Forest fire effects assesment in Andalusía: a review of strategies and methodologies for severity mapping and vegetation recovery monitoring at the long-term

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Abstract

Mediterranean forest has been particularly affected by degradation due to the human activities, suffering extensive loss of diversity and soil erosion. Wildfires under these conditions are changing the natural post-fire ecosystems dynamics promoting a more homogeneous and poorer structure of the landscape. This promotes an increase in fuel accumulation and therefore a highest risk of wildfires recurrence. For this reason, knowledge of fire effects at short-term as long-term is fundamental for the assessment of restorations strategies. Taking into account the actual situation of forest fire management in Andalusia, this work propose an integrated mapping project focused on the need to quantify fire effects over large and long time intervals.

This mapping project combines processing, data archive, and remote sensing expertise of the Department of Forestry (Córdoba University) obtained during the last decade. The project is focused in fire affects assessment along a period of 20 years. The goal to achieve is to monitor all the large fire recorded in Andalusía during the period 1990 to 2010. The product results will be a complete semi-automatic system to monitor: i) pre-fire vegetation classification, ii) burnt area assessment and burn severity, iii) post-fire biomass and biodiversity regeneration rates.

Introduction

Forest fires provoke physical changes on the land surface appreciable by most of the remote sensors. Starting from that basis, specialist in remote sensing has been developed a large number of techniques to study the effects of fire on the land cover. Techniques developed for burned areas delimitation can be found in (Chuvieco y Congalton, 1988; López y Caselles, 1991; Salvador *et al.*, 2000). Techniques developed for burned severity levels cartographies can be found in (Kushla y Ripple, 1998; Díaz-Delgado y Pons, 1999; Key y Benson, 1999). The accuracy reach in burned areas discrimination applying these techniques is very high (higher than 90%), supplanting old methods base on GPS measurements on field or photointerpretation. Results obtained from severity levels discrimination had been more variables depending of the proper selection of the methodology, the sensor and the land cover. So far, Rogan and Franklin (2001) present a great review of works on this research line. These authors' state that works that differentiate between five severity levels shows an average accuracy of 38% whereas works that consider only tree increase the accuracy to 64%.

Starting from the result obtained from all this scientific production is time to elaborate integrated methodologies choosing the best techniques for specifics area. Looking for the incorporation of the new technologies in a forest fire service, it is essential to develop a method that is operational, timesaving and cost-effective. Currently the National Burn Severity Mapping Project (NBSP), developed jointly by USGS and the

NPS (United States Geological Survey – National Park Service) of the United States, include one of the most complete methodologies for severity burned areas assessment of big fires.

After fire, long-term wildfire effects are a difficult approach to monitor in degraded Mediterranean communities and sometime even uncertain (Terradas 2001). Long-term vegetation dynamics in Mediterranean ecosystems is spatially dependent, that is, the resultant dynamic process is sensitive to the initial spatial structure (Pausas and Ramos, 2004) and post-fire environmental conditions can change the natural regeneration mechanisms. More over, the increasing in frequency and intensity of forest fires has being working on degraded areas promoting diversity loss, soil erosion and fragmentation of the landscape. As results, the change of the natural post-fire ecosystems dynamics promotes a poorer structure of the landscape, and as such increase the further risk of wildfires. Due all this factors, we consider an urgent task to develop the knowledge about the status of Mediterraneam ecosystems and the analysis of spatial patterns within the burned areas in Andalusia over time.

Although there are many works carry out by ecologists and remote-sensing experts on post-fire regeneration processes in the Mediterranean basin, few of this studies integrate both perspectives (Hall *et al*. 1991). There are even less work at community level (especially with shrubbery) associated to biodiversity changes and supported by enough fieldwork from diachronic records for long-term studies. On the other hand, given the actual environmental change conditions, a more accurate knowledge of the plant communities' recovery is needed. And finally, the need to implement conservation and restoration actions of burned areas at landscape scale; promote the need to develop more accurate models by interpreting remote sensing data. As consequence, the main objective followed by the forestry department of Córdoba during this last years had been the analysis of remote sensing data for the characterization and evaluation of burned areas over the time. All the works carry out in this line research would asses the design of an integrated methodology that would permit an operational system for decision-making.

