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in

Leone V. (ed.), Lovreglio R. (ed.).
Proceedings of the international workshop MEDPINE 3: conservation, regeneration and restoration of Mediterranean pines and their ecosystems

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 75

2007
pages 105-110

HOW DOES THE RECURRENCE OF FIRE AFFECT THE REGENERATION OF PINE-DOMINATED MEDITERRANEAN COMMUNITIES?

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Abstract

The post-fire regeneration of Mediterranean communities dominated by Pinus halepensis was examined using a regional approach in Catalonia (NE Iberian Peninsula). The study design comprised 28 study sites conformed by neighboring areas burnt once versus twice along 20 years. In all of them, last fire occurred in 1994.

Several surveys have been conducted from year 2002 on: records on vegetation structure (height, cover, Rothermel's fuel models), P.halepensis (density, percentage of trees bearing cones, height), and soil organic horizons (frequency of appearance, dry masses) have been taken and comparatively analyzed in paired once- and twice-burnt areas.

Our study reveals that fire recurrence has important, cumulative effects on the regeneration of the studied communities. In more recurrently burnt areas, a noticeable structural simplification of vegetation and soil organic horizons has been observed, together with a decline of P.halepensis populations. Both structural and compositional changes seem to be related with an insufficient length of fire intervals.

INTRODUCTION

Fire is a dominant ecological factor in MTEs, and changes in fire regimes could have important consequences for the conservation of Mediterranean landscapes. In the Mediterranean Basin, shifts in historical patterns of fire occurrence have been observed that are attributable to changes in land use and to an increasing climatic fire risk, but also to human action, which constitutes a main source of ignition [16, 20, 19]. The increase of fire recurrence -number of fire events that occur at a site along a given period of time- is of special concern. Firstly, it can reach extremely high values in certain areas. For instance, in Catalonia (NE Iberian Peninsula), about the 80% of fires occurred along the last decade were caused by humans [4]. Thus, it is not striking that some areas in the region have been burnt up to 6 times along 23 years [5], i.e., average fire interval (*sensu* [11]) in those is shorter than 4 years. Secondly, fire recurrence could have very relevant ecological consequences. Recurrent fires could lead to long-term cumulative effects on some ecosystem properties, such as vegetation regeneration [27, 6], and have been pointed as capable of converting shrublands into herb-dominated systems [27, 13]. Approaches to the study of fire effects which consider broad spatial and temporal scales are required to satisfy current needs for understanding the effects of both the sequence and the sum of fire events occurring in a certain landscape.

In the present study we aimed to deal with fire recurrence effects and to work at a regional level, in order to evidence ecological patterns occurring throughout a range of geomorphic and climate conditions. We focused on communities dominated by the tree seeder species Pinus halepensis (Aleppo pine), since this is a species commonly affected by fire and one of the most abundant trees in the Mediterranean Basin [22], and particularly in the Eastern Iberian Peninsula (data for Catalonia in [2]). We used a block design providing 28 study sites located throughout the area of distribution of P.halepensis in Catalonia (a 32,000 km^2 extent region). Each study site was conformed by two areas very closely located and which shared similar environmental conditions: a once-burnt area (burnt in 1994) and a twice-burnt area (burnt firstly between 1975 and 1993, and secondly by the same 1994 fire). In the present work we provide data from several surveys that were conducted from the year 2002 on, and which considered vegetation structure, P.halepensis populations, and soil organic horizons. We comparatively analyze the surveyed parameters between once- and twice-burnt areas, to specifically address fire recurrence effects.

MATERIAL AND METHODS

Study sites

We used vegetation maps to identify P.halepensis-dominated communities, and fire history maps for the period 1975-1998 [5] to identify localities where two areas affected by a different level of fire recurrence where placed adjacently. Thus, we defined a total of 28 study sites (Fig. 1), in such a way that each one corresponded to P.halepensis-dominated communities, and was formed by a once-burnt area (burnt in 1994) and a close twice-burnt area (burnt firstly between 1975 and 1993, and secondly by the same 1994 fire). Fire intervals for twice-burnt areas ranged from 1 to 16 yr. Study sites were located in the field by means of a global positioning system, and, in addition, once- and twice-burnt areas were recognized according to the presence of field indicators of burning history. One stand of ca. 1 ha was selected in each area such that paired once- and twice-burnt stands were as similar as possible in relation to geomorphic characteristics, and were separated by a minimum buffer distance of 10 m.

