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Original article

The influence of fire on the seed bank in the soil of a *Quercus faginea* forest (NW Spain)

Leonor Calvo*[a], Baudilio Herrero[b], Felipe Bravo[c]

[a] Area de Ecología, Facultad de Biología, Universidad de León, 24071 León, Spain
[b] Dpto. de Ciencias Agroforestales, Escuela Técnica Superior de Ingenierías Agrarias, Universidad de Valladolid, 34004 Palencia, Spain
[c] Dpto. de Producción Vegetal y Silvopascicultura, Escuela Técnica Superior de Ingenierías Agrarias, Universidad de Valladolid, 34004 Palencia, Spain

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Abstract – A study was carried out on the effect of a fire on the seed bank of a *Quercus faginea* forest situated close to the town of Palencia (NW Spain). Soil samples were taken at two depths: upper layer at 0–2 cm and deeper at 2–5 cm, in a burned area and in one nearby which did not suffer from the fire. The specific richness values, obtained 2 years after the fire, in samplings carried out in the field as well as the soil seed bank were higher in the burned area than the control. The number of germinated seeds was also higher in the burnt area than the control and more abundant in the surface stratum than the deeper one in both areas. In the control area the richness was 33 species, while in the burned area the richness was greater by five species. On the other hand, the cover value was 58 % in the burned area and 61 % in the control area. (© Inra/Elsevier, Paris.)

fire / seed bank / *Quercus faginea* / germination / northern Castilla

Résumé – Influence du feu sur le stock de semences dans le sol d'une forêt de *Quercus faginea* du Nord-Ouest de l'Espagne. On a étudié l'effet d'un incendie sur le stock de semences d'une forêt de *Quercus faginea* située à Palencia (NW de l'Espagne). Pour atteindre cet objectif, on a pris deux séries d'échantillons du sol respectivement à deux niveaux de profondeur : 0–2 cm et 2,5 cm, dans une zone brûlée et dans une zone avoisinante non incendiée. Deux ans après l'incendie, la présence des espèces, aussi bien dans les échantillons prélevés sur le terrain que dans le stock de semences du sol, était plus importante dans la zone brûlée que dans la zone témoin. Le nombre de semences ayant germé était plus élevé dans la zone brûlée que dans la zone témoin et aussi plus important dans la strate superficielle que dans la strate profonde des deux zones. Dans la zone témoin, on a identifié 33 espèces, contre 38 espèces dans la zone brûlée. Par ailleurs le couvert était de 58 % dans la zone brûlée et de 61 % dans la zone témoin. (© Inra/Elsevier, Paris.)

incendie / stock de semences / *Quercus faginea* / germination / nord de la Castille

1. INTRODUCTION

Over the last few decades more than 200 000 ha have been burned annually by fires in Spain, 41.2 % of which were woods [25]. In the Castilla and León regions 47.6 % of the surface burned was covered with woods. In Palencia province a total of 1 630 ha covered with *Quercus* forest were burned between 1988 and 1996. Therefore, fire is a relatively frequent disaster in Mediterranean climate areas and also very important in Castilla and León within the Iberian Peninsula.

* Correspondence and reprints
deglcg@isidoro. unileon.es

Recolonization of species after a disturbance can be from subterranean organs or by seeds germination [22, 30]. Re-establishment of species from seeds after fire is often from the soil seed bank [31, 33, 37].

The seed bank is defined as the viable seeds and those in a dormant state in the soil of a defined area [4]. The seed bank in the soil contributes significantly to the dynamics of plant communities [9, 10, 15, 20]. It is a reserve from which the population can be renewed [13, 15] and where a certain genetic variability can be found [3].

When seeds arrive on the soil they reach different depths, using complex ways of attaining depth (by percolation with rainwater, their own digging mechanisms, by accumulating successive layers of fallen leaves on top after the seed fall) [26]. Seeds are normally stored in the soil in a latent state and need a stimulus or determined conditions to germinate. Fire plays an important role in germination stimulation. Many species in communities repeatedly subjected to burning show strong dependence on the heat from the fire as a scarification mechanism [19].

