ELSEVIER

Forest Ecology and Management 93 (1997) 227–234

Forest Ecology and Management

Clearing of vegetation in Mediterranean garrigue: response after a wildfire

Francisco Lloret *, Montserrat Vilà

Centre Recerca Ecològica i Aplicacions Forestals, Universitat Autònoma Barcelona, 08193 Bellaterra, Barcelona, Spain

Accepted 8 October 1996

Abstract

Plant resprouting and seedling establishment one year after a wildfire was evaluated in plots in which all vegetation was clipped three times a year for 5 years before the fire. Vegetation regeneration was compared between burned-cleared plots and: i) burned-uncleared plots; ii) unburned-cleared plots. Ground cover was not influenced by the vegetation clipping carried on before fire, except that there was less resprouting of the dominant resprouter *Quercus coccifera* in cleared-burned than in uncleared-burned plots. Number of seedlings and species richness was not significantly influenced by clearing treatments. When comparing burned-cleared plots with unburned-cleared plots, fire increased the ground cover of shrubs and resprouting species, but not the total ground cover and the cover of forbs, grasses or *Q. coccifera*. Seedlings were more abundant and species richness greater in burned-cleared plots than in unburned-cleared ones. Vegetation clearing does not appear to strongly affect the regeneration ability of the community, except for the decrease of some dominant species. Our results suggest that before the fire, the seed bank in burned-uncleared plots may be larger than in burned-cleared ones, but the higher temperatures reached in uncleared areas would deplete the seed bank able to germinate, leading to the observed lack of differences in seedling establishment. Seedling establishment in long-term cleared areas is largely dependent upon the seed output from neighbouring well-structured communities and, consequently, it may be affected by the size of cleared areas. © 1997 Elsevier Science B.V.

Keywords: Clearing; Fire; Ground cover; Mediterranean shrubland; *Quercus coccifera*; Resprouting, seedling establishment

1. Introduction

Approaches to the study of plant community dynamics have incorporated disturbances as phenomena that must be considered in all ecosystem-types (Pickett and White, 1985). The main effects of disturbances in plant communities are the total or partial destruction of plant parts and consequent release of resources as well as the opening of gaps that can be occupied by regrowth of previously established plants or by new ones. New plants arise from germination of seeds from the soil seed bank or from arrival from neighbouring areas by dispersal. Wildfires are natural disturbances influencing vegetation dynamics in Mediterranean ecosystems (Trabaud, 1981). Fire frequency and areal extent has increased greatly during recent decades in the Mediterranean Basin regions (Le Houéru, 1987; Vélez, 1988). Management to avoid catastrophic damage includes both direct fire fighting and use of preventive techniques, such as fuel reduction by prescribed fires or selective

* Corresponding author.

0378-1127/97/$17.00
PII S0378-1127(96)03965-5

plant removal. Prescribed fires are a relatively inexpensive technique allowing fuel reduction in relatively large areas. This technique is commonly used in California, Australia and South Africa (Green, 1981; Gill and Bradstock, 1994; van Wilgen et al., 1992). In the Mediterranean regions of Spain, prescribed fires are not used because of the high risk of accidents affecting private properties, including farms and holiday resort areas. In addition, the risk of erosion and the limited ability of many plant communities to regenerate under high fire frequencies make the implantation of prescribed fires as a general management practice difficult (Whelan, 1995; Terradas, 1996). In these regions, manual clearing of the vegetation in selected places, such as belts besides roads or below electric power lines, are common fuel reduction management practices (Rico et al., 1981; Favre, 1992; Terradas, 1996).

The main regeneration mechanisms of Mediterranean plants after fire are resprouting and seedling establishment (Keeley and Zedler, 1978; Gill, 1981). Resprouting occurs by recruitment of new shoots from above-, or under-ground organs after the removal or damage of above-ground parts. Resprouting vigour depends upon: the plant's anatomical features (Canadell and Zedler, 1995); the characteristics of the individual before disturbance, such as plant size, number of shoots and physiological status of the plant (Jones and Laude, 1960; Canadell et al., 1991); the intensity of disturbance (Malanson and Trabaud, 1988; Lloret and López-Soria, 1993; Moreno and Oechel, 1994); the environmental conditions after disturbance (Schlesinger and Gill, 1980; Mooney and Hobbs, 1986). Clearing of vegetation prior to burning may affect resprouting after fire in several ways: i) the reduction of fuel load by clearing decreases fire intensity (Whelan, 1995), allowing plants to resprout more vigorously (Lloret and López-Soria, 1993); ii) clearing may reduce the capacity to produce new shoots by decreasing the bud bank or because the physiological status of the plant is altered (Zammit, 1988); iii) previous clearing may also modify the initial community composition, changing flammability and combustibility features of the community.

