MONITORING OF PLANT COMMUNITY REGENERATION AFTER FIRE BY REMOTE SENSING.

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Abstract

In this paper we present a first approach to evaluate the plant regeneration processes after wildfires. Ten burnt areas were selected and their NDVI variations were monitored throughout the post-fire period. The main objective was to recognise the different regeneration patterns of each burnt area. Several variables (such as the amount of rain, lithology, slope, aspect, etc.) were considered in order to analyse their possible relationship with the recovery process. Some of these variables showed a significant effect over the regeneration time, although further analyses seem still needed.

Keywords: Fire-scars, fire-history, NDVI, post-fire regeneration process.

Introduction

Fires occurring in Mediterranean ecosystems have diverse effects on vegetation as a consequence of the great complexity of communities and the interference exerted by grazing, clearing and burning activities, but also because of the different responses of vegetation to the type and intensity of every fire, season of occurrence and the burning frequency (Le Houerou, 1973). These elements and their combinations are known as the fire regime (Gill, 1975, 1981a,b; Christensen, 1993; Bond and Van Wilgen, 1996). Considering such aspects leads to a comprehensive view of the wide range of vegetation responses to fire, of the natural regeneration process, and consequently, of the actual stage of plant communities.

In this sense, detection of burnt areas has a considerable value in order to determine fire occurrence (Johnson and Gutsell, 1994). Many different techniques have been used to identify, date and describe the fire history of a selected region. Among them, detecting fire scars and dendrochronology have been widely used (Romme, 1982; Minnich, 1983; Christensen, 1993). Unfortunately, the information given by these methods can be mistaken with scars resulting from other causes (e. g. Mitchell *et al.*, 1983) such as pathogenic infections, lesions in plants, lightning, frost or mechanical effects (Molnar and McMinn, 1960). Since several decades, remote sensing (also including photo-interpretation techniques) has aided to fire ecologists and fire managers to geographically locate both past fires and currently active burning areas and therefore the frequency and extent of such fires

(Roughgarden *et al*., 1991). Minnich (1983) and Richards (1984) provide specific examples of the usage of remote sensing applied to characterise the fire regimes in different regions.

Salvador *et al*. (1997) applied a semiautomatic remote sensing method to detect burnt forested areas in the Catalonia region (North-East of Spain) in a 19 years period (1975-93). The methodology developed by these authors was based on the subtraction of NDVIs (Normalised Difference Vegetation Index, Mather, 1987) coming from a time series of images of the MSS sensor, boarded on Landsat satellites since 1972. Results were confronted to administration inventories of fires available (Díaz-Delgado *et al*., 1997) and gave place to a map series of fire history of Catalonia (1975-1993 period). Once boundaries of fires were obtained, the high amount of images acquired enabled the authors to monitor the changes through time of the NDVI in some of these burnt areas. Some researchers have used NDVI to evaluate vegetation areas that have undergone considerable changes such rainforests (Sader, 1995; Di Maio and Seltzer, 1997) and it has even started to be employed as an indicator of the rate of ecosystem recovery after fires (Viedma *et al*., 1997). The suitability of the NDVI for this type of studies comes from its general response to the amount of green biomass, irrespective of the plant species forming the community (Blackburn and Milton, 1995; Gamon *et al*, 1995) and also to its adequacy for monitoring of plant cover changes in multi-temporal series of remote sensing images (Curran, 1980; Justice *et al*., 1989). In addition, NDVI response becomes saturated when vegetation reaches a 100% of cover, which allows to properly monitor the initial stages of vegetation retrieval after severe disturbances such as fires.

While most of the research in post-fire regeneration studies have been carried out through analysis of populations, individuals or simple communities –dominated by relatively few, or even a single species (Rothermel and Philpot, 1973)-, less work have been done in describing the response of whole species-rich communities (Trabaud and Lepart, 1980; Musil and de Witt, 1990). Such a response varies widely and may depend on inherent parameters related to the type of community, on life-history traits of composing species, on previous site history, on fire severity and on landscape mosaic and seasonality (Christensen, 1993). These features and human activity will determine how and when those communities will burn again in the future, according to every fire-regime type.

