DETECTION OF CHANGES IN FOREST LANDCOVER TYPE AFTER FIRES IN PORTUGAL

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ABSTRACT

We present a methodology to detect terrain mobilization in the years following a fire using multitemporal Landsat TM imagery. Furthermore, we show the spectral evolution of the land cover since fire occurrence, and analyze the feasibility of detecting the type of land cover a number of years after fire occurrence.

The methodology developed here is a spectral change identification technique based on vegetation index differencing. Spectral change identification has the advantage that it is based on the detection of physical changes between image dates, which avoids the propagation of accuracy errors. The vegetation index used was the Atmosphere Resistant Vegetation Index (ARVI). Although ARVI differencing was obtained through a simple subtraction between two different dates, the critical element was to decide the thresholds between change and no-change.

The spectral evolution of the land cover was done through a multitemporal analysis from 1990 until 1998, and can be seen as a first step to help identifying the post-fire vegetation species.

To assess the efficiency of this methodology in detecting the different land cover changes after a fire, a change detection error matrix was used. The reference data used for the validation was a land use map from 1990 in order to detect the land cover type before the fire, ortho-rectified aerial photographs from 1995 in order to detect the land cover type after the fire, and also burned area maps for each year. This study demonstrated the feasibility of using earth observation data to assess land cover changes in burnt forest areas.

1 INTRODUCTION

The problem of forest fires in Portugal is intimately linked to land cover and land use change purposes. Forests are periodically burned with higher or lower intensity, resulting in an immediate change of the land cover towards a burned surface. This can result in the recover of the natural vegetation or of the forest species that was present before the fire. However, it is not uncommon that human intervention leads to a land cover type different from the one that was present before the fire. The major land cover changes that might occur in Portuguese forests after fires are growth of shrub-land, re-growth of the forest stands, and terrain mobilization followed by forest plantation. Less common are the changes of the burned surface into urban or agricultural areas.

We are currently developing methodologies to characterize post-fire land cover maps using satellite data, under an European Commission funded project - APERTURE (ENV4-CT97-0437). This project aims at promoting the use of Earth Observation (EO) data in judicial and extra-judicial proceedings to enforce the application of environmental law. In Portugal, we are addressing the implementation of burned forested area legislation, which requires the characterization of land cover, before and after fire occurrence, with EO data. Our most important goal, within APERTURE, is the development of methodologies that use EO data to identify areas where illegal land cover transitions occurred. Illegal actions entail, for example, the plantation of eucalyptus in areas occupied with pine forest before fire occurrence. This explains our interest in separating different types of land cover after a fire.

The study reported here aims to characterize post fire land cover change with a particular emphasis on terrain mobilization. Our main goal is to detect terrain mobilizations in burned forest surfaces, and analyze the possibilities of identifying the forest species used in the plantation.

Most of the reforestation actions, which are due to economic interests, take place in the first few years after fire occurrence. For this reason, the algorithm developed for post-fire detection of terrain mobilisation was tested only on the first two years after fire occurrence. However, the same technique can be used for a longer time period. Three fire seasons were considered in the post-fire change analysis: 1991, 1992, and 1993.

2 STUDY AREA

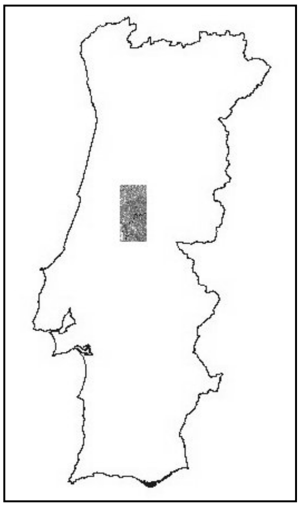

Figure1- Study area in Portugal.

The study area is located on central Portugal and comprehends an area of 2240km^2 (Figure 1). This area has been severely affected by vegetation fires in the last decade. Maritime pine (*Pinus pinaster* Ait.) and Tasmanian blue-gum (*Eucalyptus globulus* Lab.) are the most representative forest species, along with large patches of Mediterranean shrubs. This site was chosen based on the following conditions: (1) to be a forest area largely affected by fires and (2) to be an area where specific land cover changes have occurred in the past - such as pine stands (before fire) to eucalyptus stands (after fire).

3 DATA SET

A multi-temporal Landsat 5-TM data set was assembled for this study. The period analyzed was 1990-1998, with one image per year obtained in spring or early summer. The pre-processing of this data set included geometric correction and radiometric correction. However, since we were dealing with a multi-temporal data set, some particular aspects had to be considered.

