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Mapping Burns and Natural Reforestation Using Thematic Mapper Data

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Abstract

Remote sensing techniques are specially suitable to detect and to map areas affected by forest fires. In this work, Landsat 5 Thematic Mapper (TM) data has been used to study a number of forest fires that occurred in the province of Valencia (Spain) and to monitor the vegetation regeneration over burnt areas.

A reference area (non-burnt forest) was established to assess the change produced by fire. The radiance in the thermal band (10.4-12.5 µm) and the normalized difference in reflectance between near IR (0.76-0.90 µm) and middle IR (2.08-2.35 µm) were the most suitable parameters to map burnt areas. This index can also be used for monitoring vegetation regeneration in burnt areas. About a month after the fire, the burns show temperatures of 5-6°C higher than those found in the reference area, and the vegetation index shows negative values whereas the reference area values remain positive. The differences between the burns and the reference area for the vegetation index decrease with time as vegetation regenerates.

1. Introduction

Since the launching of ERTS 1 in 1972, later renamed Landsat 1 (NASA, 1972), different studies have been carried out with the purpose of evaluating the size of the areas affected by forest fires using data from the Multispectral Scanner (MSS) sensor onboard this satellite. Husson (1980, 1985), using supervised classification techniques, studied forest fires that occurred in Corsica (France) from 1973 to 1980. Richards and Milne (1983) and Richards (1984) studied the potential of principal components transformation to map burns and to study vegetation regeneration. They analysed two forest fires that occurred near Sydney (Australia). On the other hand, Bermudez (1983), using Heat Capacity Mapping Mission (HCMM) data (NASA, 1978) showed the possibilities of using thermal images to map burns. She studied the forest fires that occurred in the province of Valencia (Spain) in 1978.

Since 1982, Landsat satellites have incorporated the Thematic Mapper (TM) sensor which has greatly improved spatial, spectral and radiometric resolution. The major design improvements of TM over the MSS include: 30 m versus 80 m ground resolution in the visible and reflected infrared bands; seven bands versus four bands, among these are a new band in the blue wavelength region, two new middle infrared bands and a high resolution (120 m) thermal infrared band; and 8 bits versus 6 bits radiometric resolution data, i.e., 256 levels compared to 64. (Spectral characteristics of the TM bands are given in Table 1).

This work has a twofold objective: firstly, to study the possibilities of the Thematic Mapper sensor, especially the newly incorporated bands, for mapping forest fires; secondly, to develop a procedure for monitoring vegetation recovery over burnt areas based on the use of multidate data.

2. Study Area

The study area is situated in the province of Valencia (Spain). This province is on the Spanish Mediterranean coast, between 39° and 40° North latitude, with a surface of about one million hectares, of which 212,379 hectares are forest and over 100,000 hectares are scrub or bush. In the last few years, each summer a great number of forest fires have destroyed a large part of the forest area of the Valencian region. Forest fires are becoming one of the main environmental problems in this zone.

From a climatic point of view, the province of Valencia is included in the so-called "Dry Iberia" and within this zone, in the eastern part of the semi-arid dominium, the climate tends towards mild-warm or subtropical. Therefore, the main climatic characteristics are a tendency to aridity and to climatic irregularity (Lines, 1970). As a result, the vegetation is adapted to the aridity and, consequently, there is a high risk of fire.

In the province of Valencia (Figure 1), the zone of Buñol has been selected as a test area to carry out the study of vegetation regeneration because there were forest fires on three different dates within this area: October 18, 1978 (4600 ha), April 27, 1982 (550 ha) and April 22, 1984 (550 ha). The vegetation of this area is a typical Mediterranean forest growing on limestone substratum. The Mediterranean forest is a heterogeneous formation composed mainly of oaks *(Quercus rotundifolia)*, considered to be the "climax vegetation", which have given way, in the present, to coniferous species *(Pinus halepensis, Pinus pinaster)*, and to secondary formations, originating from the degradation of the climax vegetation, composed of: *Quercus coccifera, Ulex parviflora, Rosmarinus officinalis, Thymus vulgaris, Stipa tenacissima, etc.* (Costa, 1982).