Framework description.

Burned area assessment: description of the methodology applied until 2003:

1.- Obtaining comparable remote sensing images and adjusting the images for atmospheric, sensor, and growing season differences between dates.

2.- Burned area assessment.

Long-time assessment of large burned areas: preliminary result of the research carry out in sierra de Huétor.

3.- Select most representative samples plots as training areas for multitemporal evaluation.

4.- Using field observations or aerial photos from one of the years to determine the ecological states of ground plots.

5.- Computing the spectral characteristics of the ecological states, and based on these characteristics, computer classifying the remaining image pixel into ecological states.

Burned area assessment: description of the methodology applied until 2003:

Sumary

Following a forest fire, forest managers require a quick, complete assessment of the environmental and financial damages that were wrought. As a result, a territorial description of the fire impact becomes necessary. This description of the level of damage, together with resources that might include a map of the previous vegetation, can be very useful when making decisions for restoring vegetation in the affected areas.

The Forestry Department of Córdoba University (Andalucía, Spain) and the Environmental Information and Evaluation Service of the Andalucían government collaborates together from 1997 in the application of a common methodology, based upon remote sensing and GIS techniques, to asses burned areas. So far, it has been produced several reports of cartographic representation of pre-fire vegetation levels and damage-intensity levels, plus a restoration management plan (Navarro et al., 1997, 2000, 2001, 2003). The forest fires that have been included under this collaboration framework are forest fires bigger than 500 ha occurred from 1990 until current days.

Methodology

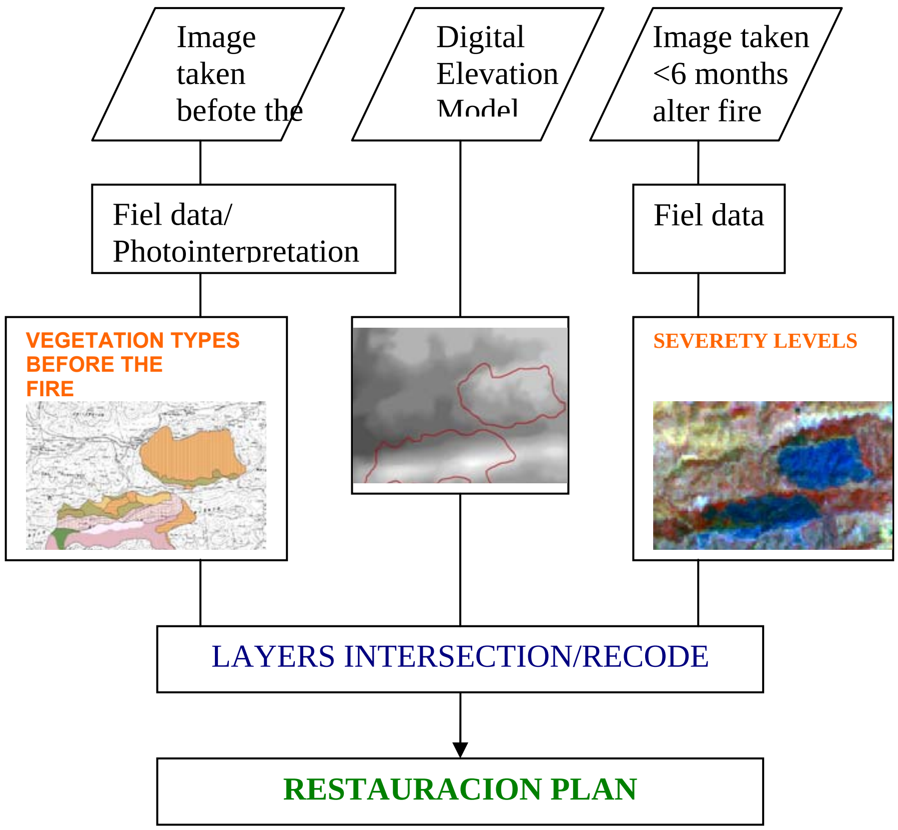

Figure 1-Sistematic methodology for Burned areas asesment.