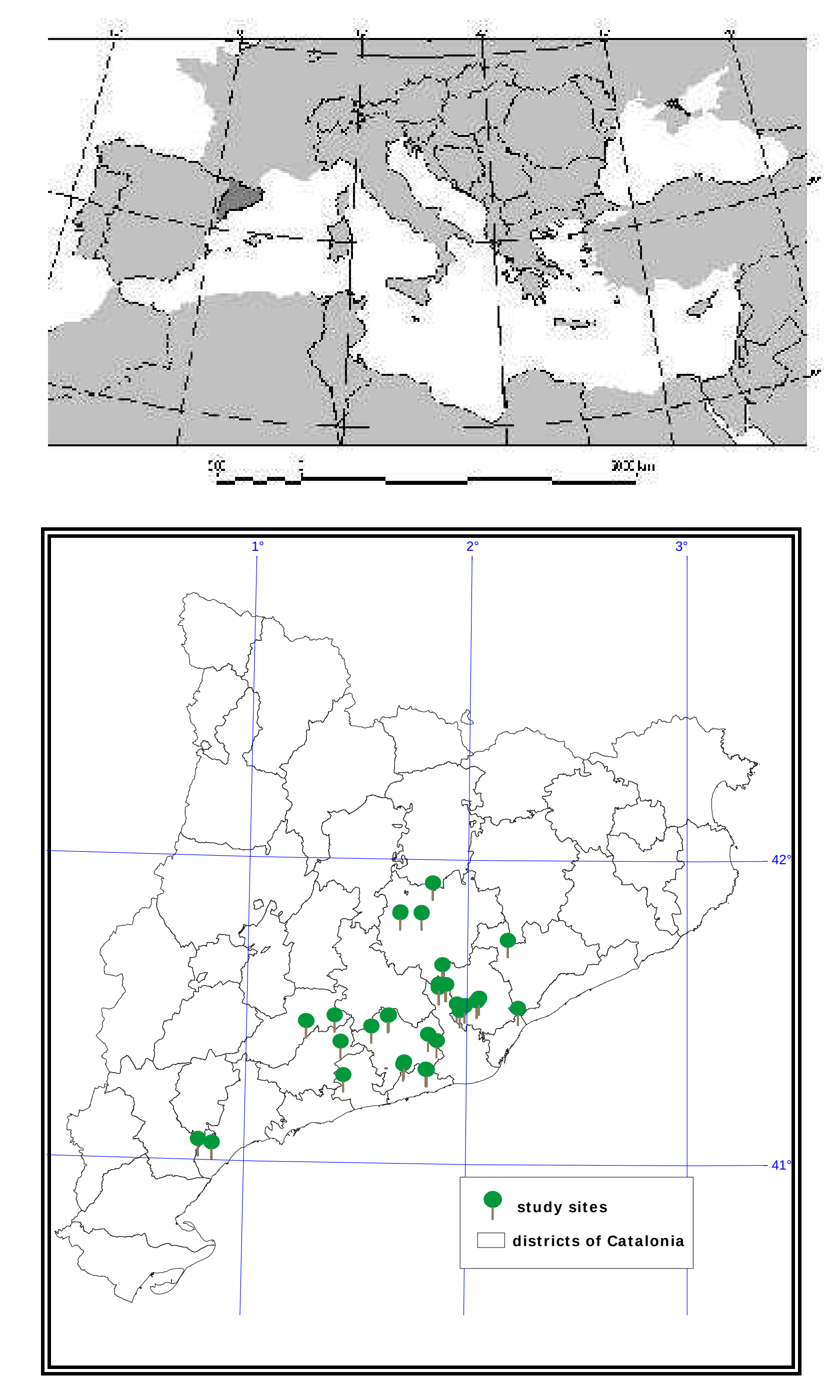

Fig. 1. Location of Catalonia in the Mediterranean Basin (a) Location of study sites in Catalonia (b)