Increasing seed germination of some species after a wildfire is a well recognized phenomena in sclerophylous Mediterranean plant communities such as shrublands dominated by *Quercus coccifera* L. ('garrigues') (Papió, 1994; Keeley, 1995). Two proposed mechanisms for induced seed germination by fire are: 1) breaking of hard seed coats (Aronne and Mazzoleni, 1989); 2) depletion of allelopathic substances in the soil (McPherson and Muller, 1969; Keeley and Keeley, 1989). An increase of resources such as light, soil nutrients or water after a fire may also indirectly favour seedling recruitment (Christensen and Muller, 1975). Clearing of the vegetation may also influence seedling recruitment in the following ways: i) the soil seed bank suitable for germination after fire may be smaller because of the lower abundance of parent plants (Zammit and Zedler, 1988; Bond et al., 1984); ii) alternatively, moderate temperature levels occurring in cleared areas (Davis et al., 1989) may induce high levels of germination (Auld, 1986); iii) the change of light quality after fire in closed areas may promote germination in some species (Roy and Arianoutsou-Faraggitaki, 1985), while stimulation by light was operating in cleared areas before fire, depleting the seed bank.

The main objective of this study was to explore the effect of vegetation clearing before a wildfire on the regeneration response of a Mediterranean garrigue. The specific questions addressed were: i) Does clearing before a wildfire reduce ground cover? ii) Does clearing modify the abundance of the different growth forms in the community? iii) Does clearing modify the abundance of *Q. coccifera*, the dominant resprouting species of the garrigue? iv) Does clearing influence seedling establishment? v) Does clearing affect species richness and species dominance? By answering these questions we hope to further our understanding of the role of vegetation structure before fire on the regeneration dynamics of Mediterranean garrigues. For example, if the size of the seed bank is the main factor controlling seedling establishment after fire, more seedlings will be expected in pre-fire, dense vegetation sites where the seed bank is larger than in sites where vegetation cover before fire is reduced by clearing. This trend may be counterbalanced by inhibitory effects of higher temperatures on germination at dense vegetation stands (Auld, 1986; Zammit and Zedler, 1988; Davis et al., 1989), as suggested in laboratory experiments (Oustric, 1984; Salvador and Lloret, 1995).

2. Methods

2.1. Study site

The study site was located in a dense garrigue about 1 m tall on the Serra de les Comes (40° 53′N, 0° 41′E) in El Perelló (Catalonia, Spain), at an elevation of 300 m above sea level and 9 km from the sea. The soil is stony and shallow, classified as *Lithic haploxeroll*. The climate is typically Mediterranean, characterized by summer drought. Mean monthly temperature ranges from 4.5°C in January to 29°C in July. The mean annual temperature is 16°C. Mean annual precipitation is 591 mm, of which 45% occurs in the spring and autumn. The area was burned by wildfire in 1976. At present, the shrubland vegetation is dominated by *Rosmarinus officinalis* L., *Q. coccifera* L., *Erica multiflora* L. and *Ulex parviflorus* Pourr., which contribute approximately 40, 15, 10 and 10%, respectively, of ground cover. Other relevant shrubs also present are *Pistacia lentiscus* L. and *Globularia alypum* L. The herbaceous layer is dominated by *Brachypodium retusum*, (Pers.) Beauv., which covers approximately 60% of the ground.

2.2. Experimental design

In June 1988, twenty plots, each of radius 2 m, were manually cleared in a competition experiment in which the resprouting vigour of one randomly selected target plant of *E. multiflora* without neighbours was compared to that of target plants with neighbours (Vilà and Terradas, 1995a). These clearings were similar to those carried out by management practices in order to decrease fire hazards by reducing standing biomass. All plot regrowing vegetation, except the target plant, was clipped from the beginning of the experiment until July 1993, at 4-month intervals. In July 1993 a wildfire burned most of the experimental site. Out of the original twenty clearings, eight were completely burned, eight were not affected by fire and four were partially burned or could not be located after the fire. This created an ideal situation for studying the effect of clearing practices on vegetation regeneration after fire. We do not think that the presence of the target plant of *E. multiflora* in the centre of the clearings will influence our result, because they were at the resprouting stage and were less than 30 cm in height.