Data processing.

Remote sensing data should be comparable to each other and corresponding to the following scenarios:

-Before fire. It's recommended that time acquisition of the image have correspondence with the last available cartography of vegetation types.

-From 1 to 6 months after fire.

One of the image is registered to an orthophoto (highest available spatial resolution) produced by Junta de Andalucia. And the remaining images are co-registered to this image. Corrected images should provided a maximum root mean square error of less than 1 pixel. Standard gain and offset coefficients for each satellite and period are applied in order to transform digital numbers into radiance levels. Next, the Pons and Sole-Sugrañes (1994) radiometric correction model is used to obtain reflectance and allow comparisons among images taken at different times of the year. A final normalization of the different bands by means of invariant training areas is required, which should yielded a mean correlation coefficient (r) around 0.98 with a standard error (ES) of 0.030.

Burned Area Discrimination

The perimeter provided by the government of Andalucía (as determined by GPS coordinates) is corrected over an RGB color composite of bands TM4-TM3-TM7.

A visual analysis of the post-fire LANDSAT image (TM4-TM3-TM7) for the burned area offer better results than did traditional methods used by forest managers. Although there are several automatic algorithms that discriminate burned areas via satellite data–undoubtedly useful when one works at a national or regional scale–determining the perimeter of a burned area through visual analysis can be both quick and accurate, provided that information about the location of the fire is readily available.

Previous Vegetation

Different vegetation-cover polygons were determined by using pre-fire aerial photographs and IRS-PAN images. Afterwards, detailed information on each polygon is collected during the fieldwork campaign. With this information, polygons have been labeled as "previous vegetation maps". These maps are more detailed than currently available land-use and vegetation maps of Andalucía.

Damage Intensity Levels

Three damage intensity levels are distinguished (Navarro et al., 1997). These include the following designations:

- No damage–Zero damage was done to the vegetation.
- Moderate–The vegetation is partially damaged. In regard to the areas with trees, the moderate level is determined by the remaining of parts of green crowns. Also it is possible that very damaged trees can be found together with little damaged or no damaged trees. For shrubs and bushes, the vegetation is partially damaged.
- Extreme–The fire destroyed every bit of vegetation.

In order to produce the cartography for damage levels of this intensity, supervised classification techniques are employed. It became necessary to know the ground truth in a number of field sampling sites, at training sites where the classification was carried out, and at many of the validating sites in order to certify the produced cartography. Following each fire, a field campaign is carried out that used topographic cartography at 1:10,000 to locate several sites for each damage level (both moderate and extreme). An area corresponding to 80 pixels of a LANDSAT scene per damage level is located for the training phase, and an area corresponding to 40 pixels per damage level is located for the validating phase. Most often, plots of 3x3 pixels per damage level are chosen. Wherever possible, the same number of plots for the three non-affected classes is located and considered as the training phase (with lush vegetation, with scarce or null vegetation, with water, and shaded areas).

The next step in the process is the digitalization of the field training sites. During visits to the area of study, an insufficient number of non-affected plots are located. Therefore, plots are selected visually on the LANDSAT scene to complete the number of pixels recommended for the training and validation phases.

Afterwards, the LANDSAT post-fire scene is classified using the maximum likelihood algorithm concept. The three non-affected classes are grouped into a single class. A majority filter of 3x3 is applied to the then-generated thematic scene. In the firsts works the classification process was developed base on the six reflectance bands. With time and experience, the classification was obtained from other products such us NDVI or dNBR. The improvement of the methodology can be following through the different reports produced over the time (Navarro et al., 1997, 2000, 2001, 2003).

Restoration Plan

The ultimate aim of this project is to produce information for making a number of restoration proposals in a burned ecosystem by using GIS and remote sensing techniques. By means of overlaying the previous-vegetation map and the damage-intensity-level map, a third map is created that offered various restoration proposals in which polygons smaller than 0.5 hectares are removed. These proposals are based upon the fire response of the various Mediterranean ecosystems. All these processes can be carried out with software programs ERDAS IMAGINE (v. 8.x.), ARC/INFO (v.x) and ARCGIS (v.x).