When a disturbance such as fire affects an area, the number of seeds that remain viable in the seed bank is reduced and this depends on the extent and severity of the fire. Thus, when an event of this kind occurs to seeds, its effect can tend to a) eliminate a species, b) change its numerical representation in the soil seed bank, c) modify its germination ability aptitude, or d) modify its status as far as inter- and intra-species competition is concerned.

This paper investigates the changes suffered by a seed bank in the soil of a *Quercus faginea* forest 2 years after having undergone burning in the summer of 1991. We have also tried to determine the differences existing in the seed bank at different depths.

2. MATERIALS AND METHODS

The study was carried out in a *Quercus faginea* (gall oak) stand situated close to the city of Palencia, northern Castilla (30TUM7050) in NW Spain, at 790 m above sea level. The stand covers 720 ha and holm and gall oaks alternate. This area represents the most important forestry resources for Palencia city, which provided basic economic support in the past and at present is considered to be an exceptional area for leisure and spare time [24].

This fact has not prevented a substantial decrease of its surface throughout the last few decades. In 1750 this area covered a total of 1 590 ha [8] and nowadays it has decreased by 40 %.

In the past all the resources that this natural area provided were completely exploited (wood, pasture, hunting). In the 1970s all of these activities came to an end owing to social and economic transformations carried out at that time. This has had an influence on the accumulation of fuel, and consequently caused a growing risk of fires. For historic reasons this area is an island of forest vegetation in the area surrounding Palencia and is of ecological importance as it is a conjunction of a basophyle holm oak (*Quercus rotundifolia*) stand in a mesophyte fasciation with many gall oaks, in this studied area *Quercus faginea* represented the 80 % of the forest. The gall oaks are more demanding as far as edaphic humidity is concerned and mix with the holm oaks in an area that has a basic soil with a similar percentage of sand, slime and clay and a lack of organic material. The fact that it has a very compact upper limestone layer means that soil humidity is greater, favouring gall oak development. This area stands upon a calcareous plateau which stuck out because of the erosive process caused by the Carrión river in the sedimentary basin which forms the north plateau.

The study area is climatologically in the Mediterranean region: phytoclimate IV $(VI)_I$ according to the Allue classification [1]. In the area the yearly mean temperature is 11.7 °C and the annual mean rainfall is 351.4 mm [16]. It has the phytosociological attributes of subsclerophyll species that are in transition to sclerophyll formations in this area.

The soils present are inceptisols (Xerochrepts) with good structure and incipient pseudomycelial limestone [11].

In order to determine the influence of fire on the seed bank in the soil two nearby areas were selected, one burned in a fire occurring in the summer of 1991 and the other unburned and used as a control.

Four soil samples measuring 12 × 16 cm were taken in May 1993 from each area at two depths: the surface 0–2 cm and the 2–4 cm layers, after removing the organic forest litter.

These soil samples were placed in trays in a greenhouse for 8 months. The greenhouse temperature was between 14 and 24 °C and the samples were kept damp during the whole study period. The samples have not been stirred. The number of germinated seedlings was counted weekly separating all the possible morphologic types, and they were identified when their morphologic aspect permitted it. For the identification of each species, ordinary keys were used in this sort of study [35, 38].

In order to define the floristic composition of the area ten sampling units each measuring 1 square meter in the burned area and another ten in the control area were carried out. All the herbaceous (annual and perennial) and woody species present in each unit were noted, with their importance in terms of percentage cover in vertical projection, as well as the percentage of bare soil. Plant nomenclature is according to Tutin et al. (1964–1993).

3. RESULTS AND DISCUSSION

Using the data of mean cover values (*table I*) it was determined that the burned area had a species richness of 38, which represents 58 % mean cover. Species richness in the control area was less with a total of 33 species and yet mean cover value was 61 %, that is to say slightly higher but not significantly different.

Fire contributes to increase the number of species during the first years of retrieval. However, throughout the years the number of these species diminishes, and those which are dominant cover a greater area; in this case: *Festuca hystrix*, *Helianthemum cinereum*, *Quercus rotundifolia*, *Koeleria vallesiaca*. The recovery mechanisms used can be of two types: either stump sprouting or seed germination. Both models of simultaneous reproduction are often found in many of the species [5, 6], to such an extent that they help to increase the number of species during the first few years after a fire [5, 7]. Two species most favourably helped by fire in this area are *Brachypodium distachyon* and *Reseda phyteuma*, both using germination as their recovery mechanism. However, *Cistus laurifolius*, whose recovery mechanism is only germination [29] and which is stimulated by fire according to Naveh [22], does not appear in the burned area yet does in the control. This could be due to the fact that the summer fire was very intense and the seeds of this species were altered by fire, which would mean their not being identified in the field samples.