All images were geometrically corrected not only to eliminate geometric distortions present in the images but also to register the satellite images to ground data. Ground Control Points (GCP) were extracted from topographic maps (1:25 000), using geographic features such as road intersections, land/water interfaces or field patterns. Polynomials of 2nd order were used in each registration. The nearest neighbor re-sampling method was used, because it is the only one that keeps the original brightness values. All images were re-sampled to a 25 m pixel grid. Considering that the study was carried out in more than one image acquired at different periods we had to guarantee that the images were not only registered to the reference map but also co-registered. For this reason, an image was referenced to a map (target image) and all the others were then registered to this one. An assessment of geometric correction results is presented in Table 1.

Acquisition date	# GCP used	RMSE
4 - 5 - 90	50	0.66 pixel
26 - 7 - 91	43	0.63 pixel
12 - 7 - 92	42	0.59 pixel
13 - 6 - 93	64	0.68 pixel
29 - 4 - 94	61	0.70 pixel
5 - 7 - 95	69	0.70 pixel
5 - 6 - 96	58	0.75 pixel
24 - 6 - 97	120	0.92 pixel
27 - 7 - 98	40	0.58 pixel

Table 1 – Imagery acquisition dates, number of ground control points (GCP) used for each image and Residual mean squared error (RMSE) obtained in the geometric correction procedure of the Landsat 5-TM data set (path: 204; row: 32).

The radiometric correction involved the conversion of digital numbers (DN) of each image to Top-of-Atmosphere (ToA) reflectance units. In this procedure DN were converted to radiance units using the sensor calibration coefficients retrieved from the image headers and corrected to account for the sensor drift over time using the approach proposed by the Canada Centre for Remote Sensing (1999). To perform the conversion of radiance units to ToA reflectance, the following model was used for each wave band (λ):

$$\rho_{ToA\ \lambda} = \frac{L_\lambda \cdot \pi \cdot d^2}{E_{0\lambda} \cdot \cos\theta}$$

$\rho_{ToA\lambda}$ is the top-of-atmosphere reflectance,

L_λ ($mW.cm^{-2}.sr^{-1}.\mu m$) is the spectral radiance,

d (AU) is the Sun to Earth distance in astronomic units,

$E_{0\lambda}$ ($mW.cm^{-2}.sr^{-1}.\mu m$) is the exo-atmospheric solar irradiance,

cos θ is the cosine of the solar zenith angle.

The Sun to Earth distance was retrieved from tabular data (Iqbal, 1983) using the image acquisition date and time. The solar exo-atmospheric irradiance was retrieved from Slater (1980). The use of ToA reflectance units instead of the original DN units allows a better comparison of images through time, since at least a part of the scene specific characteristics like differences in sun illumination geometry and sensor characteristics can be accounted for in the conversion process.

Three sets of ancillary data were used: burned area maps, pre-fire land cover maps (1990), and ortho-rectified aerial photography from 1995. The Portuguese Forest Service (*Direcçăo-Geral das Florestas*) funds the production of burned area maps based on Landsat 5-TM data. This is available for the entire country and contains all the burned areas larger than 5 ha since 1995, and larger than 15 ha before 1995. Maps for the period from 1991 to 1995 were used in this study. Approximately every 10-years, land cover maps are produced for the entire country by visual interpretation of aerial photographs. This information is available at 1:25 000 scale with a minimum mapping unit of 1 ha. For this study, land cover maps from 1990 were used to characterize the land cover before the fires. For the post-fire land was cover, it performed a visual interpretation of the ortho-rectified aerial photographs from 1995 in order to obtain test areas.

4 METHODS

The methodology used for the post-fire change detection was based on vegetation index differencing. The vegetation index used was the Atmosphere Resistant Vegetation Index (ARVI). In our study area, this index showed high values for vegetation cover, low values for forest burned area, and even lower values for terrain mobilisation (Santos et al, 1999).

ARVI was computed using Landsat TM near-infrared (NIR), red (R), and blue (B) bands in ToA reflectance units (Kaufman and Tanré, 1992):

$$ARVI = \frac{NIR - RB}{NIR + RB}$$
$$RB = R - \gamma(B - R)$$

In this study, γ - an atmospheric self-correcting factor which depends on aerosol types - was set to 1 since it permits a better adjustment for most remote sensing applications, when the atmospheric data are unknown (Kaufman and Tanré, 1992).