In June 1994, plant regrowth and seedling establishment after fire was estimated in the eight burned and unburned-cleared plots. Vegetation ground cover in each plot was estimated as the percentage of plant contacts at 2-cm intervals in four transects 1 m long. These transects started at the edge of the plot and were orientated to the four cardinal points. In addition, four 30×30 cm quadrats were randomly located in each plot quadrat and all seedlings were recorded. This sampling procedure was repeated in eight randomly-selected burned plots that were covered by dense vegetation before fire. In addition, sampling of seedlings was carried out in eight randomly-selected natural gaps of at least 1 m diameter which had remained unburned. Sampling plots were at least 2 m apart from each other.

Species richness was estimated in each plot separately from the list of species found by ground cover transects and by quadrats used for seedling counting. An estimation of the total species richness in each plot was also obtained from the combined list of both types of sampling procedures.

2.3. Data analysis

Because clearing treatments were randomly chosen for each plot before fire, we compared burned-cleared and burned-uncleared plots by one-factor analysis of variance (ANOVA) for the following variables: total ground cover; ground cover of the different growth forms (shrubs, forbs and grasses); ground cover of *Q. coccifera*; ground cover of all resprouting species; total number of seedlings; species richness. Fire treatment after clearing could not be randomly selected for each plot, but it was considered useful to compare burned-cleared and unburned-cleared plots for the same variables mentioned by one-factor ANOVAs. Differences in number and species richness of seedlings between unburned-cleared plots and natural gaps were also analysed by one-factor ANOVA. To normalize errors, cover and species richness was square-root transformed, while total number of seedlings was log-transformed. Seedling establishment of the five most common species (*R. officinalis*, *U. parviflorus*, *Fumana ericoides* (Cav.) Gandg., *Polygala rupestris*

Pourr. and *Cistus salviifolius L.*) was compared separately following the same procedure, after $\log(x+1)$ transformation.

3. Results

3.1. Ground cover

Vegetation clearing before the wildfire did not influence total ground cover one year after treatment ($F_{1,14} = 4.01$, $P = 0.06$). The percentage of ground cover of shrubs, forbs and grasses was not significantly different between treatments ($F_{1,14} = 3.08$, $P = 0.10$; $F_{1,14} = 0.23$, $P = 0.64$; $F_{1,14} = 0.12$, $P = 0.73$, respectively, Fig. 1). The overall ground cover of resprouting species was not significantly affected by vegetation clearing ($F_{1,14} = 3.64$, $P = 0.08$). However, clearing reduced the ground cover of *Q. coccifera* ($F_{1,14} = 5.27$, $P = 0.04$). Mean percentage cover of *Q. coccifera* in burned-cleared plots was 4.2 (S.E. = 4.3), while it was 12.6 (S.E. = 3.0) in burned-uncleared plots.

Fire increased the ground cover of shrubs in plots which had been previously cleared ($F_{1,14} = 13.30$, $P = 0.003$, Fig. 1). Overall, cover of resprouting species also increased in burned plots ($F_{1,14} = 4.77$, $P = 0.046$). Nevertheless, the total ground cover and the cover of forbs and grasses were not different between burned and unburned plots ($F_{1,14} = 4.25$, $P = 0.06$; $F_{1,14} = 0.24$, $P = 0.63$; $F_{1,14} = 0.76$, $P = 0.40$, respectively). Fire did not affect the ground cover of *Q. coccifera* ($F_{1,14} = 1.78$, $P = 0.20$). Mean percentage cover of *Q. coccifera* in unburned-cleared plots was 2.2 (S.E. = 0.9). Although some of the results about the effect of fire show clear patterns, they must be considered with caution because fire treatment was not randomly selected in each plot. This also applyes to seedling establishment and species richness analysis.