Objectives

In this paper we examine the variability of the vegetation responses to fire. This variability is evaluated from rates of recovery after fire in different Mediterranean plant communities located in several areas of Catalonia. In this preliminary study we attempted to fit regression models on the dynamics of the regeneration processes -monitored by the NDVI response- and to analyse the influence of several environmental parameters on such dynamics.

Study Area and Selection of Zones

Catalonia has an area of 3 million ha from which two thirds are classified as "natural" vegetation and from which one third is considered as tree-covered (Boada *et al*., 1991). Mediterranean climatic traits and human activities along centuries have led to consider fire an evident ecological factor (Quezel, 1980). Table 1 and 2 show some statistical information taken from field surveys of fire events occurred in the analysed period in Catalonia and also from those obtained from the methodology described in Salvador *et al*. (1997).

10 burnt areas detected as fires by the previously mentioned methodology were extracted from the wild vegetation areas (see Fig. 1). These were chosen in order to be distributed sparsely regarding several criteria such as (in order of relevance):

Table 1: Fire statistics of Catalonia during the 1975-93 period obtained from administration inventories. Sources : Departament d' Agricultura, Ramaderia i Pesca (DARP) and Instituto para la Conservación de la Naturaleza (ICONA).

Number of fires	Burnt surface (km^2)	Averaged Nr. of fires/year	Averaged burnt surface (km^2)/year
699	2248	36.8	118.3

Table 2: Frequency values and surfaces affected by fire recurrence, extracted from the map series of fire history of Catalonia (period 1975-93). Source : Salvador *et al.*, 1997.

Frequency of fires >30 ha in 19 years	Burnt surface (ha)	% of forested surface (ha)
Once	111008.88	5,7
Twice	14506.56	0.74
Three times	1532.52	0.078
Four times	395.64	0.02
Five times	66.96	0.0034

(1) all the areas had been burnt only once; (2) they comprised different lithological substrates, which are intimately linked to the processes of soil genesis (Alcañiz *et al.*, 1996) which, in turn, condition the type of successional communities over it, and determine the level of exposure to erosive agents (Chandler *et al.*, 1983); (3) the areas were distributed along the rainfall gradient across the region increasing from South to North and from inland NW to coastal SE (ICC, 1996). In addition, some physical variables such as slope, aspect, and altitude were included in the analysis (see Table 3 and Appendix 1).

Methods

Image treatment

One hundred and twenty images were initially acquired from Landsat MSS satellites (spatial resolution 79 x 59 m) for the period 1975-1993. When available, 3 images per year were employed.

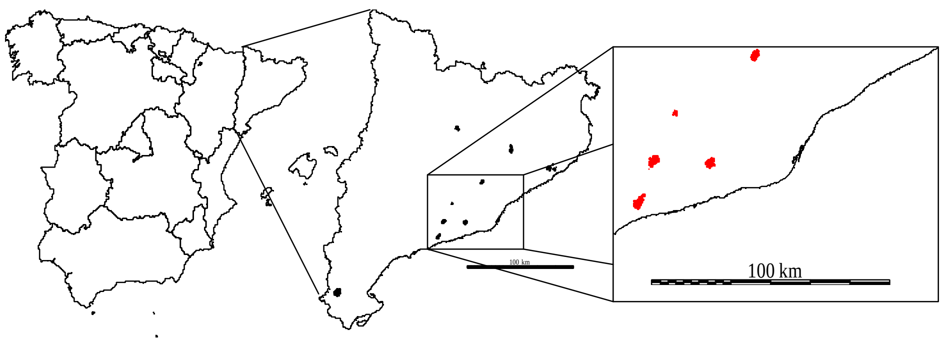

Figure 1: Localisation of Catalonia in the Iberian Peninsula and selected burnt areas for the regeneration monitoring.

Geometric and radiometric corrections and registration processes were applied to the full frames (Pons and Solé, 1994; Palà and Pons, 1995). Due to the radiometric differences among images of different decades, a final normalisation was carried out based on invariant training areas (Salvador *et al.*, 1997). Bands 2 and 4 were used for calculating NDVI images. Equation 1 shows the way to calculate NDVI value for each pixel (Chuvieco, 1996):

$$\mathrm{NDVI} = \frac{r_{\mathrm{IR}} - r_{\mathrm{R}}}{r_{\mathrm{IR}} + r_{\mathrm{R}}} \qquad (-1 <= \mathrm{NDVI} <= 1) \tag{1}$$

where ρ is the reflectance of each pixel in the Red (R) and Infrared (IR) bands.

