ANALYSIS OF THE DISCRIMINATION OF BURNT SITES TEMPORAL EVOLUTION IN A MEDITERRANEAN AREA

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ABSTRACT

A two stage temporal analysis was applied to six MSS geometrically and radiometrically corrected NDVI images, ranging from 1975 to 1985, and the radiometric and temporal behaviour of the main cover types present in the studied area was characterised. The features of these areas were compared to the radiometric and temporal dynamics of burned sites with the purpose of searching for clear differentiating traits. Initially, an Unstandardized Principal Component Analysis was made, obtaining areas of change in the second and following component images. Next, a temporal analysis of mean NDVI values of some of these changing areas, together with patches of invariable land cover types, was performed. Burnt areas had a temporal behaviour clearly different from that of some of the major land cover types. However, some confusion was found in low covered shrub areas, irrigated crops, inland waters and clouds.

INTRODUCTION

Fire plays a major role in the modelling of structure and dynamics of Mediterranean ecosystems. Present landscape, in part, is a result of past fire events that usually broke the gradual change of vegetation towards more mature types. Due to the large extension of some fires, remote sensing has been used to monitor and map them. There are as early studies as those done by Wightman (1973) and Deschler (1974) in Africa, using Landsat imagery. Many other studies have been made in this field such as the ones of Hall *et al.* (1980), Minnich (1983), Chuvieco and Congalton (1988), Pereira and Setzer (1993), and others. More interesting than the location and mapping of fire scars, would be the monitoring of evolution of the vegetation of the burned area, related with erosion and forest regeneration. Multitemporal analysis of satellite imagery can be applied to the study of changes, through different automated (Eastmann and McKendry 1991) or manual techniques (Minnich 1983). Some of these techniques have been applied to studies of fire dynamics and its consequences (Hall *et al.* 1980, Richards 1984).

OBJECTIVES

The general aim of the project where this study was included is the monitoring of fires that have happened during the last 23 years in Catalonia (North-East of Spain) by means of multitemporal analysis of 90 MSS images. In this paper we present first results based on a series of six images ranging from 1975 to 1985 over an area of 172 km x 188 km. The actual objective of this previous work was the analysis of temporal behaviour of main land cover types in order to prove the applicability of automatic processes to discriminate burned sites.

The proposed process is a twofold process: As a first stage, a Principal Component Analysis was applied to a temporal series of images in order to discriminate areas of local change from all other information given by the images. The second stage was the analysis of the temporal evolution of the previously selected areas (obtained in the first stage) with the view to evaluate the separability of burnt site dynamics from the dynamics of other land cover types.

The multitemporal remotely sensed information obtained was conceived to give a basic spatial information for a wide range of later ecological studies engaged with long term fire effects in Mediterranean ecosystems. Direct analysis of the images may give information on areas, shapes, and frequencies of burned sites, and the effects of these factors on the regeneration of vegetation. In addition, some future field research is also planned to be made in plant cover, regeneration, and biodiversity based in this remotely sensed information.

METHODOLOGY

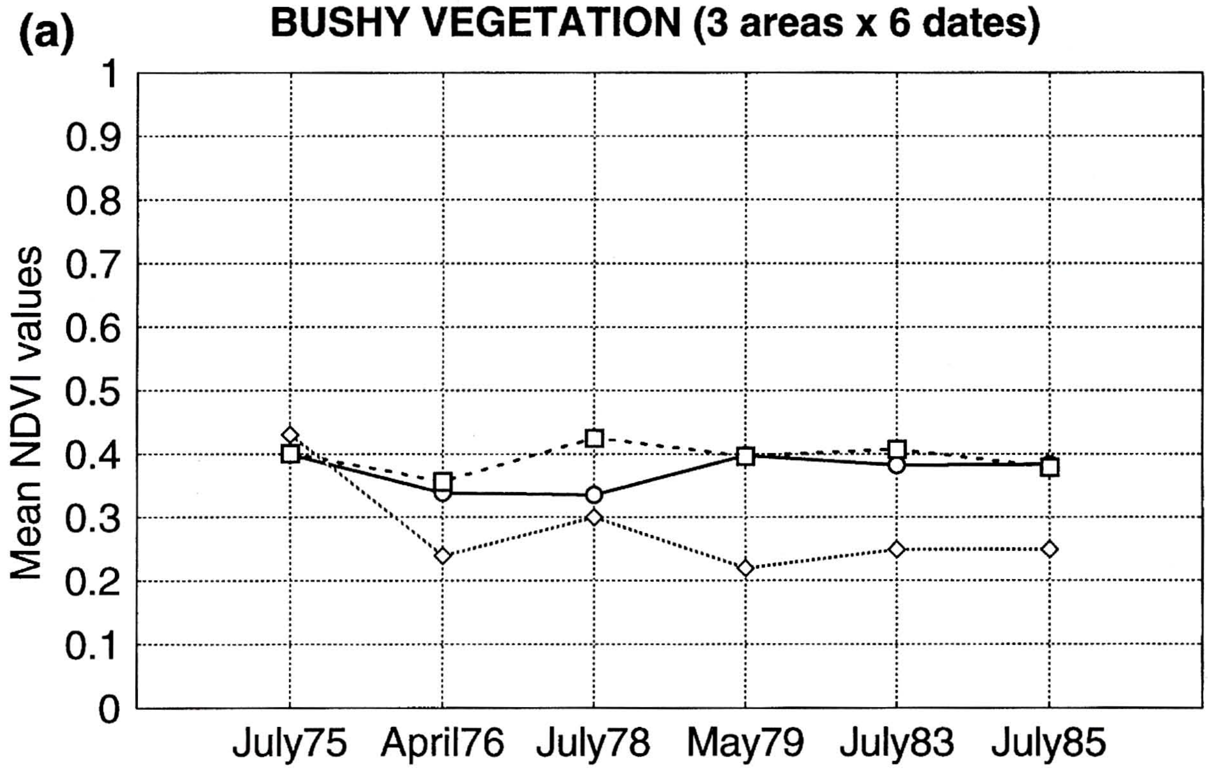
Prior to their use, original MSS images were geometrically corrected by means of a correction model