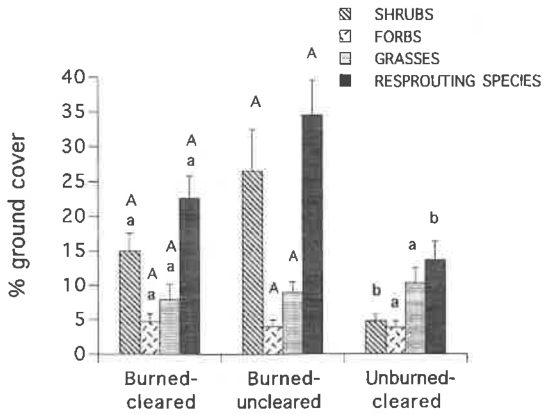

Fig. 1. Percentage of ground cover (±S.E.) of shrubs, forbs, grasses and resprouting species 1 year after fire in burned-cleared and burned-uncleared plots and in unburned-cleared plots. For each type of growth form, significant differences ($P < 0.05$) between burned-cleared and burned-uncleared plots are shown by different capital letters, while significant differences between burned-cleared and and burned-uncleared plots are shown by different lower case letters.

3.2. Seedling establishment

Vegetation clearing before the wildfire had a non-significant effect on total number of seedlings one year after treatment ($F_{1,14} = 3.6$, $P = 0.08$). Of the five species considered separately, only *P. rupestris* recruited more seedlings in burned-uncleared plots than in burned-cleared ones (Table 1).

Table 1
Mean number of seedlings per square metre (±S.E.) of the five most abundant species and of the total set of species established in the different clearing treatments and in natural gaps 1 year after fire

	Burned-cleared		Burned-uncleared		Unburned-cleared		Natural gaps	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Rosmarinus officinalis (s)	88.9	14.28	49.3	12.46	13.5	3.12	15.0	4.44
Ulex parviflorus (s)	23.3	7.33	42.0	12.97	8.7	1.61	10.8	2.94
Cistus salviifolius (s)	42.7	20.61	8.0	3.98	2.8	1.29	1.7	1.39
Fumana ericoides (f)	22.9	4.72	21.5	9.75	25.7	10.23	23.3	6.50
Polygala rupestris (f)	4.5	1.57	20.5	4.20	2.4	0.97	3.5	1.03
Total	260.0	26.23	184.3	27.47	76.2	13.81	66.3	14.25

The letter beside each species name indicates its growth form (s, shrub; f, forb).

Table 2
Mean number of species per plot (900 cm^2, ±S.E.) 1 year after fire

	Burned-cleared		Burned-uncleared		Unburned-cleared		Natural gaps	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Cover transects	8.4	0.92	8.9	0.69	8.2	0.96		
Establishment quadrats	9.5	0.46	9.0	0.50	8.1	0.81	6.4	0.80
Total	15.9	0.69	15.2	0.49	13.1	0.99		

Mean number of species per plot (900 cm^2, ±S.E.) 1 year after fire was estimated by two sampling methods (transects to estimate ground cover and quadrats to count seedlings) and from the combined list obtained from both methods in the different clearing treatments and in natural gaps. In natural gaps, the only method to estimate species richness was by quadrats, so the value of the total number of species has been omitted for this habitat.

The total number of seedlings was significantly higher in burned-cleared plots than in unburned-cleared ones ($F_{1,14} = 39.85$, $P < 0.001$). Of the five species considered separately, only *R. officinalis* and *C. salviifolius* showed this pattern (Table 1). There were not significant differences between the number of seedlings in unburned-cleared plots and in natural gaps ($F_{1,14} = 0.61$, $P = 0.45$, Table 1).

3.3. Species richness

There were no significant differences between burned-cleared plots and burned-uncleared ones in species richness in the cover transects ($F_{1,14} = 0.01$, $P = 0.91$), nor when comparing burned-cleared plots and unburned-cleared ones ($F_{1,14} = 0.40$, $P = 0.53$, Table 2). The same pattern was observed when doing the same comparisons for seedling species richness in the sampling quadrats ($F_{1,14} = 2.34$, $P = 0.15$ and $F_{1,14} = 0.54$, $P = 0.47$, respectively). Species richness of seedlings was not significantly different between unburned-cleared plots and natural gaps ($F_{1,14} = 2.38$, $P = 0.14$).