NDVI images were employed to detect plant covered areas that undergone a sudden decline on NDVI values as a consequence of fire. Such drop in vegetation index values was taken into account when it surpassed an established threshold (Salvador *et al.*, 1997; Salvador and Pons, 1996). Dates of fires could not be exactly determined but an interval of time between the dates of the image before and after the fire were given. Accurate dates for fires occurred after 1983 were obtained contrasting remote sensing data with administration surveys.

Selection of control plots

The 10 selected areas were monitored using a framed window that also included a "control" area located near the fire scar. An empirical procedure was used when selecting plant covered areas adjacent to burnt sites. First, dominant species describing nearby communities unaffected by fire were revised from vegetation maps elaborated on the basis of forest inventories carried out in Catalonia during the 80`s decade (Mapa Forestal de Catalunya, DARP) (Table 3). Such dominant species were assumed as the ones composing the plant communities established prior to fire. NDVI averages and Standard Deviations (SD) of burnt and control areas were monitored for each one of the 10 sites. Spearman correlation coefficients were calculated for mean and SD NDVI values between control and burnt areas in the images previous to fire (Table 4). A good relationship was found between pairs of control/burnt areas before the fire.

Table 3: Some of the parameters describing each burnt area selected for monitoring. Dates in which fires occurred are given by time intervals defined by the employed images when subtraction was applied. (A.A.P.: Annual Average Precipitation)

Fire	Date	Area (ha)	Perim. (m)	A.A.P. (mm)	Previous dominant species (MFC)	Mean altitude (m) [SD]	Substrate
1	11/04/83	826.92	31320	500-550	Shrubs-*Pinus halepensis*	196.5 [64.23]	Calcareous
2	25/07/83	613.80	30960	600-650	Pine-tree forest *Pinus nigra*	775 [80.1]	Sandstones/Conglomerates
3	31/07/83	1241.64	48720	850-900	*Pinus sylvestris- Quercus humilis*	758.5 [100.6]	Calcareous
4	4/07/86	641.88	27960	550-600	Shrubs-*Pinus halepensis*	238.5 [62.5]	Calcareous
5	18/08/86	564.12	23280	600-650	Oak tree (*Qercus ilex*)	701.5 [130.04]	Sandstones/Conglomerates
6	4/11/76-19/09/78	139.68	13080	550-600	Shrubs-*Pinus halepensis*	469.5 [64.8]	Calcareous
7	11/05/79-16/08/81	1907.28	141360	550-600	Shrubs (*Buxus sempervirens*)	808.5 [361.56]	Calcareous
8	11/05/79-16/08/81	707.76	38520	600-650	*Quercus ilex-Pinus halepensis*	452.5 [101.75]	Calcareous
9	9/06/83-29/07/84	700.20	61560	700-750	Cork tree (*Quercus suber*)	167.5 [79.24]	Siliceous
A	18/09/78-25/09/80	376.20	42120	650-700	Cork tree (*Quercus suber*)	160 [73.18]	Siliceous

Table 4: Spearman correlation coefficients (S.C.C.) calculated between NDVI means of control and burnt areas. In most cases the analysis of burnt/control shows a significant related variation through time.

	S.C.C. Means	Prob.	S.C.C. S.D.	Prob.
Zone 1	0,871	p=0,011	0,972	p<0,001
Zone 2	0,998	p<0,001	0,965	p<0,001
Zone 3	0,995	p<0,001	0,921	p=0,003
Zone 4	0,976	p<0,001	0,982	p<0,001
Zone 5	0,988	p<0,001	0,926	p<0,001
Zone 6	0,995	p<0,001	0,985	p<0,001
Zone 7	0,925	p=0,001	0,954	p<0,001
Zone 8	0,998	p<0,001	0,971	p<0,001
Zone 9	0,994	p<0,001	0,913	p<0,001
Zone A	0,986	p<0,001	0,761	p=0,079