In general, analysing both plots together, burned and unburned (*figure 1*), it was observed that the total number of seedlings present in the upper layer was higher than in the lower layer. In the former we found 29 468 seedlings/m^2 and in the latter 2 617 seedlings/m^2.

Whether from burned or unburned sites, seedlings were more numerous in the upper layer than in the lower layer. This agrees with the findings of González [12], who observed a greater number of seedlings for all her study groups in the upper layer (0–3 cm); Jiménez and Armesto [17] found very few seeds in the samples collected at a depth of (5–10 cm) in a scrub in Chile, as for Valbuena and Trabaud [37] in a *Quercus pyrenaica* community. Also the majority of viable seeds in the seed bank are located in the first few centimetres of soil [12, 20, 26, 28, 36, 37].

Table I. Mean cover (X) and standard deviation (d) of species present in each plot.

	Burnt		Control	
	X	d	X	d
Alysum alyssoides	5.3	4.6	2.7	3
Aphyllantes monspeliensis	0.1	0.3	1.3	3
Asterolinum linum-stellatum	0.1	0.3	0.4	0.9
Cerastium glomeratum	5.6	9.6	2.6	3.1
Coris monspeliensis	0.8	1.7	0.5	1.5
Deschampsia flexuosa	4.8	6.2	13.5	11.6
Euphorbia serrata	1.7	3.1	6.7	6.6
Festuca hystrix	7.8	5.6	22	14.7
Halimium lasianthum	10.5	8.9	10.7	7.3
Helianthemum cinereum	9.1	7.7	10.3	7.4
Koeleria vallesiaca	3	4.6	16	1.8
Linum narbonense	1.7	3.1	7.8	11.9
Lithospermum fruticosum	1	3	1	3
Lithospermum officinale	0.6	1	0.6	1
Logfia arvensis	0.6	1	0.1	0.3
Lonicera etrusca	1.5	4.5	3	6
Moenchia erecta	1.3	3	2.5	4.4
Omphalodes linifolia	1.6	2.1	0.5	1.5
Quercus rotundiolia	7.3	20.9	15	28
Rubia peregrina	1.1	1.6	1.5	4.5
Sanguisorba minor	3.5	3.3	0.5	1
Anthriscus caucalis	1.3	3	0.5	
Aristolochia longa	1	3		
Avenula sulcata	0.3	0.9		
Brachypodium distachyon	15	24.2		
Centaurea sp.	1.5	4.5		
Dianthus sylvestris	1.6	1.6		
Echium lusitanicum	2	4		
Euphorbia exigua	0.3	0.9		
Leuzea conifera	4.9	5.9		
Muscari comosum	0.7	1.5		
Phlomis lychnitis	0.5	1.1		
Potentilla reptans	2.2	3.1		
Reseda phyteuma	11.1	15.1		
Stipa lagascae	3	4.6		
Thymus mastichina	0.2	0.2		
Vulpia ciliata	7.5	22.5		
Achillea ageratum			0.3	0.9
Bromus erectus			0.8	2.4
Cistus laurifolius			1.5	2
Coronilla minima			3	6
Hieracium pilosella			2.8	6.2
Lavandula latifolia			5.5	5.7
Sedum sediforme			5.3	5.1
Teucrium capitatum			0.5	1.5
Thymelaea passerina			0.2	0.6
Thymus zygis			0.5	1.5
Total	58	5.4	61	4.9

The fire can affect the seeds present in the soil as its intensity can profoundly modify the quantity of species seedlings emerging after fire [21].