(Palà and Pons 1995) based on polynomials that take into account the altitude of control points. Next, the model proposed by Pons and Solé (1994) was applied for the radiometric correction of the images. This correction model considers both the illumination effects related to the relief and the atmospheric effects, which were evaluated by means of the Histogram Minimum Method (Chavez 1975, 1988). The model outputs pixel values in reflectance units, allowing the comparison among images of different dates.

Table 1 - Table of eigenvectors, loadings and proportion of variance given by the six principal components, obtained from an Unstandardised Principal Component Analysis of the six NDVI images.

	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6
	% VARIANCE GIVEN BY EIGENVALUES:					
	69.8979	11.3815	6.01489	5.79635	4.1446	2.76476
	EIGENVECTOR MATRIX:					
16th July 1975	0.4533	-0.4252	0.2379	0.0014	0.1308	-0.7349
11th April 1976	0.4352	0.0349	-0.0148	0.8493	-0.2116	0.2075
9th July 1978	0.5066	-0.4950	-0.0232	-0.3982	-0.0694	0.5782
11th May 1979	0.3812	0.3379	-0.7710	-0.2125	-0.2007	-0.2461
13th April 1983	0.3084	0.5503	0.5856	-0.2736	-0.4290	-0.0154
2nd April 1985	0.3287	0.3949	0.0720	-0.0097	0.8420	0.1474
	LOADING MATRIX:					
16th July 1975	0.8853	-0.3351	0.1363	0.0008	0.0622	-0.2855
11th April 1976	0.8639	0.0280	-0.0086	0.4854	-0.1023	0.0819
9th July 1978	0.8910	-0.3514	-0.0120	-0.2017	-0.0297	0.2023
11th May 1979	0.8062	0.2883	-0.4784	-0.1294	-0.1033	-0.1035
13th April 1983	0.7056	0.5080	0.3930	-0.1802	-0.2390	-0.0070
2nd April 1985	0.7818	0.3790	0.0502	-0.0066	0.4877	0.0697

In order to check for the suitability of the corrected images in a multitemporal study, the spectral signature of some invariant patches, selected from urban areas of the images, was obtained. When signatures were analysed, significant differences were found. These differences were probably due to both calibration problems (early images of Landsat 1, 2 and images of Landsat 4 were used) and to restrictions in the atmospheric correction (as standard optical thickness parameters were used for all images). Thus, in order to minimise this variability, a