3. Methods

The assessment of the areas affected by forest fires and vegetation regeneration studies involve the use of multidate images. In such studies, we must distinguish in the total information contained in the scene between that which relates to the particular subject studied (forest fires in this case) and that which refers to other factors such as: viewing and illumination geometry; radiometric sensor calibration; atmospheric, topographic and climatic effects; and detector gains or offsets. These latter factors cause artificial differences that are added to those produced by the forest fire. Viewing geometry is not relevant in the case of the Thematic Mapper sensor because its scan angle is only ±7.5° (Staenz *et al.*, 1986; Sobrino *et al.*, 1988). Therefore, this effect can be neglected in this study.

In order to avoid sensor and sun angle dependence, digital counts of the images have been converted into the corresponding physical magnitudes, as Price (1987) suggested. So, apparent spectral reflectance values ρ_λ have been obtained through the expression:

The radiance values for the seven bands are obtained from the digital counts, DC, through the expression:

$$L_\lambda = a_1 DC + a_0 \tag{3}$$

where a_0 and a_1 are the calibration coefficients for each band (Table 1).

In order to minimize the effect of the remaining scene-dependent factors (atmospheric, topographic, and climatic effects and changes in detector gain or offset), a vegetated control area, "the reference area" was chosen. This area was selected from the non-burnt forest because it was spatially near burns and because its general characteristics (soil, humidity, topography and type of vegetation) were representative of pre-burnt conditions. Satellite data can be acquired nearly simultaneously over both the test and reference area; thus, the existing differences between burnt and unburnt forests may be obtained. In this way, the scene-dependent effects will not affect the results because they could be considered to be the same for both area.

The areas affected by forest fires were located on the digital image starting from the information on size and site provided by the *Instituto para la Conservación de la Naturaleza* (ICONA). Georeferenced registration was not required since the spatial resolution of Thematic Mapper data facilitated the location of affected areas by using the identification of local features (streams, roads, reservoirs, villages...). Band 4 data was particularly useful. However, a scene-to-scene registration was used in the natural reforestation study with multidate images.

4. Results and Discussion

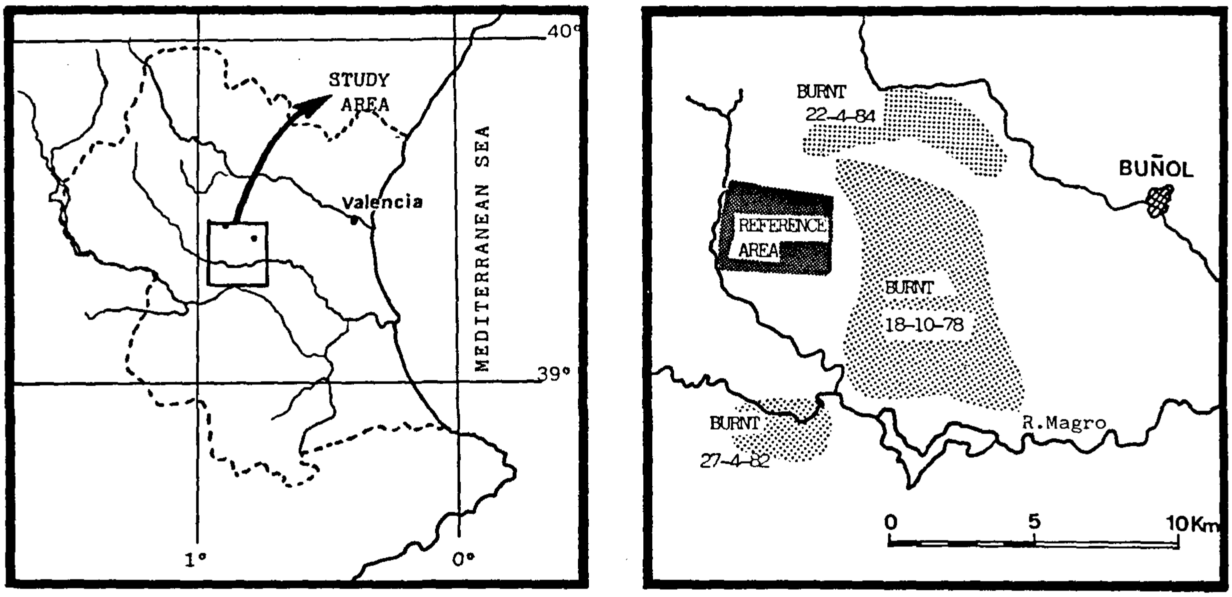


Figure 1 Map or the study area.