When considering the total species richness from the combined list of both sampling procedures, there were no significant differences between burned-cleared and burned-uncleared plots ($F_{1,14} = 0.54$, $P = 0.47$). However, it was significantly higher in burned-cleared than in unburned-cleared plots ($F_{1,14} = 5.16$, $P = 0.04$, Table 2).

4. Discussion

The overall ground cover after fire was not very different between previously cleared plots and intact ones. This pattern is not a consequence of a uniform response of all species. *Q. coccifera*, the dominant resprouting shrub species of the community, has a very extensive rhizomatous system which allows this species to resprout vigorously even after repeated clearing (Tsiouvaras et al., 1986; Papió, 1994), and to recover very rapidly after fire (Malanson and Trabaud, 1988). Nevertheless, our study shows that prior clearing reduced *Quercus*' s ability to resprout after fire; therefore, clearing may increase the dominance of other shrub species that were previously present in the community. The lack of difference on *Q. coccifera* cover between burned-cleared and unburned-cleared plots shows that the negative effect on resprouting is due to vegetation clearing and not to fire. Both fire and clearing produce a loss of above-ground biomass. Fire has a slight effect on underground organs and results in increased soil resource availability. Instead, repeated clearing may eventually deplete the bud bank able to resprout (Zammit, 1988; Vilà and Terradas, 1995b) and reduce the ability to use underground resources (Canadell, 1995).

In burned-cleared plots, overall shrub cover increased when compared to unburned-cleared ones, while grasses and forbs did not. Most of the ground cover of shrubs was mainly supported by resprouting shoots of *Q. coccifera, E. multiflora, P. lentiscus* and *G. alypum*. The great ability of some species to resprout after fire is a recognized trend of Mediterranean communities (James, 1984; Canadell and Zedler, 1995), but less data are available about this response after clearing. In burned-uncleared areas, there is increased availability of nutrients shortly after fire (Christensen, 1994). Given the small size of the cleared plots, we also expect an input of nutrients from neighbouring areas, but levels in the soil will probably be lower than in uncleared plots.

Vegetation clearing before the wildfire had a non-significant effect on the total number of seedlings, and this pattern remained when considering the most abundant species individually. Vegetation structure and fire intensity are related in such a way that high fire intensity is expected in dense vegetation stands as a consequence of fuel accumulation (Whelan, 1995). In spite of the relatively small size of our plots, we expect important differences in temperature and time of burning between the two plot types. Variation of this parameter is very high even between closed sites and is highly dependent on microsite characteristics, especially on the structure and the composition of the vegetation (Bond and van Wilgen, 1996). Fire would be expected to enhance seedlings recruitment in previously dense vegetation, especially if the seed bank is higher under dense vegetation. However, this was not the observed pattern in our study. The only exception was with *P. rupestris*, which showed a higher number of seedlings in uncleared stands than in cleared ones, probably because in the studied locality this species grows more abundantly in dense vegetation habitats than in open areas, supplying more seeds to the soil in those areas (F. Lloret, unpublished data).

Laboratory experiments on the effect of heat treatment on seed germination have shown that high temperature treatment may decrease germination in some species showing low-temperature stimulation (Tarrega et al., 1992; Salvador and Lloret, 1995). Ne'eman et al. (1992) have also suggested that a high amount of ash may inhibit germination by increasing osmotic stress. These inhibitory effects will operate more intensely after burns in dense vegetation stands than in clearings. This pattern is similar to that observed by Moreno and Oechel (1994) for *Ceanothus greggii* Gray after experimentally modifying the fuel load. Our study shows that the expected high fire intensity occurring in dense vegetation stands does not increase seedling establishment, except for *P. rupestris*.

An increase in seedlings after fire is also a common trend in Mediterranean communities. In cleared plots, both *R. officinalis* and *C. salviifolius* showed an increased number of seedlings after fire. Stimulation of germination by fire, as has been observed in laboratory heat treatments for *C. salviifolius* (Oustric, 1984; Salvador and Lloret, 1995). However, *in vitro* heat exposure experiments did not increase seed germination of *R. officinalis* (Salvador and Lloret, 1995). Muñoz and Fuentes (1989) have shown that the range of temperatures used in laboratory tests often do not correspond to that experienced by the seed bank during wildfires. Moreover, germination has been proposed to be enhanced by indirect effects of fire, such as charred wood (Keeley et al., 1985), while seedling development may be favoured by an increase of soil nutrients and water availability after fire (Christensen and Muller, 1975).