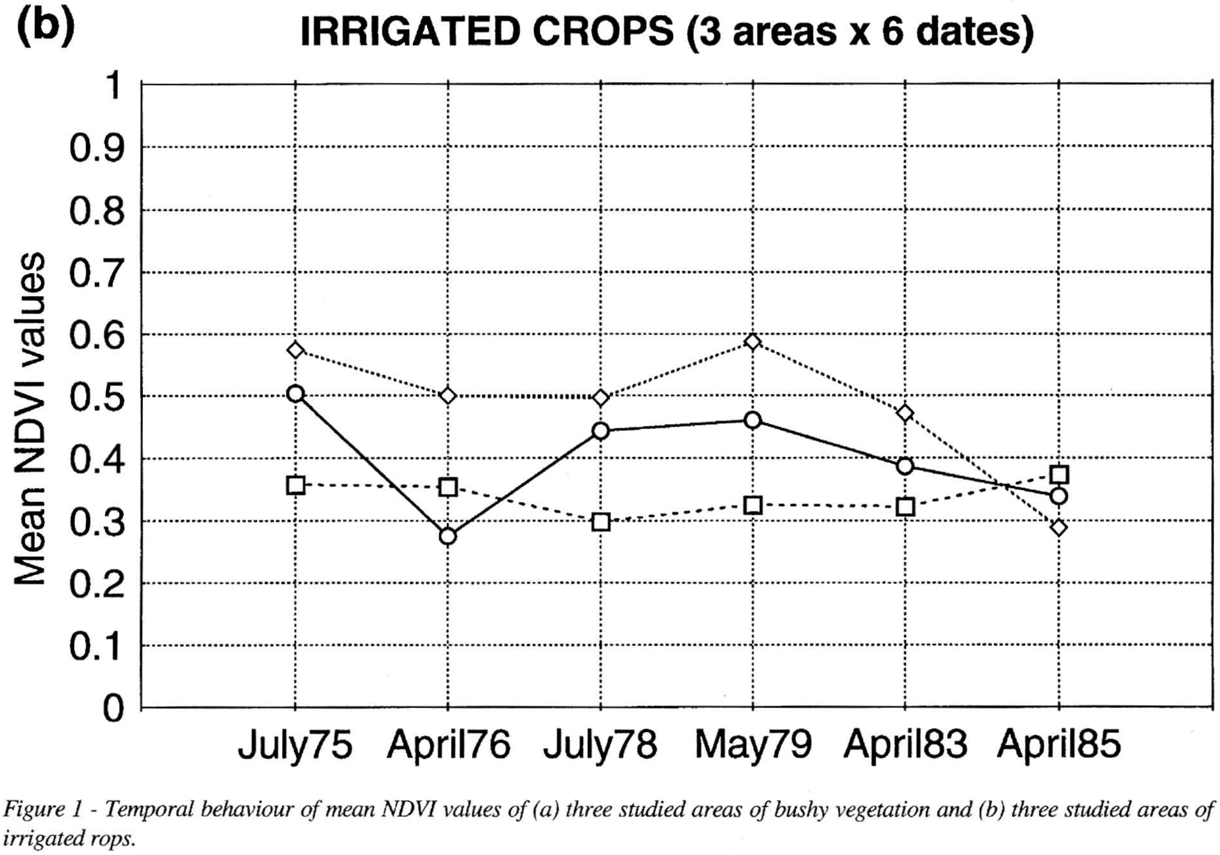
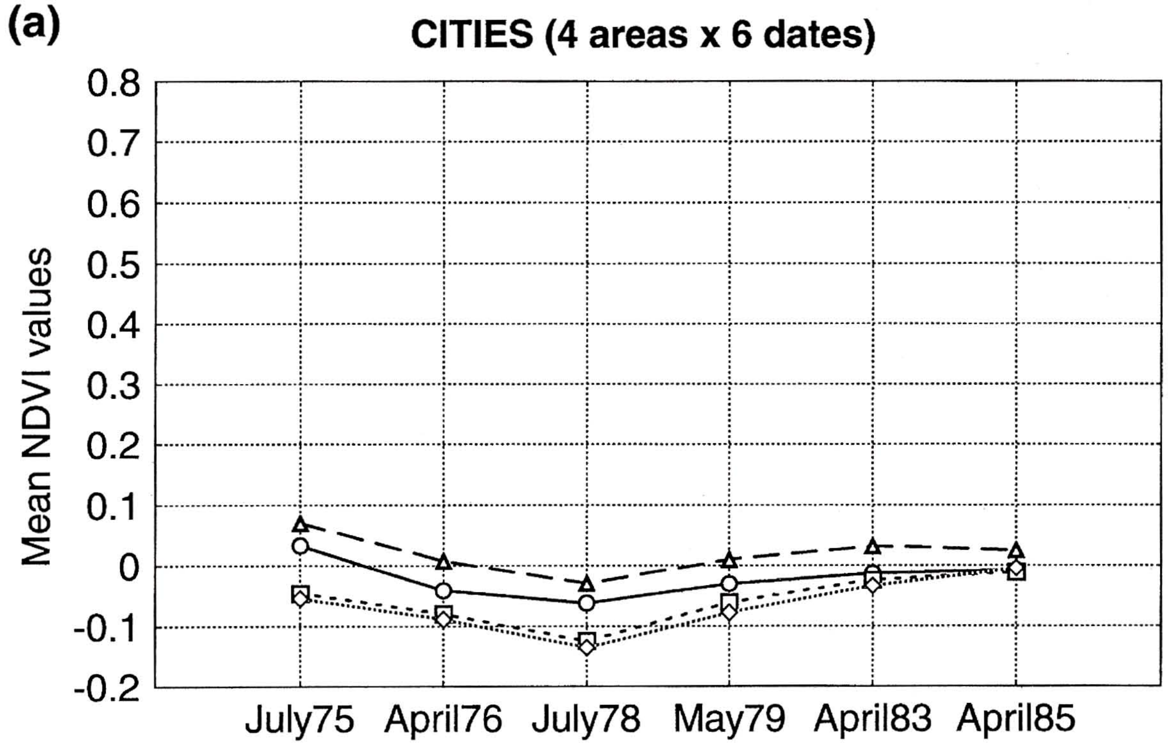


Figure 1 - Temporal behaviour of mean NDVI values of (a) three studied areas of bushy vegetation and (b) three studied areas of irrigated rops.