Results and discussion

The global accuracy of damage-level cartography, computed for all the wildfires evaluated, was greater than 80 percent. The separabilty between classes increased if different normalized band ratios were included in the classification process (band 4-band 3 / band 4+band 3 or band 4-band 7 / band 4+band 7), but global accuracy did not show any significant differences. Something similar occurred if an illumination band was included (derived from solar angles and DEM), where separability increased but global accuracy of the cartography remained the same. Global accuracy was higher for those wildfires that showed homogeneous vegetation prior to the fire.

The cartography of restoration-management practices makes recommendations about the theoretic evolution of the vegetation and optimal management actions.

The restoration-proposals map can be integrated with other thematic maps, such as geologic, soils, aspects, and slopes into a GIS, offering detailed information to forest managers. The analysis of each wildfire took a qualified individual about two weeks to complete.

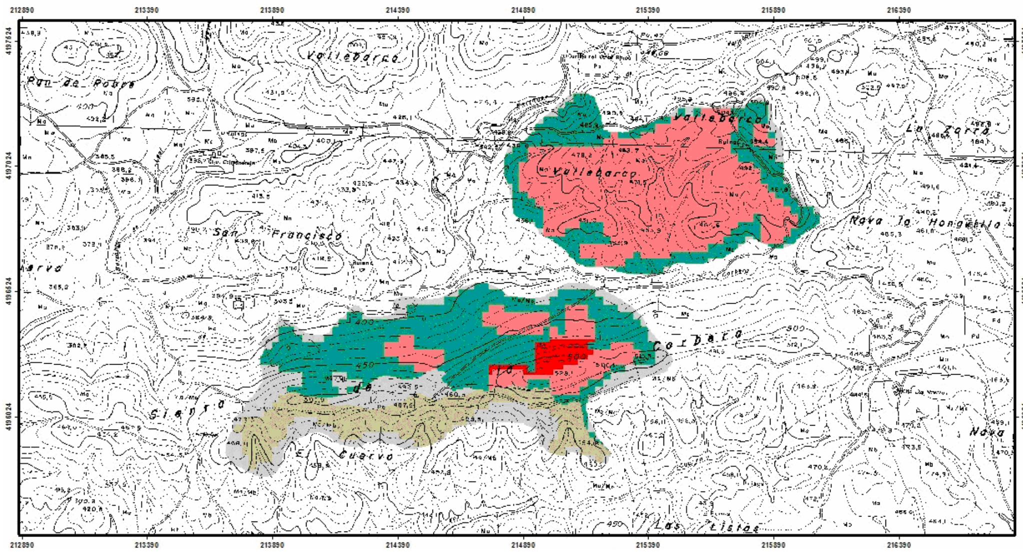

Figure 3—Cartography of restoration management. Each color is related to different recommendation management, depending of the severity of the fire, the pervious vegetation, and the slope. Cartography obtained from the intersection of thematic maps..

Conclusion.

The framework established during this last years for burned areas assesment showed that information about previous vegetation generated from photo-interpretation, and damage-intensity levels generated from the supervised classification of post-fire Landsat scene, is entirely accurate. It was also shown that the methodology herein employed is much more operative (quicker and lower-priced) than are other, more traditional methods such as in-field inventory or standard photo-interpretation. As a result, this process can form the basis of a management restoration plan for any burned area.

Long-time assessment of large burned areas: preliminary result of the research carry out in sierra de Huétor.

Sumary

The aim of this study was to examine shrub recovery and diversity patterns on micro and macro scales on permanent plots, as well as how they are related to each other. Demographical pattern associations were examined to gain a better understanding of the role of each plant formation in succession and, finally, related to remote sensing data corresponding to the same study period.