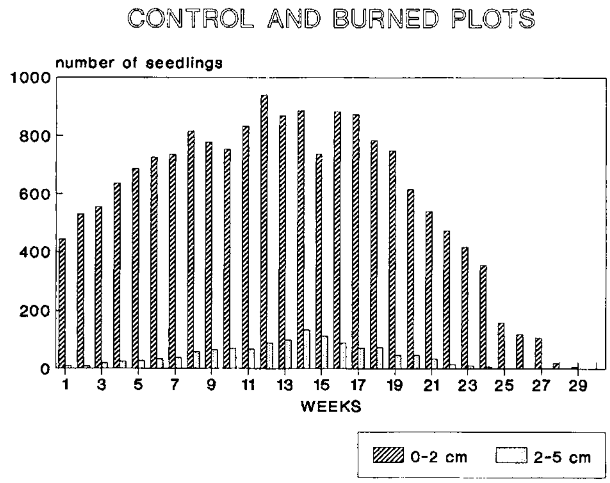

Figure 1. Total number of seedlings counted weekly on both plots in all samples in upper and lower layers.

Table II. Relative abundance of seedlings present in the soil bank of the most representated species in the unburned and burnt areas.

	Control		Burnt	
Species / Depths (cm)	0–2	2–5	0–2	2–5
Alysum alyssoides	0	0	0.3	0
Brachypodium distachyon	0.7	18.2	1.2	3.3
Cerastium glomeratum	49.3	62	36.2	63.3
Centaurea sp.	2.6	9.1	20.5	10
Koeleria vallesiana	25.4	0	8.6	8.9
Muscari comosum	0.5	0	0.2	0
Omphalodes linifolia	3.2	6.1	10.6	1.1
Sedum sediforme	5.1	3	2.5	5.6
Spergularia rubra	0.3	0	0.3	0
Thymelaea passerina	1.5	1.6	17.5	7.8
Others	11.4	0	2.1	0
Total	100	100	100	100

The total number of seedlings in the burned area (16 015 seeds/m^2: 14 648 seeds/m^2 in the upper layer and 1 367 seeds/m^2 in the deeper layer) is much higher than in the control area (7 070 seeds/m^2: 5 820 seeds/m^2 in the upper layer and 1 250 seeds/m^2 in the deeper layer) (*figure 2*). This is due to two different aspects: first fire helps to create a potentially better area for the development of seedlings and during the first steps these seedlings do not compete for light and other abiotic factors. This fact determines that the plants which survive must be heliophilic. Secondly, many of the species present in the area need heat from a fire to crack the seed coat and favour germination. It has been shown by various authors that fire stimulates germination in many species [3, 18] as the thermal shock from the fire breaks the external coat of the seeds. Keeley [19] points out that the germination percentage increase occurs in the first growing season after the fire. However, it has been observed in this area that the germination increase continued during the second year after the fire.

Table II shows the relative abundance of the seedlings of the different species that appear in the soil seed bank in both areas and at the different depths. There is a