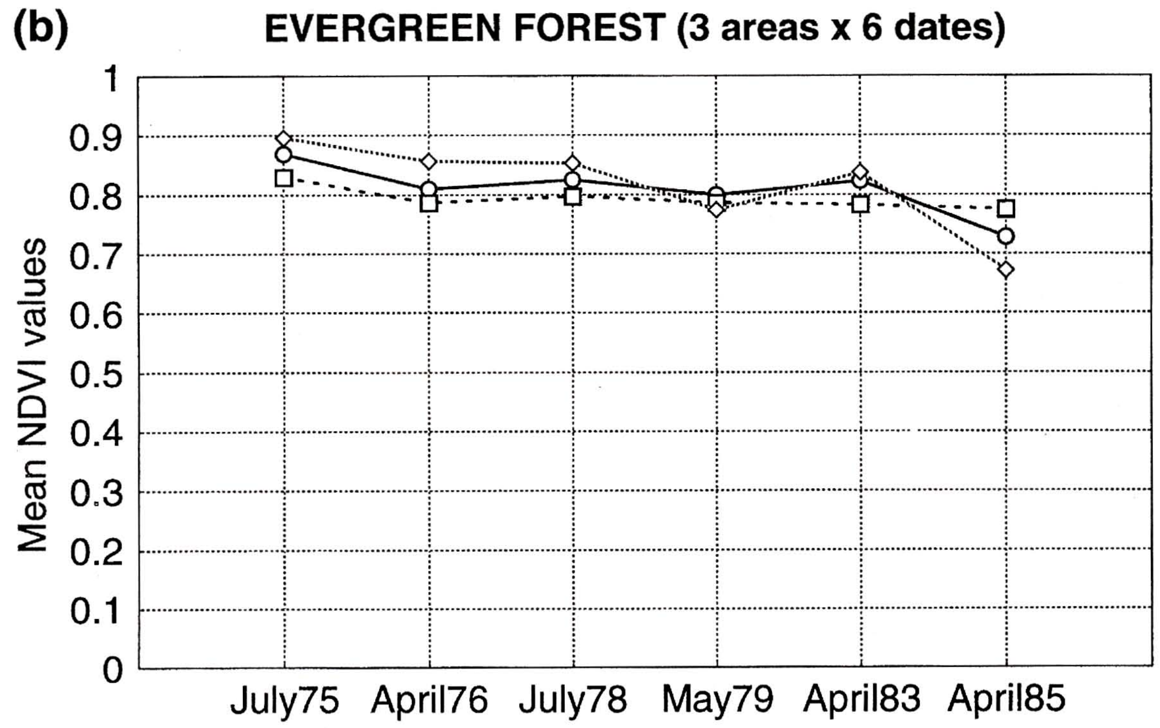
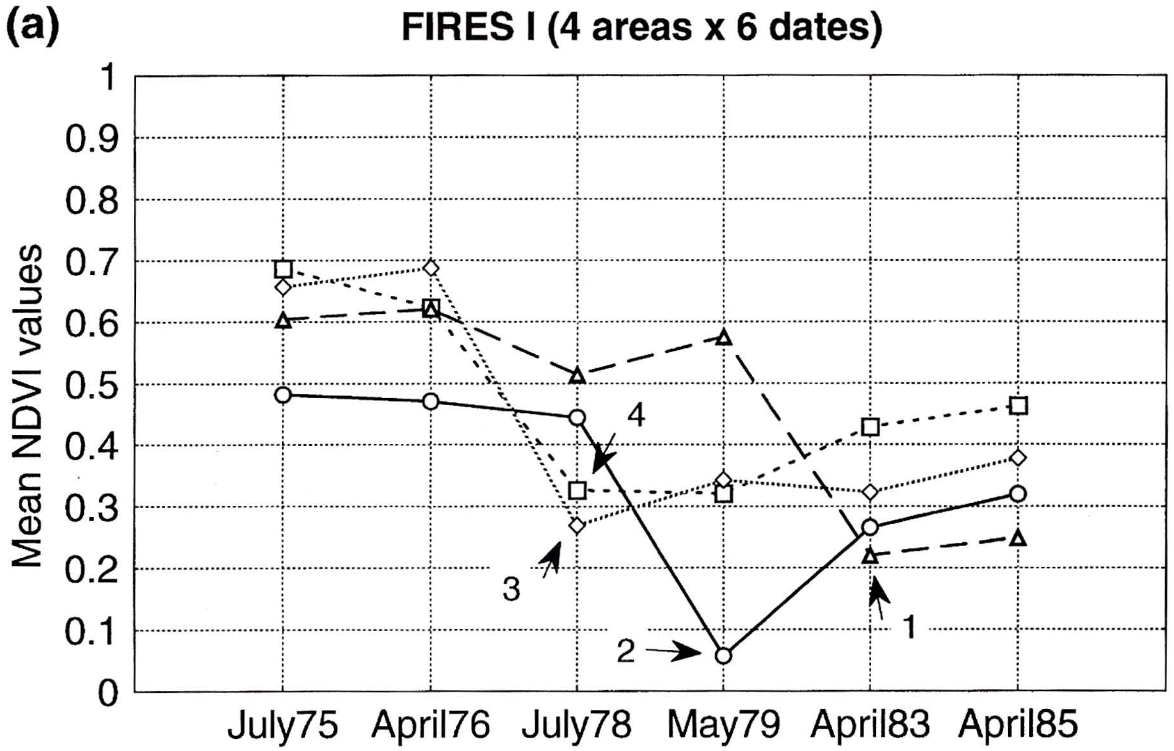


Figure 2 - Temporal behaviour of mean NDVI values of (a) four studied urban areas and (b) three studied areas of evergreen forest.