Creation of new variables

Mean values of NDVI of the burnt area and of control areas were analysed through time. In addition, the ratio given by the means of both areas (burnt and control) was also monitored (see equation 2).

$$Q_{NDVI} = \frac{NDVI_{fire}}{NDVI_{control}} \qquad (2)$$

Although the ratio of vegetation means displays properly the dynamics through time of the zones affected by fire, subtraction of indexes was also used in order to provide absolute values of NDVI mean differences (equation 3).

$$\text{Difference} = NDVI_{fire} - NDVI_{control} \qquad (3)$$

Once variables of eq. 2 and 3 were obtained for each one of the 10 areas separately, their values coming from all images after the fire occurrence, were adjusted to logarithmic regression models in order to determine their regeneration rates:

$$Q_{NDVI} = \alpha + \beta \log (t-\gamma) \qquad (4)$$

where Q_{NDVI} corresponds to the ratio defined in eq. 2, α and β are the additive and multiplicative coefficients respectively, t is the time in days and γ is a term related to the time of the theoretical beginning of the regeneration process.

Phenological variations of the burnt area in images previous to fire were used to calculate the range of variation where every type of community is supposed to remain in a steady state in absence of disturbance. Pre-fire means and Standard deviations (SD) of Q_{NDVI} are depicted as an interval of variability all along the time series. The minimum period of regeneration available in all the series analysed, which corresponded to 2544 days after fire given by the series 4 and 5 (see Fig. 2) were used as the reference time to compare the dynamics of the 10 areas monitored. Specifically, distances from values of the fitted model in the day 2544 after the fire event (t_{2544}) to the mean Q_{NDVI} in the pre-fire period were used to do such comparisons.

Correlation Analysis of Environmental Parameters

Finally, several factors which were considered to affect vegetation recovery were analised in this study (see Table 3 and Appendix 1). For each of the burnt areas the average altitude, average slope and percentage of surface within each aspect/slope class were extracted from a Digital Elevation Model of

Catalonia (with a spatial resolution of 45 m). Average annual precipitation and rainfall regime were the only climatic factors analysed. Both variables were obtained from the Climatic Atlas of Catalonia (ICC, 1996). Finally, lithological information was acquired from Geological Map of Catalonia (ICC, 1989). Once the mentioned information was gathered, correlations between each one of these variables and distances t_{2544} given by the logarithmic fittings, were calculated for the 10 study sites.

Results

Figures 2 and 3 show the time series of NDVI means for every selected burnt area and its control area. All areas display some phenological variation of NDVI due to seasonality changes. Sharp declines in mean NDVIs produced by fires on burnt sites, compared to the control areas, are clearly shown. Similarly, trends in regeneration of burnt areas can be appreciated. Some of the areas had no time in the study period to completely regenerate.

Figure 4 shows the changes of the ratio Burnt/Control compared to its mean value obtained from the images previous to fire (intervals of variation are also depicted). Specifically, burnt areas 6 and A may be considered as totally recovered within the study period. Both the observed values and the predicted values from the logarithmic model reach the interval of seasonal variation previous to fire.

Areas 2, 4 and 8 present the minimum level of recovery after fire at time t_{2544}. Such a slow response is partially involved with the values of multiplicative coefficients but also with the additive coefficients of the adjusted equation. On the other hand, after 2544 days, areas as 6, A, 5, and even 9 and 3, are very close to the previous mean of Q_{NDVI} value.

Oscillations in Q_{NDVI} along the period of vegetation retrieval are generally higher than those presented before the fire. Regeneration trend is maintained while seasonal effects increase due to the lack of similarity in phenological variations of Burnt/Control after fire. It is also possible to recognise some areas which suffer a subsequent drop of Q_{NDVI} after the first decline caused by fire. Several examples are burnt areas number 1, 2, 3 and 8.

The quite high determination coefficients (R^2) suggests the suitability of the employed logarithmic model. On the other hand, the examination of the relationships between the t_{2544} value and the environmental parameters as ancillary information, did not show any significant correlation using Spearman, Gamma nor Kendal Tau coefficients. Depicting of bivariate relationships did not add supplementary information about the influences of the analysed variables to the level of recovery (determined by t_{2544}). Additional analysis of variance of the statistical distance from the calculated t_{2544} to the previous seasonal mean were made using the types of lithological substrates as factors. Nevertheless, they showed non significant differences between sites.