The observed total number of seedlings in unburned-cleared areas was not different from that observed in natural gaps. Cleared areas remained without adult vegetation for at least 10–15 years (F. Lloret, personal observation), so we suggest that seeds from neighbouring vegetation annually refills the seed bank of cleared areas, in the same way that it does in natural gaps. If clearing is repeated periodically, only short-lived species, such as *Fumana ericoides*, *F. thymifolia* (L.) Spach and *Centaurea aspera*, L. can complete their reproductive cycles. After fire, they will again establish themselves successfully, while large, long-living shrubs will depend upon seed input from neighbouring vegetation. In our study, the distance from the centre of the clearing to intact vegetation was relatively short, and of the same order as that generated by vegetation clearing practices. Notwithstanding, we do not know if seedling establishment of long-living shrubs would be seriously affected in larger cleared areas.

Given the small size of the cleared areas and the proximity of neighbouring vegetation, seed rain composition in cleared plots probably is not very different than in uncleared areas. Most resprouting species remain in cleared areas after several years of regular clearing. These patterns may explain the lack of significant differences between cleared and uncleared plots on total species richness. On the other hand, seedling species richness was not significantly higher in unburned-cleared areas than in natural gaps, although a few species, such as *Euphorbia serrata* L. and *Teucrium chamaedrys* L., which established in clearings were not found in natural gaps.

An increase of species richness in the first years after fire has been observed in Mediterranean communities (Trabaud and Lepart, 1980), mainly as a consequence of the establishment by seeds of opportunistic, short-living species. Such species were rarely found in our plots. Therefore, the higher number of species in burned than in unburned plots suggests that fire enhanced the establishment of some species previously present in the community.

The results from this study may provide insights into the mechanisms operating in natural communities. Gaps in vegetation remain common in some Mediterranean shrub communities 10–20 years after fire. In addition to the abiotic and biotic factors operating after fire, fire characteristics show a very high spatial variability as a result of topography, weather conditions and vegetation structure. Vegetation regeneration after fire is expected to reflect the spatial variability of fire intensity (Davis et al., 1989; Rice, 1993; Moreno and Oechel, 1994). Seedling recruitment after fire would not be very different between natural gaps and cleared areas, in which for several years the only seed input came from neighbouring vegetation. If seed germination after a wildfire is only effective within a small range of temperature, post-fire environmental conditions, specially resources release, may partially explain the post-fire increase of seedling recruitment in the community.

Acknowledgements

We thank Marc Santandreu and Sara Martí for help with data collection, Javier Retana, Patricio García-Fayos and J. Aeger for suggestions on drafts of the paper and Chuck Simmons for improving the language. Financial support was provided by the Comisión Ministerial de Ciencia y Tecnología of Spain (FOR 91-1054 and AMB 94-0881 projects).

References

Aronne, G. and Mazzoleni, S., 1989. The effects of heat exposure on seeds of *Cistus incanus* L. and *Cistus monspeliensis* L. Gior. Bot. Ital., 123: 283–289.

Auld, T.D. 1986. The survival of juvenile plants of the resprouting shrub *Acacia suaveolens* (Sm.) Willd.: fire and the transition to seedling. Aust. J. Ecol. 12: 139–152.

Bond, W.J., Vlok, J. and Viviers, M., 1984. Variation in seedling recruitment in fire-adapted Cape Proteacea after fire. J. Ecol., 72: 209–221.

Bond, W.J. and van Wilgen, B.W. 1996. Fire and Plants. Chapman and Hall, London, 263 pp.

Canadell, J. 1995. Estudi sobre la capacitat de regeneració en espècies perennifolies mediterrànies: us, eficiència i pautes de distribució de nutrients en front de perturbacions experimentals. Ph. Thesis Universitat Autònoma Barcelona, Bellaterra, Spain, 147 pp.

Canadell, J., Lloret, F. and López-Soria, L., 1991. Resprouting vigour of two mediterranean shrub species after experimental fire treatments. Vegetatio, 95: 119–126.