The ARVI difference images were computed using the year of the fire as compared with the two years following the fire. For 1991 the difference images were computed for 1991-1992 and 1991-1993, for 1992 they were computed for 1992-1993 and 1992-1994, and for 1993 they were computed for 1993-1994 and 1993-1995. This allowed the identification of no change areas, as well as 2 types of change areas: 1) Re-growth of vegetation and, 2) Terrain mobilisation/reforestation.

Regrowth of vegetation after fire should appear negative in the difference image, because ARVI for vegetation is higher than for burned areas. In the case of mobilisation, the difference image should be positive, because the ARVI value is higher for burned area than for bare soil. To identify the terrain mobilisation areas thresholds were selected based on the mean and standard deviation of the image difference histogram. This is a common procedure in land change use detection (Mas, 1999). The critical element is to decide the thresholds between change and no-change. A higher number of standard deviations will originate higher omission errors but lower commission errors.

Only the area of the ARVI difference image corresponding to the burned areas was used for the computation of the mean and standard deviation in order to exclude other variability factors outside of the burned areas. The ARVI difference images (e.g.: 91-92) were density sliced to put in evidence all the negative/positive values that were located on the extremes of the distribution.

The validation of the mobilisation maps was done using the 1995 ortho-rectified aerial photographs on a number of test areas. Two types of test areas were chosen: areas that suffered terrain mobilisation and areas that didn't suffer terrain mobilisation. Since the ortho-photos were from 1995, and the period under analysis spanned from 1991 to 1995, it was necessary to use them together with the support of the RGB Landsat images, in order to define the test areas.

Apart from the production of terrain mobilization maps, a number of test areas was retrieved using the 1995 ortho-rectified aerial photographs to follow up the land cover change over forest burned areas and its spectral evolution with time.

5 RESULTS AND DISCUSSION

5.1 Production of terrain mobilization maps

The initial output data was a series of ARVI difference images: 1991-1992, 1991-1993, 1992-1993, 1992-1994, and 1993-1994, 1993-1995. Only the area of the ARVI difference images corresponding to the burned areas was used for the computation of the mean and standard deviation, since the areas that had been previously masked had zero value and were excluded from the computation. The mean and standard deviation of the masked ARVI difference images is presented in Table 1.

Table 1. Mean (μ) and standard deviation (σ) of the ARVI difference images for post-fire change detection.

ARVI image difference	μ	σ
1991-1992	- 0.042	0.165
1991-1993	-0.210	0.203
1992-1993	-0.123	0.149
1992-1994	-0.144	0.163
1993-1994	-0.094	0.143
1993-1995	-0.145	0.168

The ARVI difference images) were density sliced to put in evidence all the negative/positive values that were located on the extremes of the distribution, in the following way:

a) $\mu \pm 2\sigma$

b) $\mu \pm 1.5\sigma$

c) $\mu \pm 1\sigma$

The part regarding the terrain mobilisation will be on the right side of the mean value since the ARVI value for terrain mobilisation will be higher than for burned areas. These different output images were checked against visual analysis of the original Landsat images to assess which one was reproducing better the areas that had been subjected to mobilisation. After careful comparison with the Landsat TM images (RGB – 5, 4, 7) $\mu \pm 1.5\sigma$ was chosen to derive the final map. Because the objective of the study is to detect reforestation actions that might be infringing the law, it was found desirable to use a relatively small number of standard deviations, even if it will increase the commission errors.

The ARVI difference images (e.g.: 91-92) were density sliced using the thresholds derived from $\mu \pm 1.5\sigma$. The part regarding the terrain mobilisation, on the right side of the distribution was set to 10 and the rest of the image was set to 1.

An example of a terrain mobilisation area detected in the output map is shown in comparison with the sequence of Landsat TM images from 1990 until 1994 (Figure 2).

