DETECTION OF BURNED FOREST AREAS IN CATALONIA USING A TEMPORAL SERIES OF LANDSAT MSS IMAGERY (PERIOD 1975-93)

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ABSTRACT

The work that we present is a part of a general study aimed to characterize the fire regimes in Catalonia (NorthEast of Spain) and the effects of wildfires on regeneration dynamics of plant communities. For that purpose, a semi-automatic method was applied to detect burned forest areas in the 3 million ha region of Catalonia. The methodology employed more than a hundred of MSS images from Landsat satellites comprising a period of time of 19 years. (1975-1993). They were geometrical and radiometrically corrected and the time series was registered. NDVI images were composed. Some masks were applied in order to avoid changes on plant cover dues to different causes. Subtraction of consecutive NDVI images was employed to locate the forest areas affected by fire. This approach is based on the sudden decline that the plant communities undergone when they burn. Linear regression models were used to fit the empirical changes observed for several test fires with NDVI differences between consecutive images. Detection thresholds were obtained from the models and applied to 31 windows of the images in order to minimize radiometric effects. Results were tested with administration inventories for the 1983-93 period. Omission errors are lower than 20 % for burned areas greater than 200 ha. Commission errors are lower than 6% for burned areas greater than 30 ha. A map series of fire history was created from the obtained burned forest areas. Fire recurrence is also depicted in order to locate hot spots. Some fire statistics are presented. Several reasons were argued in order to explain the errors of the implemented methodology and to understand them.

Keywords: Landsat MSS, NDVI, mask, and reflectance fire detection.

INTRODUCTION

Since 1975 to 1993, the MSS sensor, boarded on Landsat satellite series, has been providing periodically digital images of the Earth. Such a feature, and its spatial resolution (60 x 80 m) make the MSS one of the most interesting sensors of Earth Observation satellites to be employed in monitoring and studying landscape dynamics (Hall, F. G. *et al.* 1991). A specific example of their application may be the characterization of fire regime in forest areas (Minnich, A. M. 1983). In Mediterranean ecosystems, wildfires determine in a big measure the structure and spatial distribution of the plant communities and of the species (Johnson, E. A. and Gutsell, S. L. 1994), although the structure of vegetation also marks, at some level, the frequency and extent of burns.

In this sense, the project initiated with this work aim to characterize the fire regime of Mediterranean plant communities of Catalonia and to determine its influence on regeneration processes. At the beginning, a hundred of whole images from the sensor MSS (4 bands) boarded in Landsat satellites 1,2, 4 and 5 were acquired. For the complete area of Catalonia, 3 whole frames were needed. This first part of the project where the semiautomatic methodology was applied, resulted in a cartography of burned forest areas and the frequencies of fire for the period 1975-93. Then, results were statistically evaluated – see the confusion matrix below (Chuvieco, E. 1996) - in order to obtain the percentages of success of the applied methodology.

METHODS

All the images were geometrically and radiometrically corrected by using a polynomial model (Palà, V. and Pons, X. 1995) and invariant training areas (Pons X. and Solé-Sugranyes, L. 1994) respectively. Also, a normalization process was applied to all the bands.

Several methods are employed to discriminate cover changes caused by fire, usually detected as sudden decreases of plant cover. Some of the more used are Principal Components Analysis (Fung, T. and Le Drew, E. 1987), supervised classification (Hall, F. G. *et al.* 1991), change vector analysis (Lambin, E. F. 1996) and finally, images subtraction, which was used in this work

(Kasischke, E. S. *et al.*1993). The NDVI (Normalized Difference Vegetation Index) was calculated for all the images from red band (2) and near infrared (4). This index resumes the radiometric information from the source channels (Mather, P. M. 1987). In this sense, NDVI has been directly related to the amount of green biomass irrespectively of the plant species that form the community (Gamon, J. A. *et al* 1995). The NDVI is calculated as follows:

Where ρ are pixel reflectance in near infrared band and red band.