The fire occurring in 1993 affected around 7000 Ha located in Beas de Granada with Universal Transverse Mercator (UTM) coordinates ranging from ULX: 457343 to LRX: 473918 and ULY: 4129353 to LRY: 4118806. The vegetation in the area has been strongly modified by human actions, so that it presents an advanced degradation. In the 1940's an intense reforestation activity was implemented, using *Pinus pinaster*, *Pinus halapensis*, *Pinus laricio* and, to a lesser extent, *Pinus sylvestris,* conifers and *Populus*. After the 1993 wildfire, reforestation works in this area have been few. The first one, at the end of 1996, consisted of aerial sowing which gave poor results, after having sprayed almost 78 million seeds of 16 species of pine trees and shrubs from planes. The next implementation, direct machinery planting on the field was occasional and not very relevant. The burnt area is mainly covered by black pinewoods and, to a lesser extent, oak woods (*Quercus ilex* subsp. *rotundifolia*), dwarf gorse (*Ulex* spp., *Genista* spp.) and Aleppo pinewoods (*Pinus halepensis*). Mediterranean gorse (*Ulex parviflorus*), which, having been described as a degradation stage of forest communities after fire, has also been defined as a fire-prone species.

Methodology

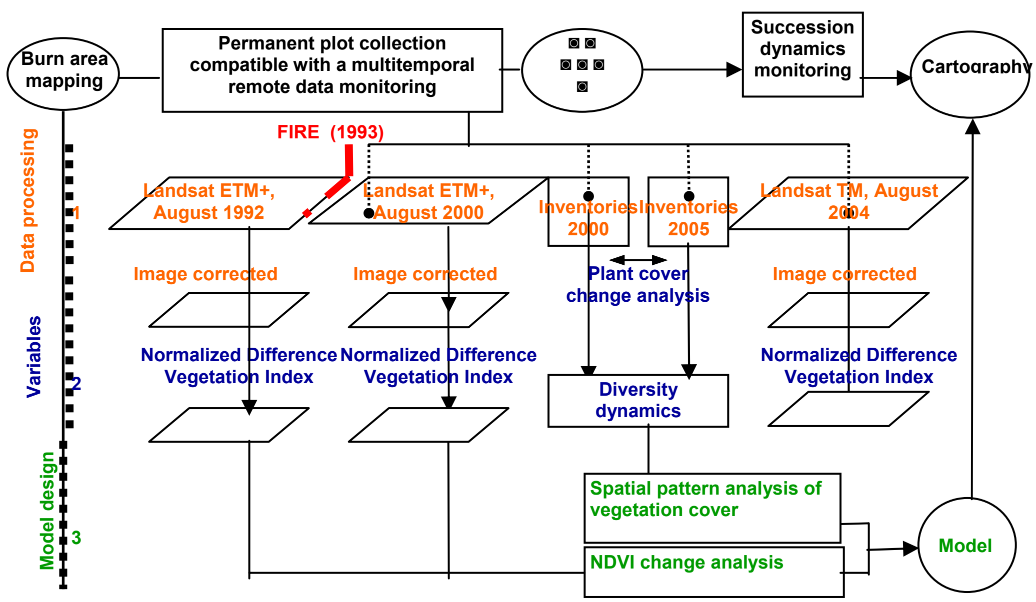

Image processing.

Corresponding with the time of the inventories (2000-2005) two Landsat ETM/ TM images were acquired. Both images were geometric and radiometric corrected. A final normalization of the different bands by means of invariant training areas was required, obtaining a mean correlation coefficient (r) of 0.98 and a standard error (ES) of 0.029.

Once all the images were normalized, NDVI values were derived from a time series image data set from bands 2 and 4 of the MSS sensor. Finally, an image difference algorithm was applied in order to detect changes in the vegetation by subtracting the NDVI values (Fig. 2), so that:

$DIFNDVI [t_2 - t_1] = NDVI_{ij} [t_2] - NDVI_{ij} [t_1]$

where, ij: pixel coordinate, t_2=2005 and t_1=2000.

Field inventory

Plot locations were carried out taking as a reference a hand-held Global Positioning System (GPS) verified through the 1999 orthophoto (1-meter resolution) and the 1:10000 topographic map and, estimating an average error of <3-5 m. Two perpendicular lineal transects 50m long (one in the direction of the maximum slope) were defined for each plot and measured in both years (2000 and 2005) following the same methodology (linear interception method) (Bonham, 1989). Along each transect, the morphologic variable measurements were: tree canopy projection diameter "$Ø^c$"(m) and brush canopy interception longitude (l_k). where, ij: pixel coordinate, t_2=2005 and t_1=2000.