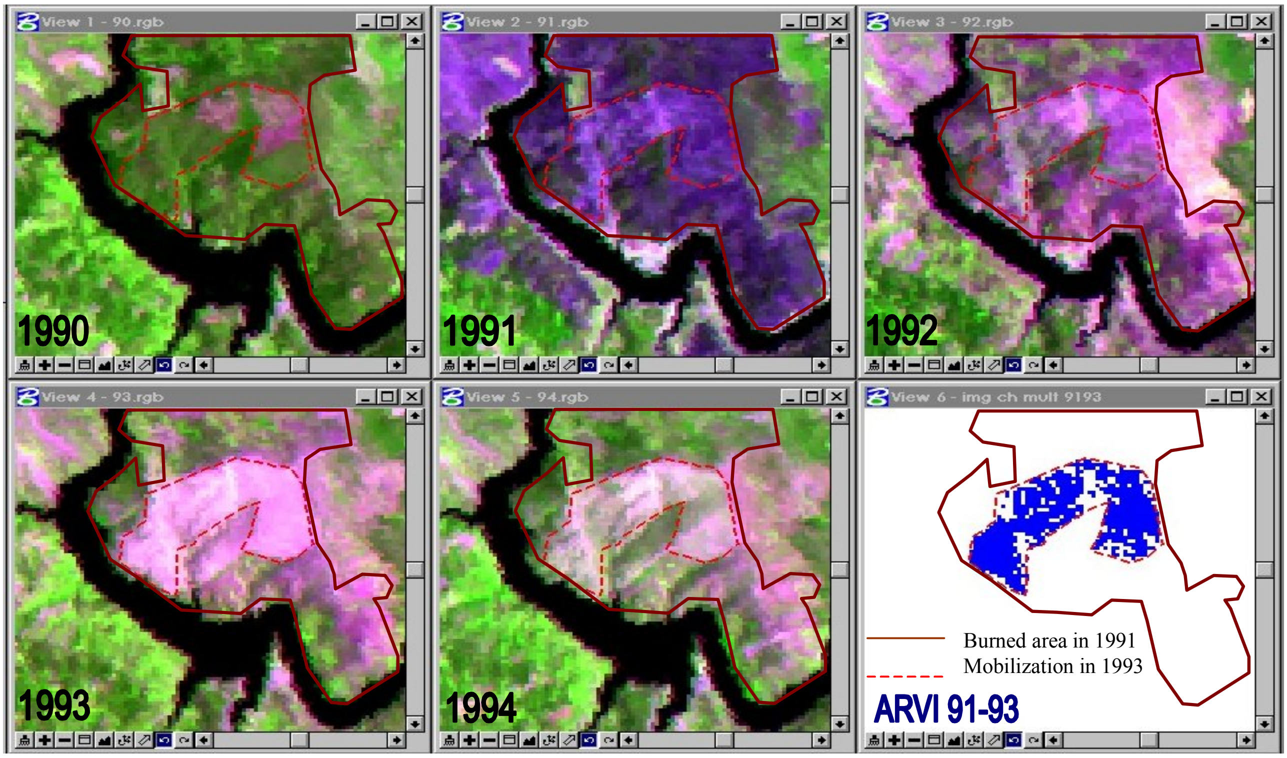

Figure 2. Landsat TM RGB image (bands 5, 4, 7) showing forest burned area in 1991 and mobilization in 1993. Comparison with the post-fire mobilization map of 1991-1993.

The validation of the maps was done using the 1995 ortho-rectified aerial photographs on a number of test areas. Two types of test areas were chosen: areas that suffered terrain mobilisation and areas that didn't suffer terrain mobilisation. Since the ortho-photos were from 1995, and the period under analysis spanned from 1991 to 1995, it was necessary to use them together with the support of the RGB Landsat images, in order to define the test areas.

The results of the validation are given in the form of a confusion matrix (Table 2), from which a number of indicators were derived (Table 3): users and producers accuracy, omission and commission errors, overall accuracy, and Kappa (Congalton, 1991).

		Mobilisation Map		
		Mobilisation	No Mobilisation	TOTAL
Ortho-photos and RGB Landsat images	Mobilisation	1881	664	2545
	No Mobilisation	149	13217	13366
	TOTAL	2030	13881	15911

Table 2. Confusion matrix showing the number of pixels used for the validation of the change detection process.

INDICATORS	Mobilisation	No Mobilisation
Producers Accuracy:	74%	99%
Users Accuracy	93%	95%
Omission Error	26%	1%
Commission Error	7%	5%
Overall Accuracy	95%	
Kappa	79%	

Table 3. Indicators of the change detection quality.

The overall accuracy obtained was high, and the Kappa coefficient that accounts for the randomness of the accuracy test is also quite high. From the point of view of the user (DGF) 93% of the pixels found in the output map as mobilisation are correct. For the control of reforestation actions, there should be a good balance between commission and omission errors, allowing DGF to perform the monitoring of the reforestation areas without a big increase in the workload of forest officers.

5.2 Land cover change spectral analysis

The temporal evolution of the land cover was analyzed for test areas that appeared burned in the 1992 Landsat TM image although the fires occurred in the 1991 fire season. The analysis was done from 1990 until 1998 using ARVI (Figure 3).