Once applied the masks for crops, deciduous, clouds and inland waters, the sudden declines of NDVI values found among pairs of consecutive images (high values of subtraction) were considered as burned areas. However, summer phenology in Mediterranean region added many changing areas not burned to the results. Consequently, 21 burned areas, validated by the administration inventories of fires, were employed to establish the suitable thresholds to discriminate properly the areas affected by fire. Three linear regression models were adjusted to the minimum and maximum threshold of subtraction values corresponding to the 21 fires, and to the iterative threshold generated by convergence with all the intervals (see Figure 1). Such models were used to build 2 different methods: (1) the method of iterated fitting and (2) the method of maximum and minimum values in order to enhance the detection by marking as "seeds" the burned areas and it extend them to the maximum precision of detected burned area.

RESULTS AND STATISITCAL VALIDATION

Both methods were applied to all consecutive pairs of sub-images (whole images had been previously divided in 31 windows or sub-images considering areas with homogeneous vegetation types and environmental conditions). In this study, 30 ha (0.3 km^2) was the minimum area considered for potential fire scars. In order to evaluate the degree of success of results of both methods, these were compared with field surveys carried out by the Government since 1983. Table 1 shows percentages of success given by the ratio of field sur-

	Iterated fitting	Method of "seeds"
Number of omitted fires	175 (**53,36%**)	143 (**43,60%**)
Number of added fires	57 (**75,43%**)	14 (**91,08%**)

Table 1. Percentage of success and number of fires detected by both methods. The total number of fires found by government field surveys was 328 (considering only those areas equal or bigger than 30 ha).

veyed fires detected by remote sensing (i.e. success in omission) and by the ratio of remotely sensed fire scars included in government surveys (i.e. success in commission). Figure 2 show the percentage of success in both methods as a function of the minimum area con-
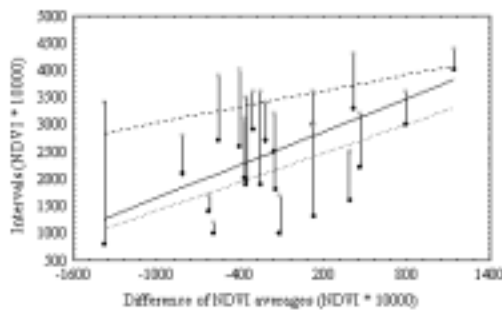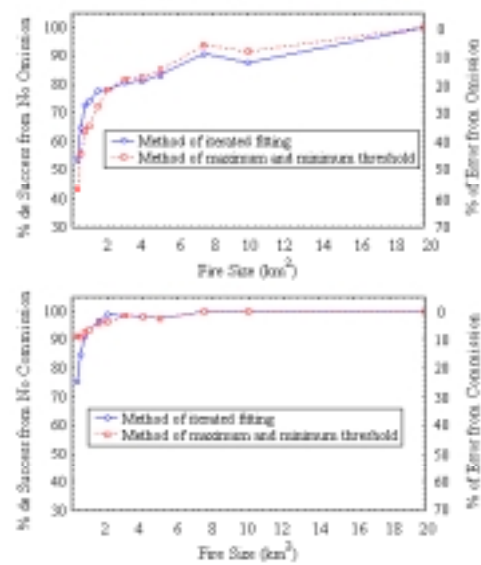

Figure 1. The graphic shows the threshold intervals of each one of the 22 fires used to feed the model. Such intervals are related to the mean NDVI subtraction values among the 2 consecutive images where fire was located. Dot line, minimum threshold; dashed line, maximum threshold; solid line, iterated threshold.

Figure 2. Percent of success of each method as a function of fire size.

sidered. Each threshold was able to discriminate sudden decreases in NDVI values (see Figure 3). When applying the absolute minimum of 30 ha (all areas equal or bigger than this size were considered), method of iterated fitting has a 53.36 % of success from no omission (175 fires detected) which was higher than the one of method of maximum and minimum thresholds (43.60 %, 143 fires detected). However, when areas bigger than 200 ha were only analyzed both achieved a 78 % of success in omission. Concerning the success from no commission, it was higher for method of "seeds" (with a 91.08 % of success) than for method of iterated fitting (75.43%) which was less restrictive for shrubland areas with high phenological dynamics (similar to those shown by burned sites).
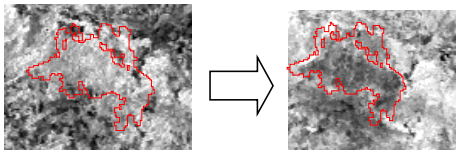

Figure 3. Example of an area with a sudden decrease in NDVI values after a fire. Boundaries of the burned area are showed up by a red polygon.