TABLE 1

CALIBRATION COEFFICIENTS AND SOLAR IRRADIANCE FOR LANDSAT 5 TM BANDS

BANDS	SPECTRAL RANGE (μm)	CALIBRATION COEFFICIENTS ($W\ m^{-2}\ sr^{-1}$)		SOLAR IRRADIANCE ($W\ m^{-2}$) **
		a_0	a_1	
TM1	0.45 - 0.52	-0.067	0.0420	119
TM2	0.52 - 0.60	-0.16	0.103	130
TM3	0.63 - 0.69	-0.11	0.0650	104
TM4	0.76 - 0.90	-0.23	0.117	133
TM5	1.55 - 1.75	-0.086	0.0273	44
TM6	10.4 -12.5	2.6 *	0.118 *	-
TM7	2.08 - 2.35	-0.0511	0.0169	18

* after Metzler and Malila (1985)
** after Markam and Barker (1985)

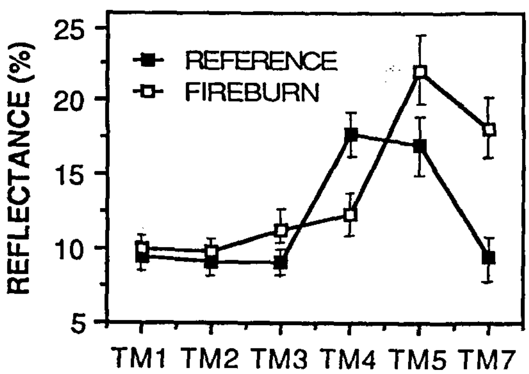


Figure 2 Special signature corresponding to the reference area and to the fire burn of April 22, 1984, derived from Landsat 5 (TM) data of June 1, 1984 (9.30h. GMT). Values n^e the mean ± standard deviation.

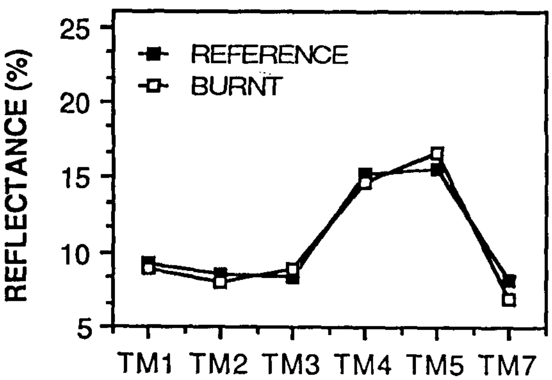


Figure 3 Spectral signatures corresponding to the reference area and to the area burnt on April 22, 1984, derived from Landsat 5 (TM) data of April 7, 1984 (9.30h. GMT).

of error bars in Figure 2, since several spectral classes are included within these areas. The bands 4, 5 and 7 showed the greatest differences between the control and the affected areas. The burnt area shows a lower reflectance value in the near infrared region (band 4) and a higher response in the middle infrared (bands 5 and 7), as a consequence of vegetation disappearance.

In order to define the most suitable "vegetation index" for mapping burnt areas, statistical analysis of spectral reflectances was employed. Thus, the correlation matrix of the reference and burnt area is provided in Table 2. The most uncorrelated pair of bands is TM4-TM7, followed by the pairs TM4-TM5 and TM4-TM1. From these results, the most uncorrelated bands have been chosen to define a vegetation index suitable for evaluating surfaces affected by fire. Therefore, this index is the normalized difference between reflectances obtained from TM4 and TM7: $\rho 4-\rho 7/\rho 4+\rho 7$. According to the characteristics of the spectral signature of vegetation and soil (Horler and Barber, 1981), this index will present negative values for areas without vegetation, such as burns, and positive values for areas with vegetation, these values being higher when denser vegetation exists.

It has been verified that the use of this index allows mapping of burnt areas from an image acquired one or two months after the fire date. As an example, Figure 4 shows the area affected by the fire on April 22, 1984 mapped from the vegetation index obtained from the Thematic Mapper data of June 1, 1984.

