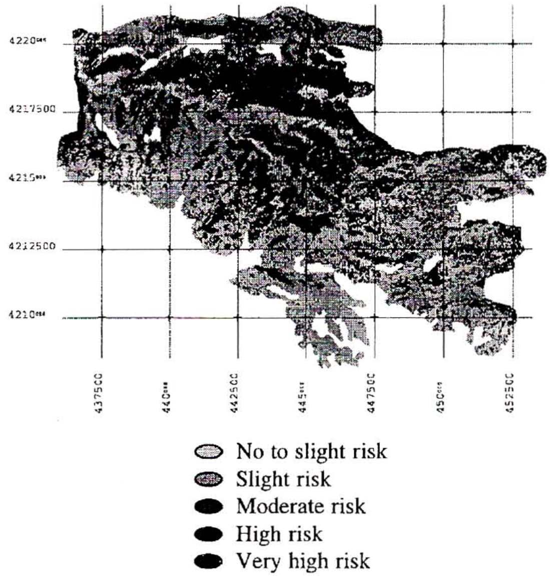

Figure 3 - Soil erosion risk map

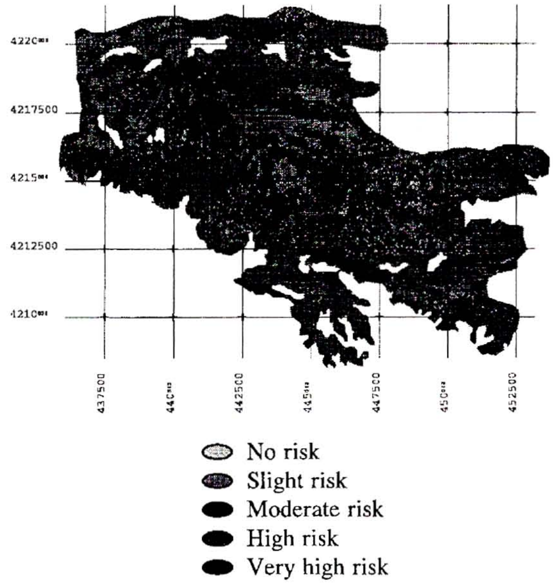

Figure 4 - Desertification risk map

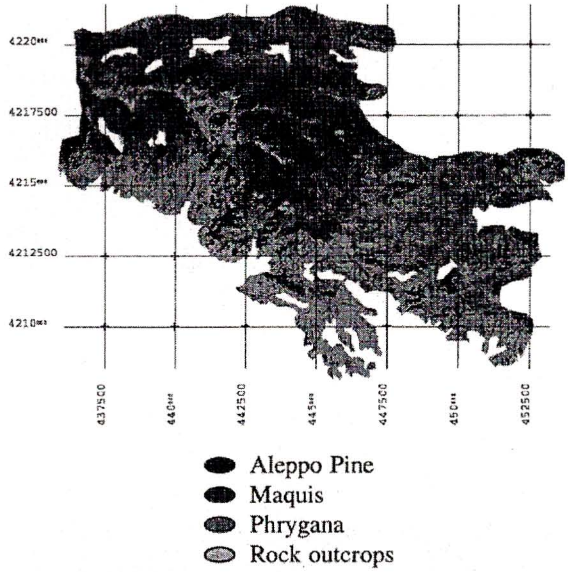

Figure 5 - Vegetation map

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