The climate of the studied region is Mediterranean, characterized by cool winters and hot, dry summers, with precipitation occurring mostly in spring and autumn seasons. Ranges of temperature for the sites were 12.9 ℃ to 15℃ (annual mean), 4.4℃ to 8.7℃ (winter mean), and 19.7℃ to 22.9℃ (summer mean). Ranges of precipitation were 523.9 mm to 772.4 mm (annual mean), and 105.5 mm to 185.1 mm (summer mean) (Atles Climàtic Digital de Catalunya ([21, 17]) http://magno.uab.es/atles-climatic/). Elevations ranged from 156 m to 758 m, and slopes ranged from 0°to 40°. About the 90% of the sites showed calcareous substrate: 60% of calcareous substrates were soft rocks (marl, clay, potter's clay, mud), and the rest were hard rocks (dolomite, limestone, conglomerate) (Geological Digital Data Base [10]).

Field surveys

The survey of vegetation structure was conducted in 2002 in the 28 study sites. Four transects 25 meters-long were placed perpendicularly to the slope in each stand. Along transects, quadrats of 1 m^2 were used as surveying units to record mean and maximum plant height, and maximum height of Quercus ilex (holm oak) and Quercus coccifera (kermes oak). Height and cover percentage of herb, shrub and tree layers, and fuel model following Rothermel types' [23] adaptation for the Spaniard territory [12] were visually recorded. Additionally, and in 14 randomly selected study sites, total vegetation cover was recorded on transects by the point interception sampling procedure, every 50 cm.

The survey of P.halepensis was conducted in 2004 in the 28 study sites. Four transects 25 meters-long were placed perpendicularly to the slope in each stand. Along those, quadrats of 1 m^2 were used as surveying units to record the number of individuals, the number of them bearing cones, and the height of the tallest individual.

The survey of soil organic horizons was conducted in 2003 in 15 randomly selected study sites. Four transects 25 meters-long were placed perpendicularly to the slope in each stand. The frequency of occurrence of soil organic horizons was recorded on them by the point interception sampling procedure, every 50 cm. In each stand, 10 samples of L horizon -basically formed by unbroken plant remains- and 10 samples of pooled FH horizons -formed by fragmented, semi-decomposed plant remains and humiferous layers- were obtained by using sharp edge quadrats of 20x20 cm in randomly selected points on transects. Such samples were afterwards pooled to obtain a single composite sample per stand of L horizon and pooled FH horizons, which was oven-dried for 2 days at 60 ºC and afterwards weighted to obtain dry masses.

Data analyses

Comparisons between paired once- and twice- burnt areas were conducted by means of paired *t* - Student tests. Whenever data did not meet the statistical assumptions required for such a test, non-parametric Wilcoxon rank tests were used.

RESULTS

The survey of vegetation structure revealed that:

(1) All height measures were significantly higher in once-burnt areas (Figure 2). Moreover, estimated heights of herb, shrub, and tree layers were also significantly higher in once-burnt areas ($t = 2.43$, $P < 0.05$; $t = 5.56$, $P < 0.0001$; $t = 6.81$, $P < 0.0001$, respectively).
(2) Herb, tree, and total cover (data *arc sin* transformed) were significantly higher in once-burnt areas ($t = 2.37$, $P < 0.05$; $t = 6.43$, $P < 0.0001$; $t = 3.69$, $P < 0.05$, respectively). No differences were found in shrub cover.
(3) Half study sites shifted to fuel models characterized by lower fuel loads, and the rest shifted to fuel models characterized by equivalent fuel loads.