4.1.2 Thermal Band Analysis:

The Thematic Mapper thermal band, TM6, has also been examined in order to determine its possibilities for mapping burnt areas. At the time of satellite overpass (9.30 h. GMT), we found substantial differences between brightness temperature of burnt and reference areas. Temperature mean values obtained in the affected area are 5– 6°C higher than those obtained in the reference one, on an image acquired one or two months after the fire date. Similar results were found by Bermudez (1983) who studied with HCMM satellite data the fire that has affected the area in 1978. This satellite overpassed the zone at the time of maximum temperature, when differences between bare soil and vegetated areas are the largest.

Figure 5 corresponds to the thermal band of the image of 1st June 1984. The brightest tones show the highest temperature values and enable the identification of the burnt area. Since emissivity corrections have not been considered, the temperature differences observed do not correspond to the absolute temperature differences. A change of surface emissivity may be expected when a forest is burnt. According to the magnitude of the errors introduced by emissivity changes, 0.6°C by each 1% in emissivity (Becker, 1978), and because the disappearance of vegetation in our zone means a decrease of less than 2% in emissivity (Caselles, 1984), the emissivity correction could only add about 1°C to the differences obtained.

4.2 Monitoring Natural Reforestation of Burnt Areas

The three fires that affected the Buñol region since 1978, (October 18, 1978, April 27, 1982, and April 22, 1984,) (Figure 1) have been studied. We have used the TM images of 1 June 1984, 19 July 1984 and 16 March 1985, which supply data approximately 1 month, 3 months and 1 year respectively after the fire on April 22, 1984. The fires on April 27, 1982 and October 18, 1978 have been studied with those same images and, consequently, we have also information for about 2, 3 and 6 years after a fire.

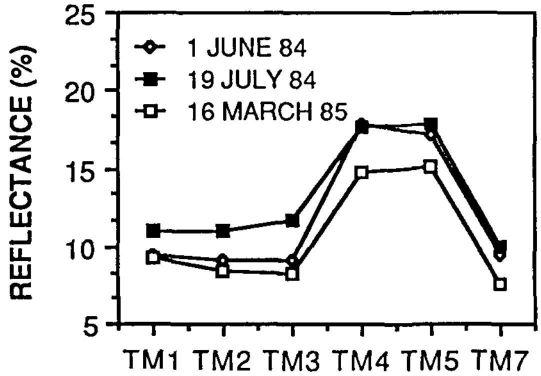
Figure 6 represents the spectral signature of the reference areas obtained from the three images used. The amplitute of reflectance variations is limited for the reference area and we are only interested in analysing the relative variations.

Figure 7 shows the spectral signature of the 3 fires studied and that of the reference are obtained from the images of 1 June 1984 (Fig. 7a), 19 July 1984 (Fig. 7b) and 16 March 1985 (Fig. 7c). The spectral curve of a burnt area has the same shape during about 1 year after the fire date (low values in TM4 and high values in TM7). After about 2 years, it changed, and progressively becomes similar to the spectral curve of the vegetated reference area. Thus, the shape of the curve 6 years after the fire is just a typical vegetation curve, similar to that of the reference area. However, there is a shift between the two curves, since the regenerated areas show higher reflectance values than the reference area. This could be explained by the fact that the vegetation regenerated over the burnt area is not composed of exactly the same species as that which were growing before the fire. As we mentioned in § 2, the vegetation existing over the reference area is a well developed forest mainly composed of oaks and pines. When a forest is degraded, as is the case of a forest affected by fire, and if the conditions make regeneration possible, the original vegetation will be replaced by the species corresponding to the first stages in the "vegetation series". Over this area, a scrub vegetation *(Phlamido-Brachypodium retusi, Saxifaga-Hornungietum petrae)* composed mainly of species such as: *Rosmarinus officinalis, Erica multiflora, Ulex parviflora,* etc. forms the first stage in the vegetation recovery to climax forest conditions. This is the vegetation that is growing in the area burnt in 1982. However, in the area affected by fire in 1978, the vegetation has reached a further serial stage. We can find a developed scrub *(Rhamo-Quercetum cocciferae ulicetosum parviflorae)* that corresponds to a second stage in the vegetation series, but differs from that

TABLE 2

CORRELATION MATRIX OF BURNT AND REFERENCE AREA DATA

	TM 1	TM 2	TM 3	TM 4	TM 5	TM 7
TM 1	1.0000	0.9291	0.9228	0.6386	0.8210	0.7738
TM 2		1.0000	0.9741	0.7892	0.8239	0.7330
TM 3			1.0000	0.7247	0.8399	0.7757
TM 4				1.0000	0.6119	0.3901
TM 5					1.0000	0.9231
TM 7						1.0000



of the reference area (climax conditions) in its degree of succession and because coniferous species are not present (R. Boluda, 1986, personal communication).