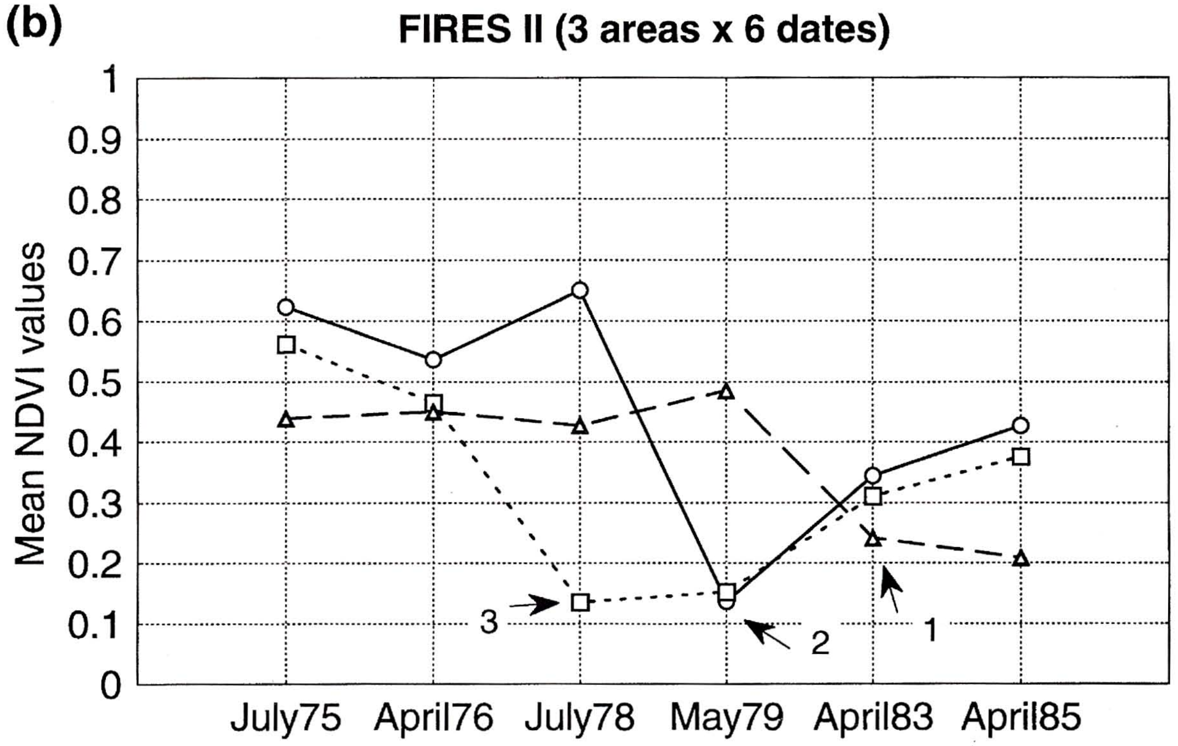


Figure 3 - Temporal behaviour of mean NDVI values of two sets of burnt sites (a & b). Arrows point to dates where fire scars were first noticed.

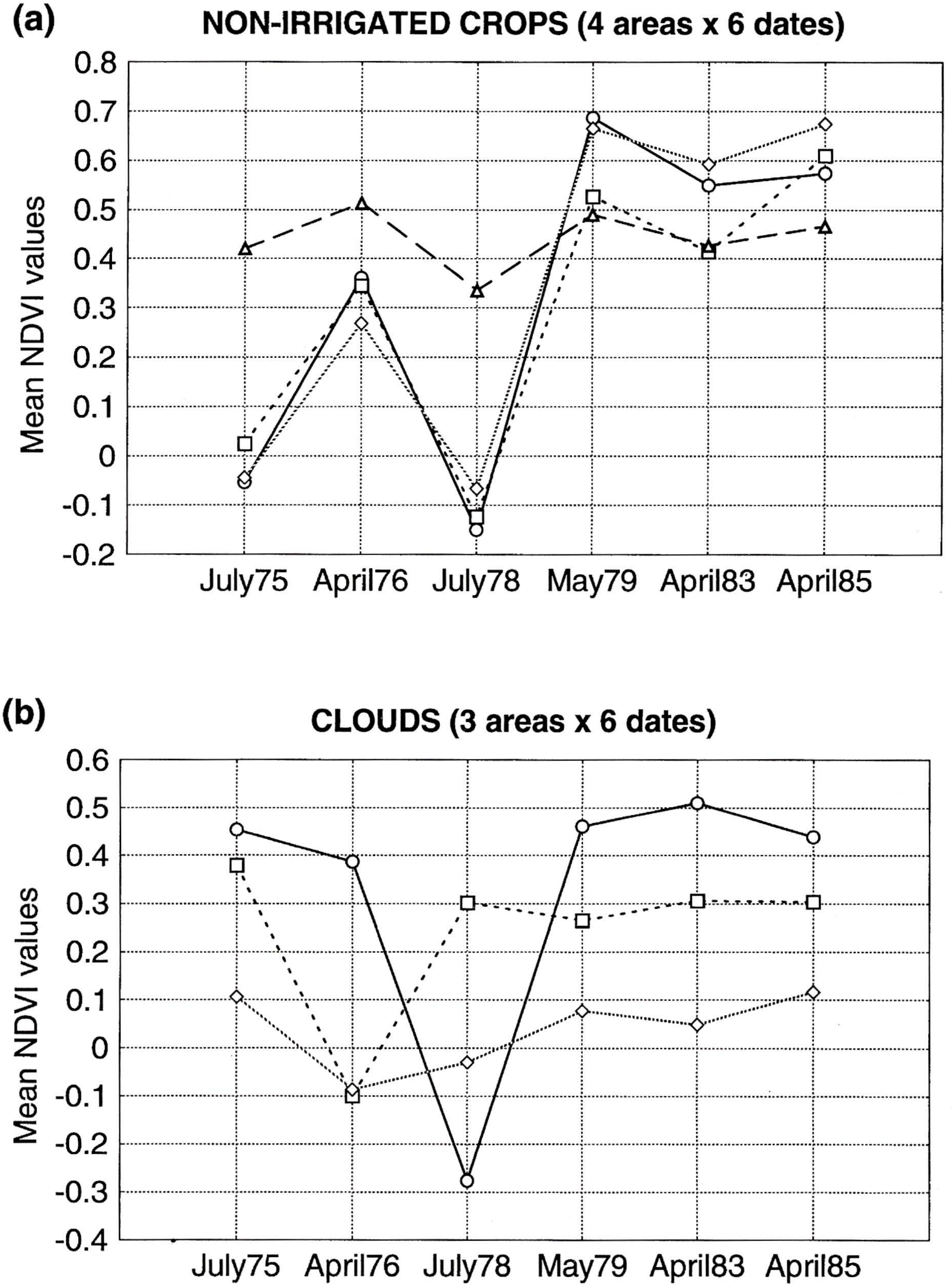


Figure 4 - Temporal behaviour of mean NDVI values of (a) four studied areas of non-irrigated crops and (b) three studied areas of clouds.