Canadell, J. and Zedler. P.H., 1995. Underground structures of woody plants in Mediterranan ecosystems of Australia, California and Chile. In: M. Fox, M.K. Arroyo and P.H. Zedler (Editors), Convergent evolution in Mediterranean ecosystems of Australia, California and Chile. Springer-Verlag. Berlin, pp. 177–210.

Christensen, N.L., 1994. The effects of fire on physical and chemical properties of soils in Mediterranean-climate shrublands. In: J.M. Moreno and W.C. Oechel (Editors), The role of fire in Mediterranean-Type ecosystems. Springer-Verlag, New York, pp. 79–95.

Christensen, N.L. and Muller, C.H., 1975. Relative importance of factors controlling germination and seedling survival in Adenostoma chaparral. Am. Midl. Nat., 93: 71–78.

Davis, F.W., Borchert, M.I. and Odion, D.C., 1989. Establishment of microscale vegetation pattern in maritime chaparral after fire. Vegetatio, 84: 53–67.

Favre, P., 1992. Feux et forêts. Forêt mediterranéenne, 13: 31–40.

Gill, A.M. 1981., Fire adaptive traits of vascular plants. Proc. Conf. Fire Regimes and Ecosystems Properties. USDA. Forest Service, General Technical Report WO 26, pp. 208–230.

Gill, A.M. and Bradstock, R.A., 1994. The prescribed burning debate in temperate Australian forests: towards a resolution. Proceedings of the 2nd Conference on Forest Fire Research, Comissao Coordenaçao Regiao Centro, Coimbra, pp. 703–712.

Green, L.R., 1981. Burning by prescription in chaparral. Pacific Southwest Forest and Range Exp. Stn., USDA Forest Service, General Technical Report PSW51, Berkeley, CA, 36 pp.

James, S., 1984. Lignotubers and burls – their structure, function and ecological significance in Mediterranean ecosystems. Bot. Rev., 50: 225–260.

Jones, M.B. and Laude, H.M., 1960. Relationships between sprouting in chamise and the physiological condition of the plant. J. Range Manag., 13: 210–214.

Keeley, J.E., 1995. Seed-germination in fire-prone Mediterranean-climate regions. In: M. Fox, M.K. Arroyo and P.H. Zedler (Editors), Convergent evolution in Mediterranean ecosystems of Australia, California and Chile. Springer-Verlag, Berlin, pp. 239–273.

Keeley, J.E. and Keeley, S.C., 1989. Allelopathy and the fire-induced herb cycle. In: S.C. Keeley (Editor), The California chaparral. Paradigms reexamined. Natural History Museum of Los Angeles County, Sciences Series 34. Los Angeles, CA, pp. 65–72.

Keeley, J.E., Morton, B.A., Pedrosa, A. and Trotter, P., 1985. Role of allelopathy, heat and charred wood in the germination of chaparral herbs and suffrutescents. J. Ecol., 72: 445–458.

Keeley, J.E. and Zedler. P.H., 1978. Reproduction of chaparral shrubs after fire: a comparison of sprouting and seeding strategies. Am. Midl. Nat., 99: 142–161.

Le Houéru, H.N., 1987. Vegetation wildfires in the Mediterranean basin: evaluation and trends. Ecologia Mediterranea, 13: 13–24.

Lloret, F. and López-Soria. L., 1993. Resprouting of *Erica multiflora* after experimental fire treatments. J. Veget. Sci., 4: 367–374.

Malanson, G.P. and Trabaud, L., 1988. Vigour of post-fire resprouting by *Quercus coccifera* L. J. Ecol., 76: 351–365.

McPherson, J.K. and Muller, C.H., 1969. Allelopathic effects of *Adenostoma fasciculatum*, 'chamise', in the California chaparral. Ecol. Monog., 39: 177–198.

Moreno, J.M. and Oechel, W.C., 1994. Fire intensity as a determinant factor of postfire plant recovery in Southern California chaparral. In: J.M. Moreno and W.C. Oechel (Editors), The role of fire in Mediterranean-Type ecosystems. Springer-Verlag, New York, pp. 26–45.

Mooney, H.A. and Hobbs, R.J., 1986. Resilience at the individual plant level. In: B. Dell, A.J.M. Hopkins and B.B. Lamont (Editors), Resilience in Mediterranean-type Ecosystems. Dr W. Junk Pub., Dordrecht, pp: 65–82.