In order to quantify the vegetation regeneration on burnt areas, Table 3 shows the values of temperature and index $\rho4\text{-}\rho7 \,/\, \rho4+\rho7$ obtained on the reference and affected areas. The thermal band, which distinguishes burnt areas one or two months after the fire date, is not suitable to study vegetation regeneration because differences between both areas quickly decrease as the vegetation reappears (the temperature differences between the burnt and reference areas are of the same order as the standard deviation of these measurements). However, the difference between the burnt and reference area vegetation indices decreases with time more slowly than the temperature. In fact, by plotting the values of the vegetation cover estimated *in situ*, CE, versus the vegetation index differences, VID, (Figure 8), the following linear regression model is obtained:

$$CE = 67.2 - 2.1\ VID \qquad (4)$$

with a linear correlation coefficient of -0.97. In these statistical analysis we have used raw data not corrected for atmospheric effects. So systematics errors are introduced into the vegetation index. Moreover the number of data points is limited. For these reasons this regression model is valid whenever the atmospheric conditions be the same that in the images used, and for vegetation cover lower than 50-60%. These results show that the mean difference between the calculated and *in situ* estimated values is about 20%. However, we consider vegetation index $\rho4\text{-}\rho7 \,/\, \rho4+\rho7$ a good parameter for study-

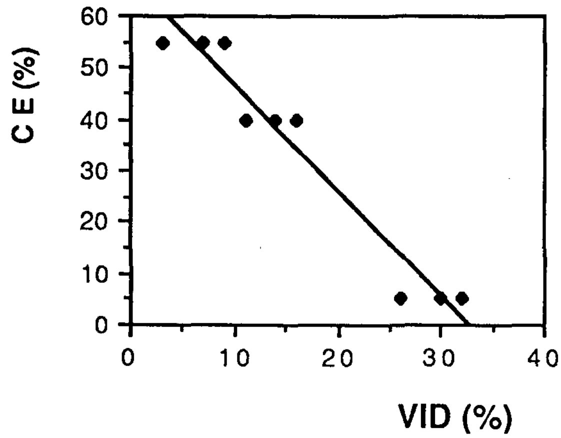
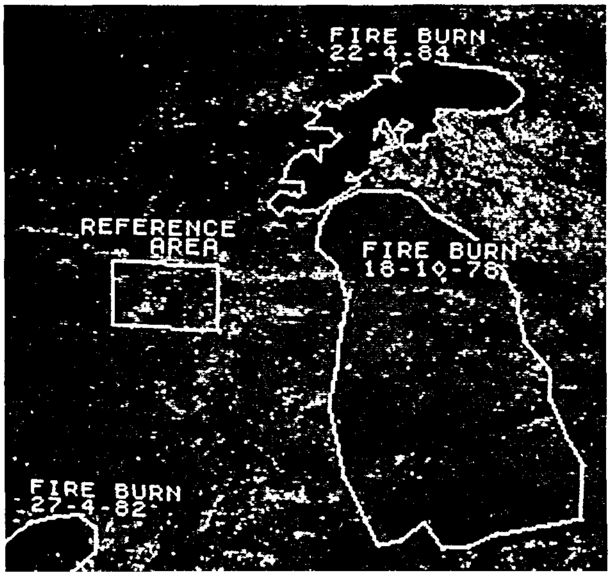


Figure 8 Vegetation cover estimated in situ (CB) versus the difference between the burnt and reference area vegetation indices (VID).



5. Conclusions

From the results obtained, we consider that the thermal band and index 4-7 / 4+7 are suitable parameters to evaluate the area affected by forest fires. This index is also appropiate for monitoring vegetation regeneration in burnt areas.

In this work, it has been also demostrated the usefulness of using a reference area in order to minimize the influence of scene-dependent factors (atmospheric, radiometric, viewing and topographical effects). This is very interesting in multitemporal studies, such as vegetation monitoring, because time computer can be considerablely reduced.

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