DISCUSSION

The Figure 4 shows the results obtained with the method of "seeds" (the more precise) and the map of fire recurrence for each surface affected by fire. Several factors influence the percentage of success of each method. Some of them are:

- Images availability.

- Impossibility to work with images of the same date.

- Marked summer phenology of some vegetation canopies.

- Vegetation regeneration speediness after fire.

- Soil radiometry.

- Drift of sensor calibration parameters during the study period (this effect has been corrected by applying a linear normalization to the whole series).

- Different fire intensity.

- And finally, the possible silvicultural activities practiced in the area.

All of them are a source of confusion. However, the methods here-applied (Figure 1) have been developed to minimize all these effects by choosing fire detection thresholds.
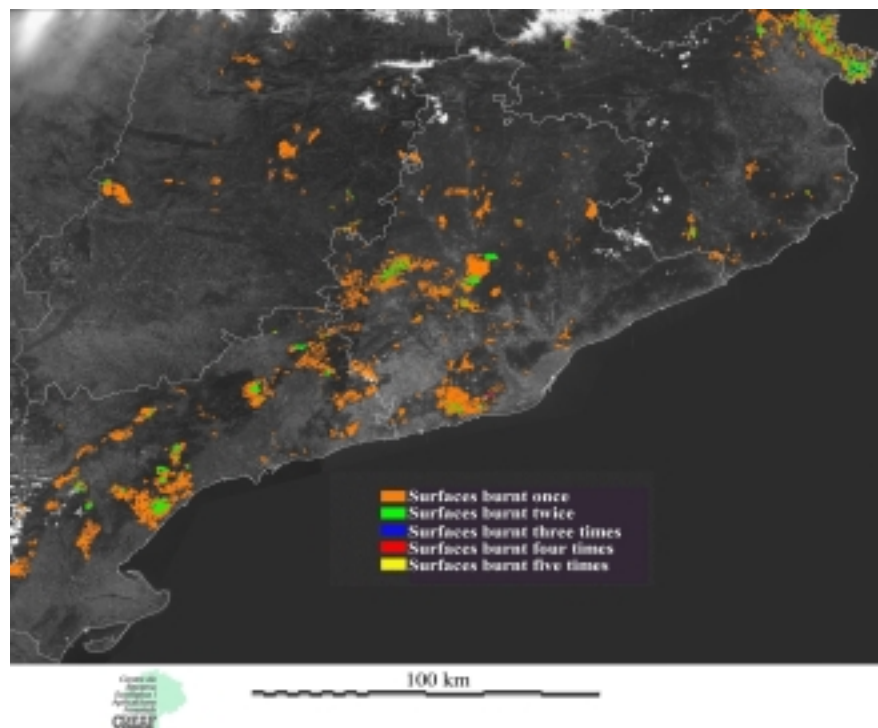

Figure 4. Map of fire recurrence in Catalonia during the period 1975-1993.

CONCLUSIONS

- Satellite images are highly interesting in order to map the fire-scars. They can be employed to characterize the fire regime of Catalonia.

- The lineal models employed are based on the subtraction of NDVI values and on the use of thresholds. Results seem to be acceptable once contrasted to administration surveys. However, percentages of omission and commission should be considered as discrepancies rather than errors due to the difficulty when accounting the whole burned surface *in situ*.

- The method of iterated fitting gives better % of success in omission while the method of "seeds" does in commission.

- Several factors caused imprecision on the methodology. Many of them might be minimized or avoided, like the phenology and the limited amount of images available by means of a higher temporal resolution. Others like different intensities of fire, silviculture activities and radiometric response of the soils do not seem to be so attainable.

ACKNOWLEDGMENTS

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