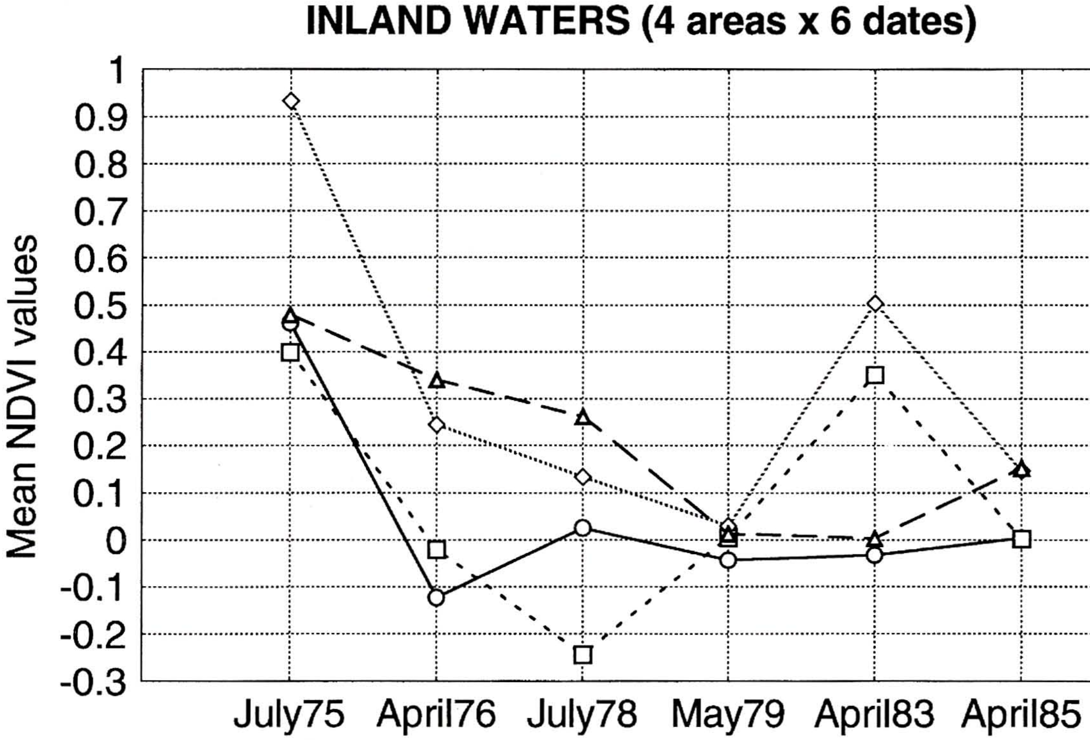


Figure 5 - Temporal behaviour of mean NDVI values of four studied inland water areas.

process of normalisation of the images had to be done until the signature of the urban areas was similar in all images.
Normalised difference vegetation indices (NDVI) extracted from corrected images were created with the purpose of being used as the basic source of remote information for the study.

As previously explained, the temporal analysis of satellite information was done in two successive stages:

1.- The first one was a Principal Component Analysis (PCA) over the NDVI images. The PCA used the previously generated covariance matrix of the NDVI images to perform all the calculations (unstandardised PCA). Eigenvalues and eigenvectors were obtained by means of the Jacobi method which, although more slow than other methods, is really robust (Press *et al.* 1992). In spite of some authors that have recommended the use of the correlation matrix as input data for the PCA (standardised PCA) (Fung and LeDrew 1987, Eastmann and Fulk 1993), we did not make the standardisation process as it might lead to a kind of non-linear variation not easily explained in a PCA. For instance, due to its linear additive nature, PCA will not adequately treat a radiometrically stable area that is standardised in different ways since images of different dates have varying average radiometric values.

As expected, and similar to the results found by other authors (Fung and LeDrew 1987, Eastmann and Fulk 1993), the first principal component (PC1) was formed by an approximately equal amount of variance coming from all six NDVI images (see loadings and components of the eigenvector of PC1 in table 1). Thus, the image of the first principal component was an evenly balanced addition of the six NDVI images, leading to a kind of unchanging image where all invariable traits where shown up. The second principal component (PC2) contained the phenological change between spring images (positive components of the second eigenvector) and summer images (negative values of the second eigenvector). The unexpectedly low value of the eigenvector component of the 1976 spring image (table 1) matches with the specially low precipitation values found in the studied area during that spring (early spring precipitation was five times lower than average). Finally, third and following principal components showed up local areas with temporal radiometric changes, which, in some cases, were burnt areas. Plate 1 shows some fire sites detected in the fifth principal component.

From the last component images some patches of changing areas were selected and, by means of some ancillary data, their nature was found out. Thus, in addition to many patches belonging to burnt areas, other common changing land cover types, such as non-