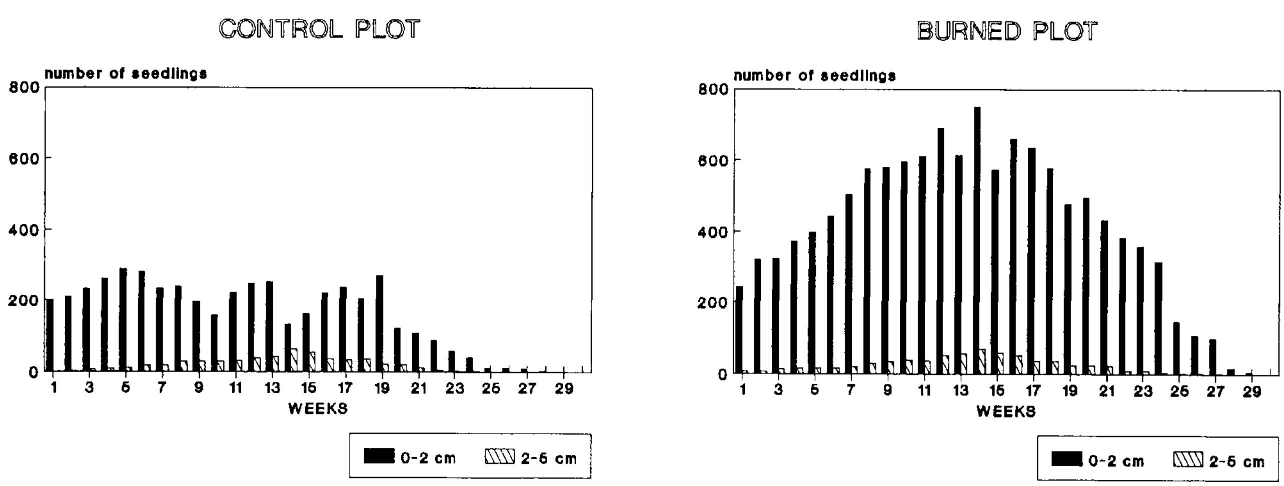

Figure 2. Seedlings from seed bank on both control and burned plots in all samples at different layers.

a)

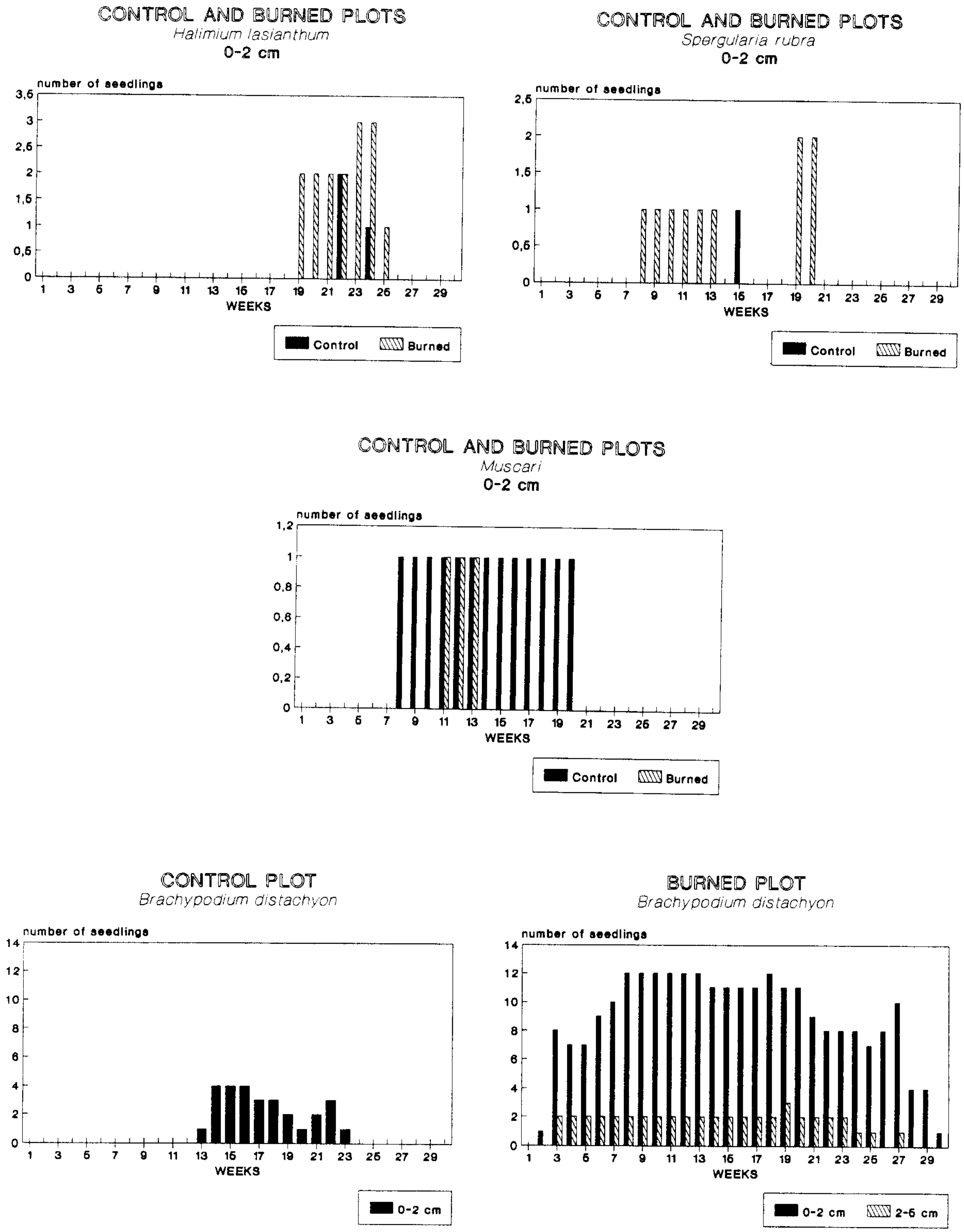

Figure 3.a. Number of seedlings of *Halimium Lasianthum, Spergularia rubra, Muscari* and *Brachypodium distachyon* counted weekly during the period studied.