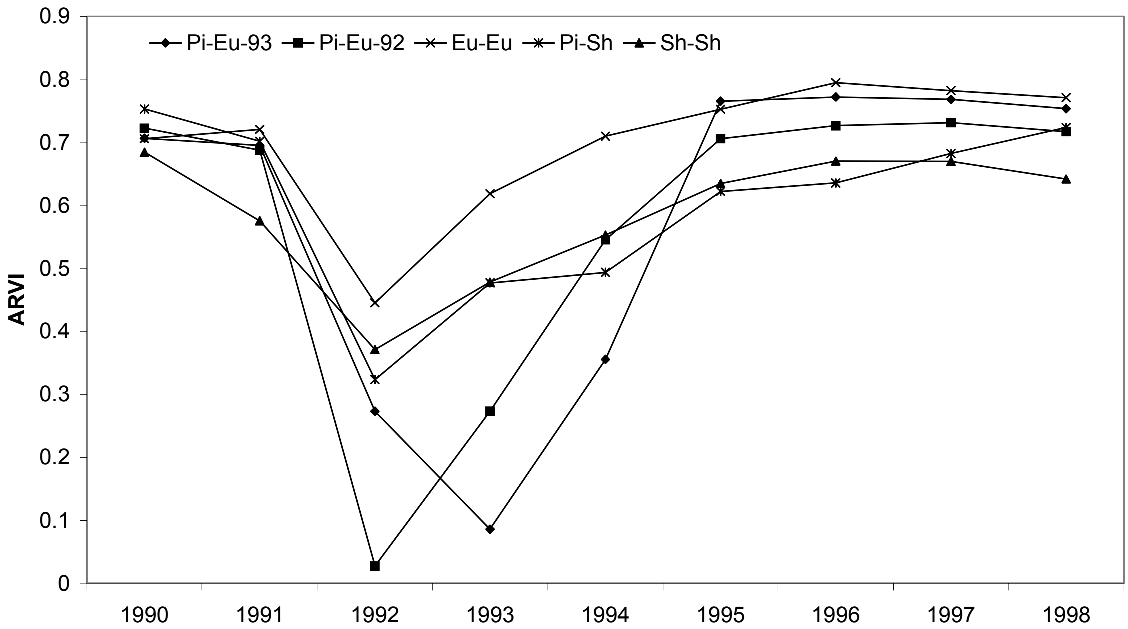

Figure 3. Comparison of the spectral evolution of different land cover transitions using ARVI.

Five different types of test areas were collected in order to follow up the spectral evolution of the land cover over forest burned areas: Shrubland – Shrubland (Sh-Sh), Eucalyptus –Eucalyptus (Eu-Eu), Pine– Shrubland (Pi-Sh), and Pine – Eucalyptus (Pi-Eu). The last test area type was divided in two different sub-types depending if the terrain preparation to plant Eucalyptus was done in the first (Pi-Eu-92) or in the second year (Pi-Eu-93) after the fire.

It can be observed that in the 1992 image, all the land cover types have an abrupt fall in ARVI due to the burned area. However, in the case of Pi-Eu-92 the fall in ARVI is much higher due to the terrain preparation. In the case of Pi-Eu-93 there is a further fall in ARVI from 1992 to 1993 due to the terrain preparation. These observations explain why the ARVI difference method can give good results for detecting terrain preparation on previously burned areas.

Regarding the evolution of the burned area with time it can be seen that while the regrowth of Shrubland is rather slow both in Sh-Sh and in Pi-Sh, the regrowth of Eucalyptus in Eu-Eu is relatively faster. This can be explained by the fact that Eucalyptus is a species that has a vegetative reproduction from stumps that allows for a rapid regeneration after a clear cut or after fire. However, the fastest regrowth of all is the one of Eucalyptus plantations (Pi-Eu-92 and Pi-Eu-93) which reaches stabilization in terms of ARVI within two to three years after the plantation.

6 CONCLUSIONS

The change detection methodology to identify terrain mobilization after forest fires was found good enough for the purposes of identifying potential illegal forest plantations after fires. The overall accuracy of the change detection method was 95%, while the Kappa index was 79%. Although from the point of view of the map producer only 74 % of the terrain mobilization areas were detected, from the point of view of the user (DGF) 93% of the areas detected as terrain mobilization were right.

Furthermore, the analysis of the multitemporal time series of the different land cover transitions showed that different types of land cover have different spectral behavior after the fire. These different temporal spectral characteristics can be used to classify the land cover type that appears after the fire, using parametric or non-parametric classification techniques. Further development on the identification of the vegetation types for the generation of land cover maps after fires should also take into account ancillary information such as pre-fire land cover and fire intensity.

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