Plant community typification.

Pant community description within the burnt area was defined from a hierarchical cluster analysis. Plant groups were established from the cover values per species in the 33 plots inventoried in 2000. The results were interpreted and related to other types of variables that could influence the grouping criteria, such as altitude or soil composition. Once the classification was established, the most representative plots in each group were selected, being those the base for the survey in 2005.

Diversity change and dominant species evolution.

Plant cover and diversity indexes were analyzed in both years to obtain different change estimators as a subtraction of 2000 from the 2005 data set. The multitemporal change analysis was applied only at shrub level, by applying a mask to discriminate the classes composed of a non-affected or slightly affected tree canopy. The classification derived from this analysis defined tree different community stages: no-change, with values approaching zero (0); negative change (-) or positive change (+). Change analysis where evaluated at two levels:

1.General change per total survey area.

2. Specific change per plot.

Multitemporal plant recovery.

A supervised classification of plant cover was obtained based on the multitemporal regression equations established among vegetation indices. Vegetation indices were related to ground cover per plot and compared through a Pearson Correlation Matrix and the most correlated vegetation index was selected. The classification approach was to define different plant cover percentage classes which were compared by means of the multitemporal data set. Multiband classes were derived statistically and each unknown pixel assigned to a class using the maximum likelihood method. The classes were defined *a priori* based on the pre-fire vegetation types and the estimated cover range was derived from similar plant cover communities in the vicinity of the fire. Thus, the plant cover percentage related to each class was:

- 0-10%: Barren land and Herbaceous.
- 10 – 25 %: Herbaceous- shrubs rangeland. Gorse-Rosemary scrubs.
- 50 – 80%: Brush land with dispersed trees. Gorse-rosemary scrubs with Holm oaks.
- 80 – 100%: Dense forest. Pine woods.

The spectral range related to each class was calculated from the regression equations obtained for the 2000 and 2005 data (plant cover/NDVI). An error matrix was determined and the Global Accuracy and the kappa coefficient of agreement were calculated for both supervised classifications. The method is a simple cross-tabulation of the mapped class label against that observed on the ground or in reference data for a sample of cases at specified locations (Foody 2002).

Results and discussion.

The cluster analysis performed from plant cover data per species surveyed in 2000 allowed the description of the main communities and the selection of the most representative sample plots. The results show two well-differentiated groups at an 80% distance strongly influenced by the soil composition and altitude location of the plots. With a 20% distance, the dendogram show six subgroups representative of the different plant communities found in the area.

The ecological relation between diversity rates, dominant species and the evolution of the main species per plot presents the key to understand post fire regeneration patterns.

At global scale, the total cover per species (analysed through Wilconson test) doesn't show significant variations on the floristic composition within the burnt (Sig. =0.06) from 2000 to 2005. These results were verified by the Sing test (Sig. =0.230) and Student T test (Sig. =0.005). Nevertheless, the diversity indexes show a slow recovery increase. The quantitative analysis indicate *Ulex parviflorus* (U) and *Rosmarinus officinalis* as the dominant species for both years with a mean of 40 and 20%, respectively expressed on the total cover. However, the highest cover increment is recorded by *Rosmarinus officinalis* (51%) and *Pinus halepensis* (16%) in relation to the increase on the rest of the species.

At plot level, the multivariate test shows significant changes on species composition (Sig<0.05). Assuming an aspheric level, F invariant statistics (Sig<0.001) related to the time factor reassert the significance of that change. The results identify also three species with significant contributions promoting the change: *Ulex parviflorus, Rosmarinus officinalis and Cistus clusi* (URC).

Relevant variables as indicators of sucessional processes and regeneration patterns were selected. This variables were:

$DIFC_i$ [t_2 -t_1]: vegetation cover change of the main species ($_i$) promoting the change: *Ulex parviflorus, Rosmarinus officinalis and Cistus clusi.*

$DIFC_T$ [t_2 -t_1]: total vegetation cover ($_c$) change.

$DIFD_e$ [t_2 -t_1]: diversity change estimators($_e$): Shannon (H), Simpson index (D) and richness. (S).