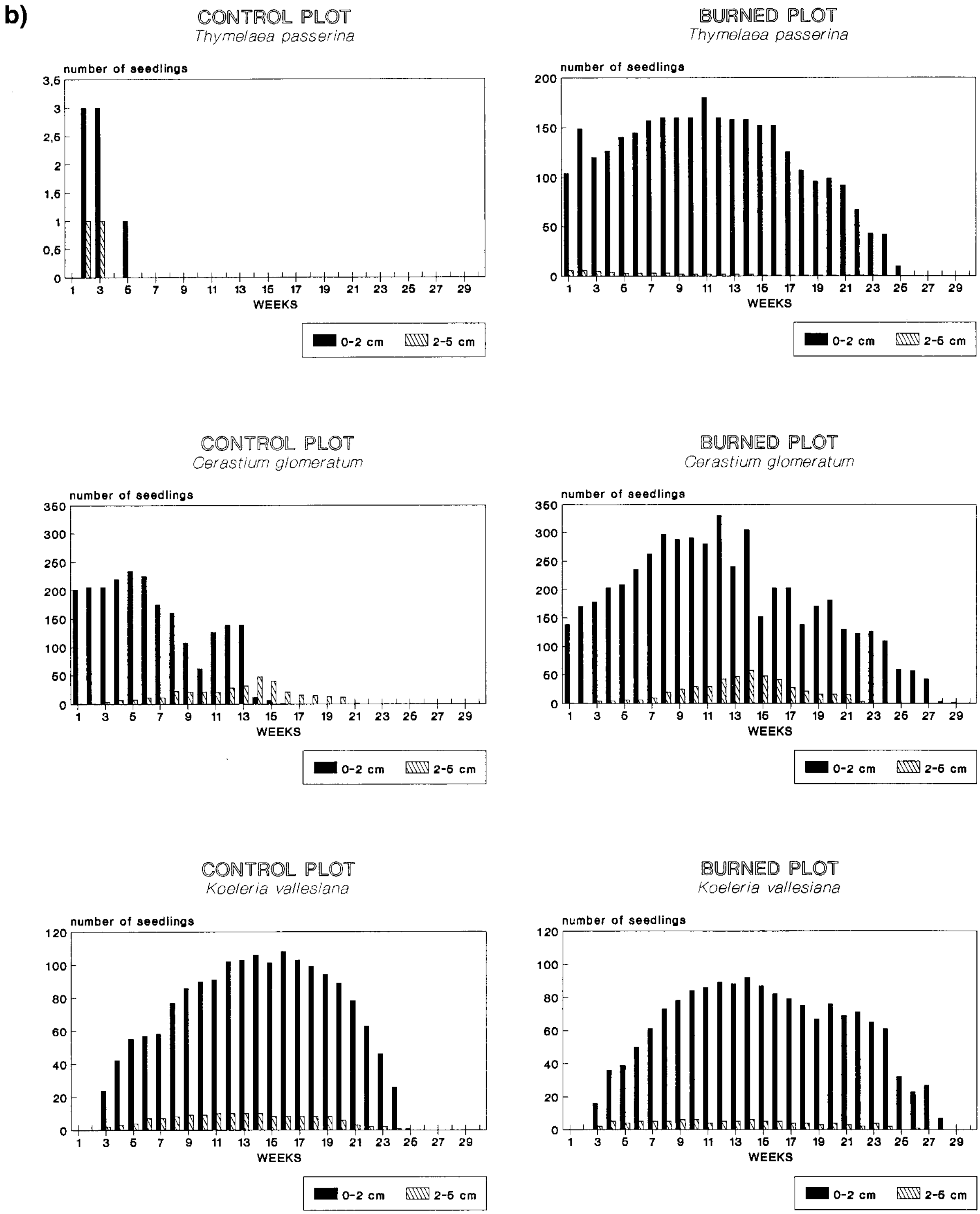

Figure 3.b. Number of seedlings of *Thymelaea passerina, Cerastium glomeratum* and *Koeleria vallesiana* counted weekly during the period studied.