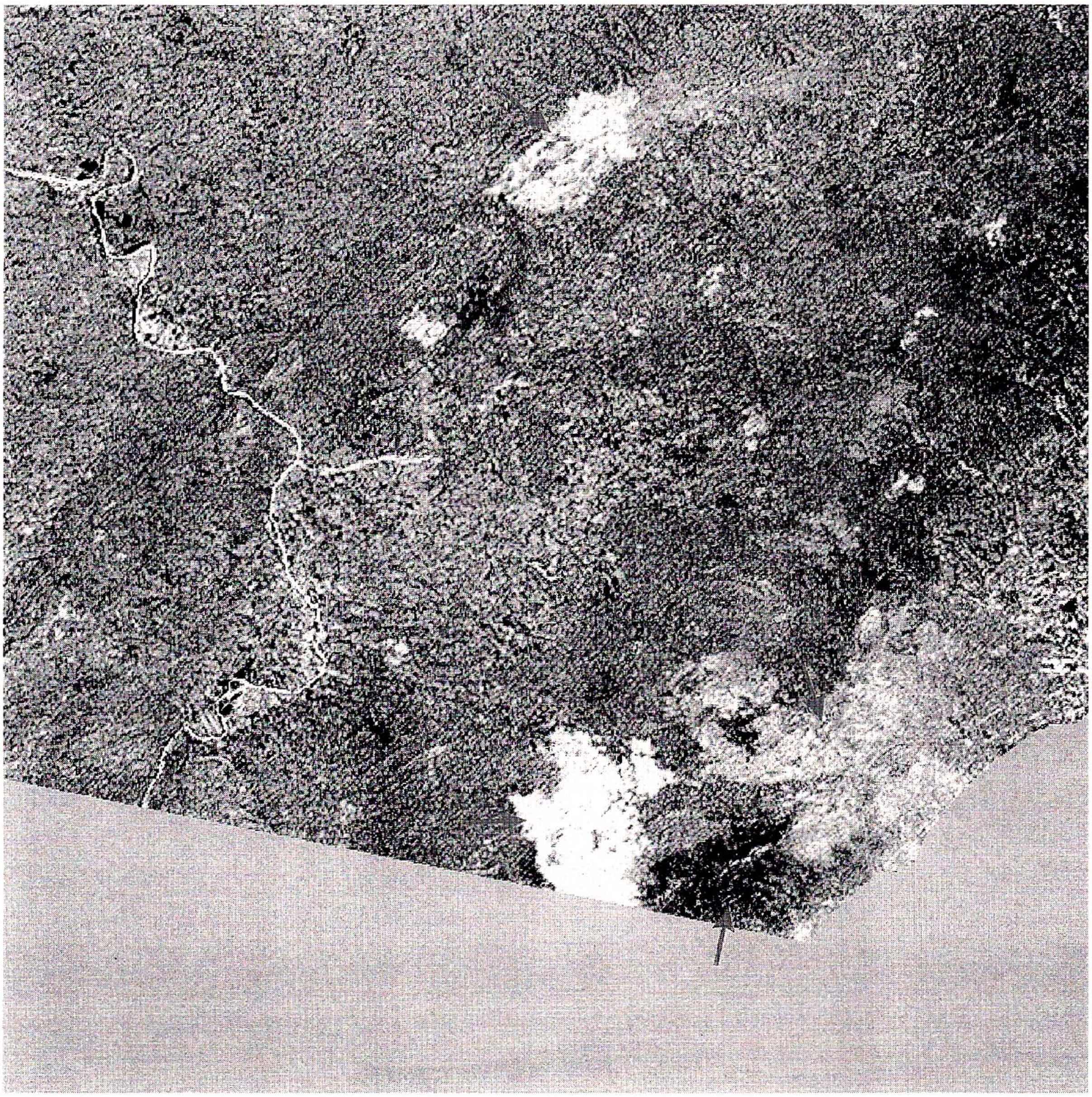


Plate 1 - Window of the 5th principal component, where some fires scars (pointing arrows) extracted from images of different dates and in various states of regeneration are shown.

See plate XIII at end of volume

irrigated crops or inland waters, were also found. Finally, clouds also appeared as areas of change in the principal component images. These selected patches were later used in the second stage of the process where the temporal behaviour of the different types of areas of change where compared. Apart from the selected dynamic areas, patches corresponding to supposedly invariant land cover types were also selected from the first principal component image in order to be compared to the radiometric behaviour of the areas of change. These stable areas were identified as patches of bushy vegetation, irrigated crops, cities and evergreen forests.

2.- As previously explained, the second stage of the process was a radiometric analysis of the temporal behaviour of the different patches selected from the principal component images. This stage finally led to the evaluation of the separability of burnt areas in front of all other dynamic and static land cover types and cover processes. The temporal analysis was done by means of the comparison of mean values of selected patches for all six NDVI images.

Finally, variance values of píxels of the different areas were also obtained.

RESULTS

Various degrees of separability from fire sites have been observed in the dynamic behaviour of the mean NDVI of the patches belonging to the different soil types and processes. Nevertheless, high values of variability have been found inside most of all different types of patches (table 2). In the following sections, results for all studied types of areas are described:

LAND COVER TYPES WITH STABLE BEHAVIOUR THROUGH TIME

- **Bushy vegetation:** This kind of vegetation, which is considerably spread out in the studied area, had a relatively invariable temporal behaviour and quite similar radiometric values in the three analysed patches (figure 1a). However, some variability has been found among patches and along the years. Since specific composition of bushy vegetation is highly diverse and it spatially changes, this variability might be due to phenological variations in these plant communities. Many of the shrub patches found in the studied area had their origins in past burned sites that had never recovered their forest stands. In fact, radiometric values observed in the images taken after fire events (figures 3a and 3b) are similar to the ones observed in the three studied shrub patches.

Irrigated crops: The three analyzed patches of irrigated crops have quite stable values through the different dates (figure 1b). In spite of that, some variations probably due to ploughing practices and different states of growth, may lead to some confusions with burned areas. Apart from that, differences among mean NDVI values of analysed patches might be caused by the proportion of different types of cultivated plants (*i.e.* herbaceous or fruit trees). Even inside the analysed patches a high variability in agricultural uses becomes apparent by their mean values of standard deviation (table 2).

- **Urban areas**: As shown in figure 2a, the four studied urban areas had similar radiometry but a slight variation was found through time in all of them. On the other hand, these urban areas were used to make the final normalisation of the MSS bands after the radiometric correction; thus, no significant temporal variation could be expected. Nevertheless, although mean values of patches in the original images were equalised, that did not imply an equalisation of the mean NDVI values. Besides the homogeneity found between urban patches, relatively low variation was also found within them (table 2). Separability of urban areas from burnt sites seems clear since the former ones kept their low NDVI values thorough time while the latter ones only reached these low values in some cases in the images following the fire event (figures 3a and 3b).

Table 2 - Mean values of standard deviations for each type of land cover and for each one of the 6 dates.