The result derived from the 6x6-correlation matrix constructed with the difference (2005-2000) of all this variables shows that, the diversity (estimated through H and D) is highly correlated with the richness, i.e. implying an increasing tendency in the number of species per plot throughout the time. On the other hand, the diversity index (H, D) and richness are negatively correlated with the difference value of the dominant species cover, which is implying that the global regeneration dynamics is directly related to the re-growth pattern of this dominant species. In contrast, none of them (H, D,S) showed any relation with the overall cover recovery change.

Linking all this information to remote data, changes on NDVI values are statistically significant to diversity indices (H, D, R) and the three dominant species cover. Those correlations are positive between NDVI and plant cover (highest correlations with U cover) and negative between NDVI and the diversity indices R, S and H (highest correlations with S).However, it is very interesting to appreciate how all these correlations are higher and more significant than the ones between NDVI and the total cover change.

Once the regeneration patterns were analyzed, five models were created in order to evaluate the process and geographically define the evolution of the vegetation.

Running each of these models and based on a geographic Information System, the spatial diversity dynamics and cover changes record were set up within the burnt area (Fig 4).

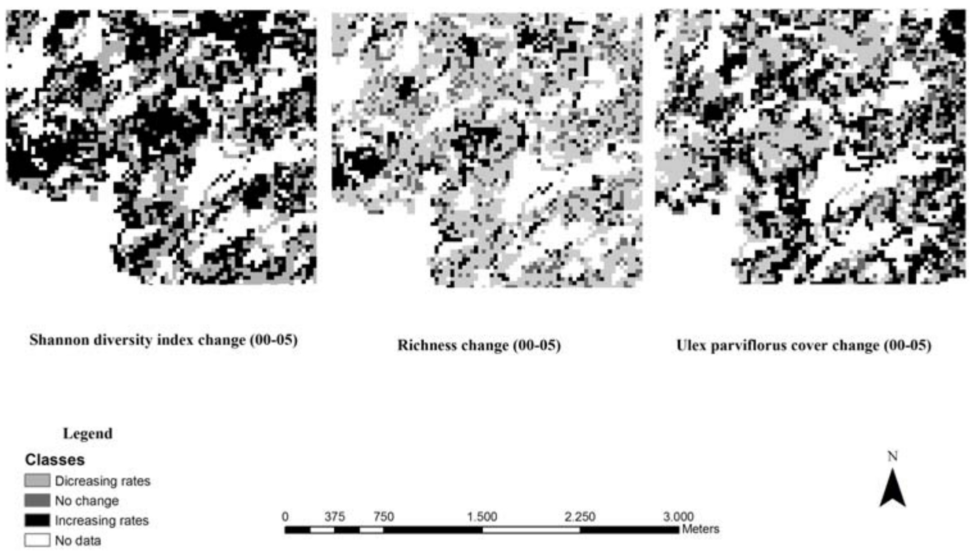

Figure 4—Cartography of the change in richness recorded (S), Shannon index (H) and *Ulex parviflorus* cover (U) between the years 2000 and 2005.

Multitemporal recovery assesment using pre- and post-fire scenes showed different spatial patterns within the burned area. Fig 5 shows the results obtained from the time-series supervised classifications. These classes were defined based on the relationships established between NDVI and plant cover ground data and related to pre-fire vegetation types. The plant cover averages calculated for the entire burned area perimeter showed that the vegetation had already reached 38% ground coverage seven years after the fire, and 52% twelve years thereafter. Given that the pre-fire ground coverage was 63%, the results can be considered to indicate adequate recovery rates. However, the recovery distribution area per class showed communities in ecological stages far removed from the pre-fire ecological stage. While dense forest only reached 50% of the pre-fire coverage, Gorse-

Rosemary scrubs already exceeded almost 9% of the pre-fire stage, maintaining an increasing trend. On the other hand, the gorse-rosemary scrubs with holm oaks class recorded adequate recovery rates, even though ground data indicated gorse-rosemary as being mainly responsible for these increases. So far, gorse-rosemary was found to hinder Holm oak regeneration (Hernández *et al.* 2006). Finally, barren land and grasses followed their expected post-fire regeneration, reaching a maximum during the first years and decreasing in the long-term (Tabaud and Lepart 1981).