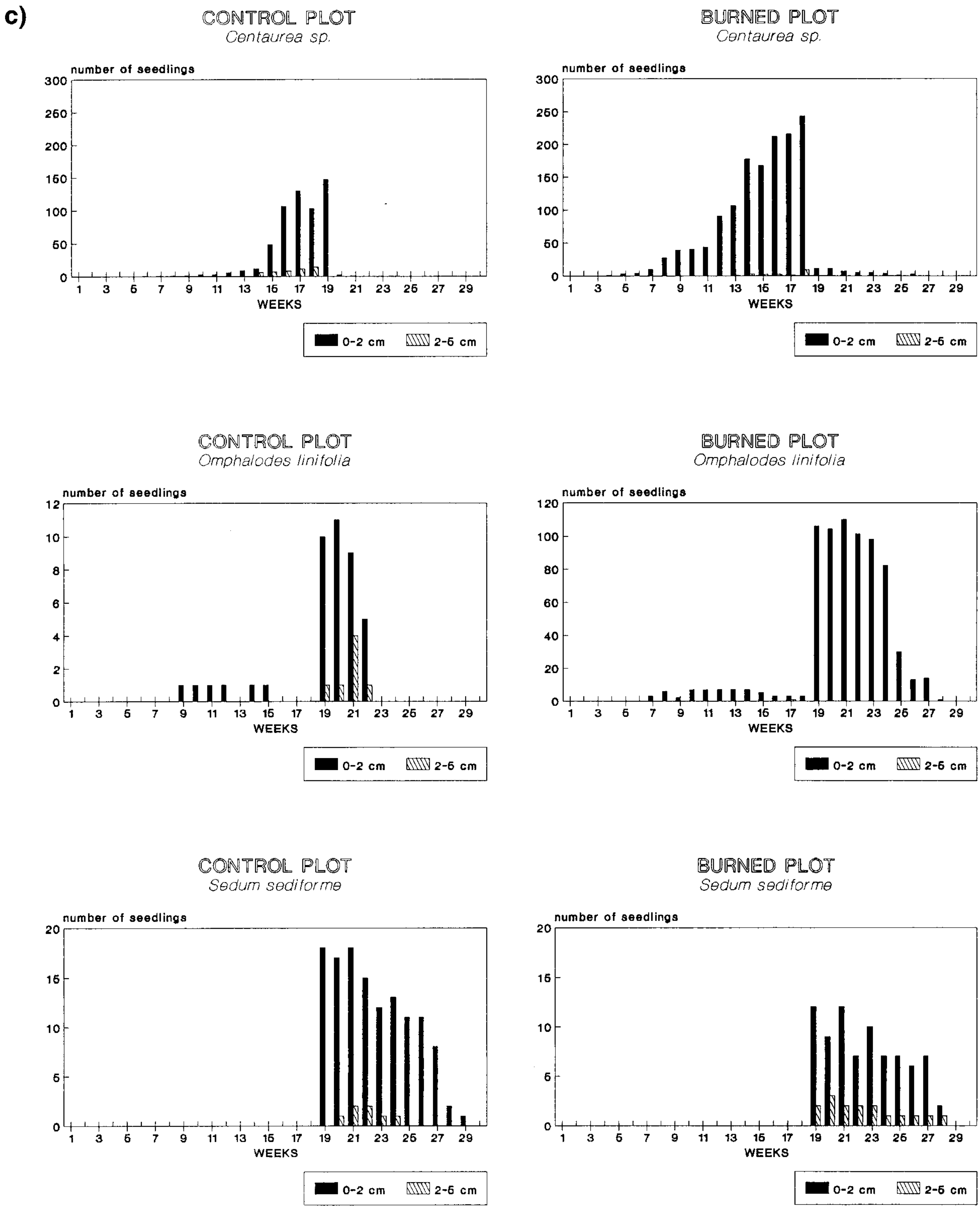

Figure 3.c. Number of seedlings of *Centaurea*, *Omphalodes linifolia* and *Sedum sediforme* counted weekly during the period studied.

greater number of species germinating in the burned area than in the control. The same occurs if the number of species germinating in the surface stratum is compared with those that do so in the deep one.