	July75	April76	July78	May79	April83	April85
Cities	0.0818	0.0800	0.0992	0.0908	0.0903	0.0769
Irrigated crops	0.1600	0.1931	0.2044	0.2179	0.2144	0.1824
Bush	0.1370	0.1709	0.1770	0.1683	0.1774	0.1530
Forest	0.1598	0.1809	0.1891	0.1794	0.1971	0.1643
Fire sites	0.1788	0.1923	0.1927	0.1724	0.1657	0.1458
Non-irr. crops	0.1344	0.2121	0.1203	0.2265	0.1929	0.2122
Clouds	0.1851	0.1576	0.1921	0.2499	0.2318	0.2218
Inland waters	0.3038	0.2014	0.2882	0.0935	0.2489	0.1792

Evergreen forests: In general, NDVI values for the three analysed forest areas were quite constant through time, and very similar between one another (figure 2b). As expected, they had the highest mean NDVI values of all studied land cover types. Thus, the separability of evergreen forests from burnt sites became clearly apparent from both mean NDVI values and their temporal stability.

LAND COVER TYPES WITH CHANGING BEHAVIOUR THROUGH TIME

- **Burnt areas**: Temporal behaviour of mean NDVI values of burnt areas usually gave a minimum in the first image obtained after the fire (figures 3a and 3b). The value of this minimum was basically dependent on the intensity of fire and on the temporal proximity between the date of the fire and the date of the image acquisition. A clear increase in NDVI values was normally found in following images after the "burnt image" until the original NDVI was reached, but, in some cases the total recovery was slow or never happened (figure 3a, fires 3 and 4). On the other hand, although there is an intrinsic variation in forest and shrub areas due to phenology and water status, the sharp and significant decrease in NDVI values after all analysed fires is, at least, a conspicuous trait that differences burnt sites from the former land cover types. Concerning values of variability given in table 2, these come from mixtures of areas under different phases, including stages previous to and following fire events.

Non-irrigated crops: The behaviour of the four analysed patches of non-irrigated crops was linked to weather conditions and clearly showed the seasonal nature of this kind of land cover (figure 4a). While images taken in spring had high values of NDVI due to the presence of strong growth of crops, summer images showed a clear decrease of NDVI values due to the ripen and drying, or even cutting, of cultivated herbaceous plants. Nevertheless, the image of April 11th, 1976 did not reach as high NDVI values as the ones of all other spring images (figure 4a). This fact may be explained by the water deficit produced by a special period of drought happened in the spring of 1976. As in the irrigated crops, high levels of variability were found within the analysed patches (table 2), which were also probably due to different proportions of types of cultivated plants. With respect to separability from fire sites, and although sharp drops in NDVI values occurring in summer images may be misinterpreted as fire events, their seasonal nature will be evidence of their real nature.

- **Clouds**: Clouds were one of the elements with a temporal behaviour more similar to the one shown by burnt areas. When NDVI values were calculated, the conspicuous and bright response of clouds in the original red and near-infrared bands was lost. In all cases NDVI values of clouds were lower than those of areas with vegetation and close to the values of burnt areas (figure 4b), leading to possible confusions. Nevertheless, cloudy areas usually reached even significantly lower values of NDVI than values observed in burnt patches, and they have a total recovery of original levels of NDVI as next images do not have any remains of the previous presence of clouds. Concerning the high values of variability found within cloudy patches (table 2) they are obviously due to the fact that the NDVI values analysed before and after the "cloud image" belong to a mixture of varied land cover types.

- **Inland waters**: Inland waters had one of the most heterogeneous mean NDVI dynamics (figure 5), and the highest values of variability within analysed patches (table 2). That was because both red and near-infrared reflectances were very low and similar to each other, leading to an extreme variability in the NDVI ratios. Thus, in many cases where red values were higher than infrared ones, even the sign of the NDVI was changed. Thus, this varying and unpredictable temporal behaviour of inland waters may easily lead to confusions with burned sites.

DISCUSSION AND CONCLUSIONS

Principal component analysis appeared to be a useful tool to make local areas under dynamic change apparent from stable areas and regional changes. High values of variability within the different studied land cover types and processes would lead to moderate percentages of success if usual classification methods were used. On the other hand, the analysis of temporal behaviour of mean values seems to be a good alternative to discriminate the nature of the different areas.

Some of the analysed land cover types and processes have shown a characteristic behaviour, different from the one observed in fire sites, either in their average NDVI values or in their temporal dynamics. For instance, urban areas could be clearly discriminated by their constant low NDVI values, evergreen forests had also a quite stable behaviour thorough time, and non-irrigated crops, although significantly variable, showed a clear seasonal dynamics.

Nevertheless, some other land cover types have shown less separability from burnt sites. As previously mentioned in the results, there is a significant variability in degrees and ratios of recovery of vegetation after fire events. This variable dynamics makes difficult to model and characterise temporal evolution of burnt sites, and it can also be easily mistaken by the dynamics of other land cover types such as the ones of irrigated crops or shrub areas. However, the really sharp and significant decrease in NDVI values after all analysed fires is, at least, a conspicuous trait.

Clouds also showed a similar temporal behaviour to the one of burnt sites, but in this case information from the original bands (where clouds appear with high reflectance values) can easily improve the separability. Finally, inland waters might as well be confusing due to its high variable response. However, as inland waters are well known and located by their low reflectance values, a simple application of a previous mask in the images may avoid their influence on the entire process of fire site discrimination.

ACKNOWLEDGMENTS

We would thank the Institut Cartogràfic de Catalunya for the automated geometrical correction of the images and to Arnald Marcer for helping us with the manuscript. This study was funded by a grant provided by the Spanish Comisión Interdepartamental de Ciencia y Tecnología (CICYT AMB94-0881).

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