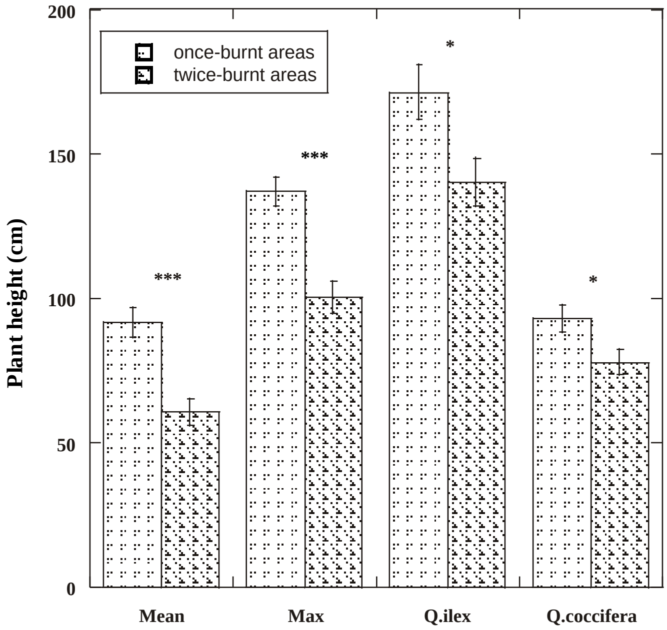

Fig. 2. Height measures (mean ± SE) in quadrats: mean and maximum plant height (Mean, Max), and maximum height of Q.ilex and Q.coccifera (Q.ilex, Q.coccifera). Asterisks denote significance (* $P < 0.05$, *** $P < 0.0001$).

The survey of P.halepensis revealed that:

(1) Pine density (data *log* transformed) was significantly higher in once-burnt areas ($t = 4.77$; $P < 0.0001$). About 19,000 pines ha^{-1} were found in once-burnt areas, *versus* 8,000 pines ha^{-1} in twice-burnt ones.
(2) The percentage of pines bearing cones was significantly higher in once-burnt areas ($Z = -3.36$, $P < 0.001$). About 11% of pines were bearing cones in once-burnt areas, *versus* 3% in twice-burnt areas.
(3) The maximum height achieved by pines was significantly higher in once-burnt areas ($t = 4.14$, $P < 0.001$). Maximum height was 133 cm in once-burnt areas, *versus* 98 cm in twice-burnt ones.

The survey of soil organic horizons revealed that:

(1) The frequency of appearance of soil organic horizons (data *arc sin* transformed) was significantly higher in once-burnt areas ($t = 4.21$; $P < 0.001$). About 96% of the sampling points in once-burnt areas showed organic horizons, *versus* about 85% in twice-burnt areas.
(2) Dry masses of L and pooled FH horizons were significantly higher in once-burnt areas ($t = 3.27$; $P < 0.05$ and $Z = -2.43$; $P < 0.05$, respectively). L dry masses were 17 Mg ha^{-1} in once-burnt areas, *versus* 11 Mg ha^{-1} in twice-burnt ones, and FH dry masses were 1 Mg ha^{-1} *versus* 0.25 Mg ha^{-1}, respectively.

DISCUSSION

Vegetation has been observed to show more developed vertical and horizontal structure and higher fuel loads in once-burnt areas, which means that it has been able to grow comparatively more along the same time period than vegetation in twice-burnt areas. We hypothesize that such growth differences may result from differences in the availability of soil nutrients during the *post-fire nutrient boom*, which at the time would rely on pre-fire fuel loads [7]. The post-fire nutrient boom is a time period of about 2 or 3 yr along which soil fertility is markedly high as a consequence of nitrification stimulation and nutrient release from burnt biomass by fire [1, 24]. Given that fire intervals before the 1994 fire were longer in once- than in twice-burnt areas (more than 20 yr *versus* up to 16 yr), vegetation was likely more developed in them, and thus, the potential amount of nutrients to be released by the 1994 fire was higher. Moreover, such higher fuel loads would presumably result in higher fire intensity, i.e., fire temperatures, which have been observed to determine the rates of soil nutrients increase and the amount of ashes released [15, 18].

Similarly, the reconstruction of soil organic horizons has been more successful in once-burnt areas, since they are heavier and cover a higher percentage of mineral soil. In relation to L horizon, this fact can likewise be related with fire intervals: assuming that higher fuel loads were found at the moment of the 1994 fire in once-burnt areas, a greater amount of partially or totally combusted plant vestiges was likely left by it [8]. However, the most important reason to be adduced is the observed higher vegetation development in once-burnt areas, since L horizon is formed by plant remains. Regarding FH horizon, we hypothesize that reburning is directly responsible for the lower dry mass found in twice-burnt areas. Considering the role that H horizon plays for mineral soil fertility and that several decades are necessary for its recovery [9], this seems to be a relevant consequence of fire recurrence.