From this analysis it is clearly shown that considerable differences among responses to fire exist. The kind of regeneration might be reflected in the monitored rates of recovery. In this sense, burnt area number 2 shows a slow regeneration velocity (distance at t_{2544}=0.4), which might be explained by the fact that pre-established community corresponded to a forest of *Pinus nigra*, which presents a regenerative strategy as obligate seeder non-sprouter. Subsequent monitoring *in situ* has demonstrated the non existence of efficient regenerative response from *P. nigra* while ancient understory shrubs have become dominants. Similar response is produced for burnt area number 4 (distance at t_{2544}=0.47), which points out a very low post-fire recovery of previous stand of open forest of *Pinus halepensis* with understory of shrubs. In such a case, regeneration rate might be affected by previous history-site (Christensen, 1993), since burnt area 6 (t_{2544}=0.07) shows a high level of recovery in terms of NDVI, and also corresponded to a *P. halepensis* forest. On other hand, sites with a plant cover dominated by cork oak forest (areas 9 and A, with t_{2544}=0.17 and 0.07 respectively) have been found very close to the previously observed interval of mean NDVI variation. Other factors as severity of fires or internal

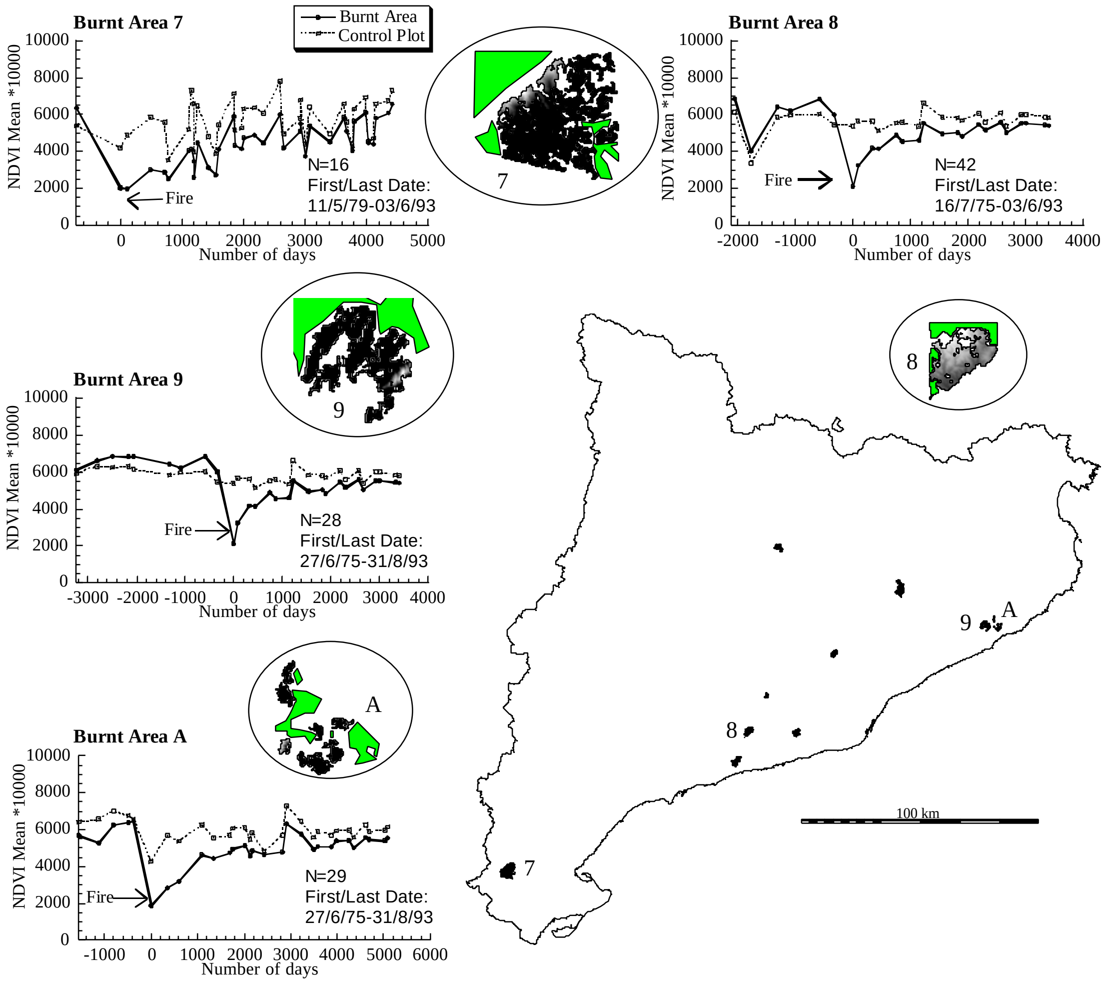

Figure 3: Representation of selected burnt sites (7-A) and their control plots along the study area. Fire perimeters delimit the digital elevation model (higher areas in white) of each plot (not for the control). Graphics show the NDVI mean changes through time of control/burnt areas. First image post-fire is marked with an arrow.

variability of burnt areas through time were not taken into account in the study and could influence directly to variability in plant response to fire (Whelan, 1995).

Discussion

Despite the apparent validity of the technical approach, results do not seem to reveal any relationship between the employed environmental parameters and the monitored regeneration dynamics of each burnt area. The low amount of selected burnt areas that pretended to characterise the regeneration variability, has not been enough to find bivariate relationships. So, next research shall enlarge the sampling size of burnt areas in order to relate influential factors with the different responses to disturbance. These results lead to reconsider the analysis for immediate future work and to discuss some aspects about the technical approach.