Muñoz, M.R. and Fuentes, E.R., 1989. Does fire induce shrub germination in the Chilean matorral? Oikos, 56: 177–181.

Ne'eman, G., Lahav, H. and Izhak, I., 1992. Spatial pattern of seedlings 1 year after fire in a Mediterranean pine forest. Oecologia, 91: 365–370.

Oustric, J., 1984. Le feu et l'écophysiologie de la germination de quelques espèces de garrigues du Bas Languedoc. CNRS-CEPE, Ecole Nationale d'Engeniers, Dijon, Quetigny.

Papió, C., 1994. Ecologia del foc i regeneració en garrigues mediterrànies. Institut d'Estudis Catalans, Barcelona, 292 pp.

Pickett, S.T.A. and White, P.S., 1985. The ecology of natural disturbance and patch dynamics. Academic Press, Orlando, 472 pp.

Rice, S.K., 1993. Vegetation establishment in post-fire Adenostoma chaparral in relation to fine-scale pattern in fire intensity and soil nutrients. J. Veget. Sci., 4: 115–124.

Rico, F., Velez. R., Villaescusa, R., Rodero, F. and Baz, L., 1981. Técnicas para la defensa contra incendios forestales. Monografía 24. ICONA, Ministerio de Agricultura. Madrid, 200 pp.

Roy, J. and Arianoutsou-Faraggitaki, M. 1985. Light quality as the environmental trigger for the germination of the post-fire species *Sarcopterium spinosum* L. Flora 177: 345–349.

Salvador, R. and Lloret, F., 1995. Germinación en el laboratorio de varias especies arbustivas mediterráneas: efecto de la temperatura. Orsis, 10: 25–34.

Schlesinger, W.H. and Gill, D.S., 1980. Biomass, production and changes in the availability of light, water and nutrients during the development of pure stands of the chaparral shrub *Ceanothus megacarpus* after fire. Ecology, 61: 781–789.

Tarrega, R., Calvo, L. and Trabaud, L., 1992. Effect of high temperatures on seed germination of two woody Leguminosae. Vegetatio, 102: 139–147.

Terradas, J. 1996. Mesures específiques de gestió per a la prevenció d'incendis. In: J. Terradas (Coordinator), Ecologia del foc. Proa, Barcelona, pp. 209–225.

Trabaud, L., 1981. Man and fire: impacts on Mediterranean vegetation. In: F. DiCastri, D.W. Goodall and R.L. Specht (Editors), Ecosystems of the world 11. Mediterranean-Type shrublands, Elsevier, Amsterdam, pp. 523–537.

Trabaud, L. and Lepart, J., 1980. Diversity and stability in garrigue ecosystems after fire. Vegetatio, 43: 49–57.

Tsiouvaras, C.N., Noitsakis, B. and Papanastasis, V.P., 1986. Clipping intensity improves growth rate of kermes oak twigs. For. Ecol. Manag., 15: 229–237.

Vélez, R., 1988. Les incendis de forêts dans les pays de la region mediterraneenne. Documentos del Seminario sobre métodos y equipos para la prevención de incendios forestales. ICONA, Madrid, pp. 60–71.

Vilà, M. and Terradas, J., 1995a. Effects of nutrient availability and neighbours on shoot growth, resprouting and flowering of *Erica multiflora*. J. Vegetation Sci., 6: 411–416.

Vilà, M. and Terradas, J. 1995b. Effects of competition and disturbance on the resprouting performance of the Mediterranean shrub *Erica multiflora* L. (Ericaceae). Amer. J. Bot., 82: 1241–1248.

Whelan, R. 1995. The Ecology of Fire. Cambridge University Press, Cambridge, 346 pp.

Wilgen van, B.W., Bond, W.J. and Richardson, D.M., 1992. Ecosystem management. In: R. Cowling (Editor), Fynboss. Nutrients, fire and diversity. Oxford University Press, Cape Town, pp. 345–371.

Zammit, C.A. and Zedler, P.H., 1988. The influence of dominant shrubs, fire and time since fire on soil seed banks in mixed chaparral. Vegetatio, 75: 175–187.

Zammit, C., 1988. Dynamics of resprouting in the lignotuberous shrub *Banksia oblongifolia*. Aust. J. Ecol., 13: 311–320.