The tree dominant species, P.halepensis, has been greatly affected by reburning. Firstly, its density is significantly lower in twice-burnt areas. P.halepensis is a seeder species whose post-fire regeneration relies on the release and establishment of seeds from a persistent canopy seed bank [3]. Only when fire intervals are long enough to allow a certain, sufficient canopy seed bank to be formed, post-fire populations show similar densities to those of the parent populations [14]. In our study, fire intervals in twice-burnt areas were as a maximum 16 years-long, which seems to not be long enough. Secondly, its reproductive performance is being worse in twice-burnt areas, where a lower percentage of trees have been able to develop cones. This could be related to the lower size of pines, since in natural, even-aged populations an extremely high correlation has been found between stem height and juvenile/mature status: most of the reproductive saplings belong to the tallest class [25]. The higher size of pines in once-burnt areas agrees with the general trend found for vegetation structure, and can not be explained by competition mechanisms, since pine density was higher in once-than in twice-burnt areas.

CONCLUSIONS

The studied level of fire recurrence 2 fires along 20 years-:

(1) Has been observed to result in relevant effects at plants' community level (less developed structure, lower fuel loads, decline of the tree dominant species), at P.halepensis populations' level (lower densities, worse reproductive performance, lower height), and at soil organic horizons' level (worse reconstruction).
(2) Thus, it would likely exceed the hypothetical natural level of fire recurrence which could allow Mediterranean P.halepensis-dominated communities to recover, i.e., it would likely overpass their resilience.

Two main changes have occurred:

(1) A compositional change which implies a shift from P.halepensis-dominated communities to shrub-dominated ones. Such shift derives from the interaction between fire interval and life history traits of the dominant tree species.
(2) A structural change that can be understood as a decrease of plant productivity. We hypothesize that it may also be dependent on fire interval, since longer fire intervals allow vegetation development and thus, fuel accumulation before the following fire. The amount of fuel determines not only the potential amount of nutrients to be released by fire, but also fire intensity, which in turn is responsible for nutrient mineralization and for the amount of ashes produced. Higher amounts of available nutrients in soils along the initial post-fire period (*post-fire nutrient boom*) would allow a better development of vegetation, and a subsequent better soil organic horizons reconstruction.

As a consequence of all the above-mentioned, current anthropogenically-increased levels of fire recurrence may result in apparent modifications of pine-dominated Mediterranean communities, which would comprise structural and compositional changes.

REFERENCES

[1] Carreira, J.A. (1992). Biogeoquímica y disponibilidad del N y P en una cronosecuencia de suelos semiáridos asociados a distintos régimenes de incendios. PhD Thesis. Universidad de Málaga, Málaga, Spain.
[2] CREAF, (2003). Inventari Ecològic i Forestal de Catalunya (IEFC). Sistema d'Informació de Boscos de Catalunya (SiBosc). http://www.creaf.uab.es/iefc

[3] Daskalakou, E.N. & Thanos, C.A. (1996). Aleppo pine (*Pinus halepensis*) postfire regeneration: the role of canopy and soil seed banks. International Journal of Wildland Fire 6: 59-66.

[4] Departament de Medi Ambient i Habitatge, Generalitat de Catalunya, 2005. Campanya Pública de Prevenció i Extinció d'Incendis Forestals Estiu (2005). http://gencat.es

[5] Díaz-Delgado, R. & Pons, X. (2001). Spatial patterns of forest fires in Catalonia (NE of Spain) along the period 1975-1995. Analysis of vegetation recovery after fire. Forest Ecology and Management 147: 67-74.

[6] Díaz-Delgado, R., Lloret, F., Pons, X. & Terradas, J. (2002). Satellite evidence of decreasing resilience in Mediterranean plan communities after recurrent wildfires. Ecology 83: 2293-2303.

[7] Eugenio, M. & Lloret, F. (2004). Fire recurrence effects on the structure and composition of Mediterranean *Pinus halepensis* communities in Catalonia (northeast Iberian Peninsula). Écoscience 11(4): 446-454.

[8] Eugenio, M., Lloret, F. & Alcañiz, J.M. (2006). Regional patterns of fire recurrence effects on calcareous soils of Mediterranean *Pinus halepensis* communities. Forest Ecology and Management 221: 313-318.