Thus, we want to point out the interest of employing the previous interval of variation in similar approaches: this range may be used as a reference to determine the maximum expected level of plant recovery to be attained in the first recovery process. This aspect could offer a different view in some studies based on chrono-sequences of plant cover recovery after fire (Gracia and Sabaté, 1996).

In sight of results, we can conclude that the use of NDVI seems to be adequate to monitor the plant regeneration processes. On the other hand, in the time series of available images, fire is shown as a sudden decline of NDVI values, fact that has allowed to elaborate the map series of fire history of Catalonia (1975-93). Logarithmic regression models were fitted to NDVIs ratio (Q_{NDVI}) offering different degrees of adjustment to the distinct regenerative responses. The comparison of recovery rates among burnt areas did not correlated with any environmental parameter considered in the analysis but further analyses will be done.

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Appendix 1

Table 5: Slope categories employed for the correlation analysis and percentage of surface of each fire included within each category.

Fire	0º_10º	10º_20º	20º_30º	30º_45º
1	45,3	24,8	1,4	28,5
2	56,1	5,1	0	38,7
3	56,6	6	0	37,4
4	50	18,7	1,5	30,2
5	41,6	31,2	1	26,1
6	32,4	13,7	0	53,8
7	10,8	22,7	21,4	45,1
8	40,1	20,8	1,6	37,4
9	36,7	7,12	13,9	42,2
A	7,12	13,9	9,1	56

Table 6: Aspect categories employed for the correlation analysis and percentage of surface of each fire included within each category.

Fire	N	NE	E	SE	S	SW	W	NW
1	11,73	13,87	18,74	14,67	20,18	9,15	7,53	4,1
2	4,95	3,56	13,95	12,96	18,31	21,17	21,34	3,73
3	12,51	10,56	9,6	8,39	13,78	13,96	17,53	13,63
4	12,25	9,66	12,72	13,86	14,85	9,6	14,05	12,97
5	8,87	5,74	13,78	18,66	18,31	11,42	17,67	5,52
6	10,6	8,68	21,2	17,7	20,3	6,65	10,26	4,62
7	12,01	9,5	18,02	14,11	20,83	11,71	9,87	3,94
8	9,73	8,94	18,23	14,8	19,7	12,5	11,37	4,72
9	13,35	4,3	13,06	12,01	17,8	8,73	16,5	14,23
A	14,73	10,13	15,75	10,13	19,45	9,31	13,91	6,55