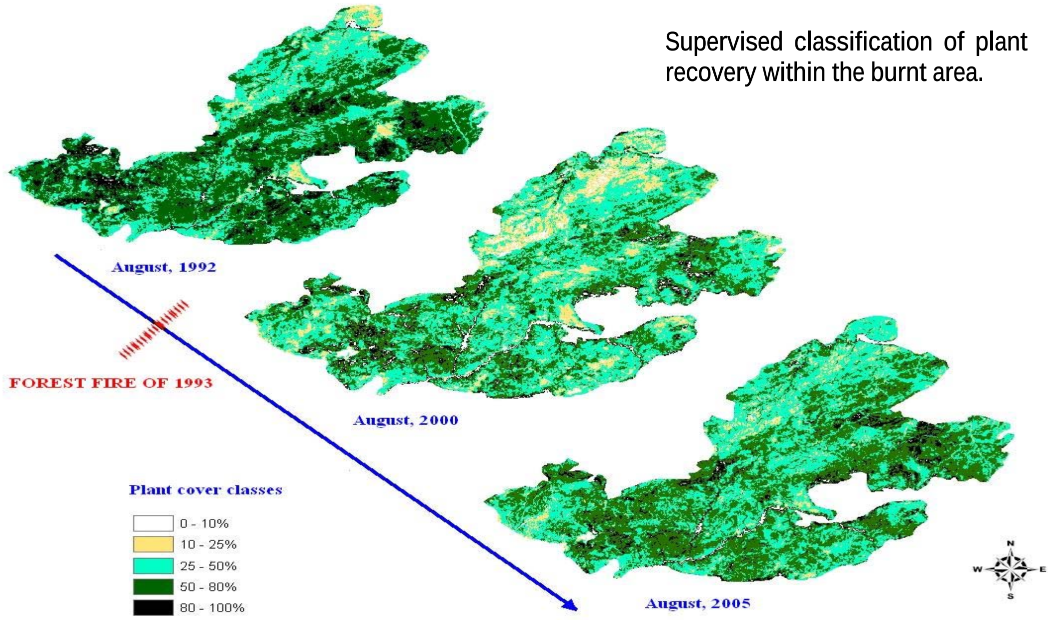

Figure 5—Supervised classification obtained from the regression models established between plant cover and NDVI value per plot and plant recovery within the burned area in 2000 and 2005. The pre-fire classification was calculated from the 2005 model.

Conclusions.

The integration and interpretation of remote data and field observations allowed the interpretation of the post-fire succession dynamics.
In the case study of Sierra de Huétor results indicated that although the appearance of some species could have caused an autosuccession process at one point, twelve years later, the dominance of these species could later slowed down the progress of the succession and hindered the maturing of the ecological system. This process may have arisen due to the history of disturbance in the area (loss of traditional uses or previous reforestation activities).
At this point, the different lineal regression equations obtained in this studies allows the description of diversity change and regeneration patterns of the main species. The statistical method presented here for calculating post-fire succession changes provides valuables models to quantify spatial changes on diversity and dominance species evolution from the integration of raster and field data set. The cluster analysis accurately identified the main plant communities of the area. This

allowed the selection of the best sample plots of each plant community, decreasing the number of study samples and reinforcing an accurate digital change analysis.

NDVI is highlighted as having a good understanding of succession stage changes, showing sensitivity to post-fire plant cover changes and diversity dynamics. With an appropriate data set and classifications, this model is suitable for being applied in the management and restoration of wildfire-affected areas.

Thus, we have avoided the use of a gap model that requires a large number of simulated variables. Long term, the role of dominant species in autosuccession processes is fundamental for determining the evolution of Mediterranean plant communities. That evolution is uncertain and depends not only on the biophysical conditions around but also on the historical status and disturbances. In this context, diachronic studies are needed to evaluate the changes produced at long-term and to obtain desirable species regeneration models. Continuation of this diachronic study in the future will be essential to evaluate the recovery pattern of these communities and assess fire risk within the burned area.

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