[9] Ferran, A. & Vallejo, V.R. 1992. Litter dynamics in post-fire successional forests of *Quercus ilex*. Vegetatio 99-100: 239-246.

[10] ICC (Institut Cartogràfic de Catalunya), IGME (Instituto Geológico y Minero de España) & DMA (Departament de Medi Ambient). 2002. 1:50, 000-scale Geologic Data Base. http://mediambient.gencat.net/cat/el_departament.

[11] Johnson, E.A. (1992). Fire and Vegetation Dynamics: Studies from the North American Boreal Forests. Cambridge University Press, Cambridge.

[12] ICONA, (1987). Guía fotográfica para la identificación de Modelos de Combustible. MAPA, Madrid.

[13] Keeley, J.E., Fotheringham, C.J. & Morais, M. 1999. Reexamining fire suppression impacts on brushland fire regimes. Science 284: 1829-1832.

[14] Keeley, J.E., Ne'eman, G. & Fotheringham, C.J. (1999). Immaturity risk in a fire-dependent pine. Journal of Mediterranean Ecology 1: 41-48.

[15] Kutiel, P. & Kutiel, H. (1989). Effects of a wildfire on soil nutrients and vegetation in an Aleppo pine forest on Mount Carmel, Israel. Pirineos 134: 59-74.

[16] Moreno, J.M., Vázquez, A. & Vélez, R. (1998). Recent history of fires in Spain. In: Moreno, J.M. (Ed.), Large forest fires, Backhuys Publishers, Leiden, pp.159-185.

[17] Ninyerola, M., Pons, X. & Roure, J.M. (2000). A methodological approach of climatological modelling of air temperature and precipitation through GIS techniques. International Journal of Climatology 20: 1823-1841.

[18] Pausas, J.G. *(*2003). Fire severity and seedling establishment in *Pinus halepensis* woodlands, eastern Iberian Peninsula. Plant Ecol. 169: 205-213.

[19] Pausas, J.G. (2004). Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean Basin). Climatic Change. 63 (3): 337-350.

[20] Piñol, J., Lloret, F. & Terradas, J. (1999). Climate warming wildfire hazard and wildfire occurrence in coastal Eastern Spain. Climate Change 38: 345-357.

[21] Pons, X. (1996). Estimación de la Radiación Solar a partir de modelos digitales de elevaciones. Propuesta metodológica. In: Juaristi, J. & Moro, L (eds.), VII Coloquio de Geografía Cuantitativa, Sistemas de Información Geográfica y Teledetección, Vitoria-Gasteiz, pp. 87-97.

[22] Quézel, P. (2000). Taxonomy and biogeography of Mediterranean pines (*Pinus halepensis* and *P.brutia*). In: Ne'eman, G. & Trabaud, L. (eds.). Ecology, Biogeography and Management of *Pinus halepensis* and *Pinus brutia* Forest Ecosystems in the Mediterranean Basin, Backhuys Publishers, Leiden, pp.1-12.

[23] Rothermel, R.C. (1983). How to predict the spread and intensity of forest and range fires. USDA Forest Service General Technical Report INT-143. Intermountain Research Station, Odgen, Utah.

[24] Serrasolses, I. & Vallejo, R. (1999). Soil fertility after fire and clear-cutting. In: Rodà, F., Retana, J., Gracia, C.A. & Bellot, J. (eds.), Ecology of Mediterranean Evergreen Oak Forests, Springer-Verlag, Berlin-Heidelberg, pp. 315-328.

[25] Thanos, C.A. & Daskalakou, E.N. (2000). Reproduction in *Pinus halepensis* and *Pinus brutia*. In: Ne'eman, G. & Trabaud, L. (eds.) Ecology, Biogeography and Management of *Pinus halepensis* and *P.brutia* Forest Ecosystems in the Mediterranean Basin, Backhuys Publishers, Leiden, The Netherlands, pp. 80-90

[26] Trabaud, L. (1991). Fire regimes and phytomass growth dynamics in a *Quercus coccifera* garrigue. Journal of Vegetation Science 2: 307-314.

[27] Zedler, P.H., Gautier, C.R. & McMaster, G.S. (1983). Vegetation change in response to extreme events: the effect of a short interval between fires in California chaparral and coastal scrub. Ecology 64: 809-818.