Thirty-five species were found, corresponding to 16 families, in the total samplings of the seed bank analysed. The most represented families were: Caryophyllaceae, Gramineae, Boraginaceae, Crassulaceae and Compositae. Twenty-eight species were found in the samplings of the control area and 16 species were observed in the burned area.

The species with the highest number of seedlings found in both areas (burned and control) was *Cerastium glomeratum*. This is an annual herbaceous species that presents as regenerative strategies: seasonal regeneration by seed. The type of seed bank is type 3, a small amount of seed persists in the soil but concentrations of seed in the soil are only high after seed has just been shed [14].

The species *Centaurea* sp. and *Thymelaea passerina* deserve a special mention in the burned area and surface stratum because of their high germination percentages. *Thymelaea passerina* does not appear in the field sampling carried out in the burned area, possibly due to the presence of other species with high cover percentages impeding its germination via competition mechanisms or possibly because it needs environmental conditions of humidity and temperature not present in the field.

Spergularia rubra germinates in the surface stratum of the seed bank of the burned and control areas in very small percentages, although it was not detected in the vegetation samplings from both areas. It is an annual herbaceous species with a persistent bank of buried seeds or spores. The type of bank is 4 (with a large bank of persistent seeds in the soil throughout the year) [14]. Lebreton et al. [20] indicate that the pool of seeds able to germinate and vegetation present in the area are usually dynamically united. However, biotic and abiotic factors, among which Keeley [19] notes light, have a significant influence on seed germination in some species, reaching the stage of inhibiting the process when there is a manifest competition for light.

On analysing the time taken to begin germination, once in the greenhouse, it can be observed that the fire does not accelerate germination start (*figure 3a–c*). Each species begins to germinate at different times, but these times are similar for the burned and control samples, except in the case of *Brachypodium distachyon* which benefits greatly from the fire as far as the number of germinated seeds and start of germination are concerned.

The species that begin to germinate later are: *Centaurea* sp., *Omphalodes linifolia*, *Sedum sediforme*, *Muscari comosum*, *Halimium lasianthum* and *Spergularia rubra*.

The role of fire as an important factor in the structure and function of Mediterranean-type ecosystems has been recognized for some time [2]. The numerous adaptations present in plants of Mediterranean-type ecosystems indicate that fire has been a strong selective force [23, 27].

Fire produces an increase in species richness in the first stages after burning, as it eliminates the competition exercised by dominant species at mature stages. This increase in specific richness is due to the fact that vegetative sprouting benefits significantly [5] as does the germination of many species whose seeds are in a dormant state in the seed bank. This positive effect on germination is kept up until the second year after the fire. The viable seed bank of an area is generally located in the first few centimetres of soil.

The species identified in the seed bank are predominantly herbs. According to other results, there exists an important bank in the soil, and those seeds do not germinate in the absence of disturbance [34, 37]. However, there is not a close relation between the species that appear in the epigious vegetation and the seedlings that germinate out of seed in the soil. This agreed with what Trabaud pointed out [32].

4. CONCLUSION

The fire helped to increase the number of species which appeared in the surface vegetation present in the *Quercus faginea* forest during the first two years after the fire. However, as time passed, the typical dominant species displaced some of the new ones. These latter species are called opportunist; in this way the specific richness diminishes. The number of germinated species coming from the soil seed bank was very high.

There was not a great coincidence between the species richness of the surface vegetation and that of the soil bank. However the species which had the highest cover values among the surface vegetation were the following: *Cerastium glomeratum, Brachypodium distachyon, Koleria vallesiaca, Sedum sediforme*. The species above mentioned also appeared very frequently in the soil seed bank.

The fire helped the germination of seeds present in the soil in contrast with the number of seeds which germinated in the control area. In the same way, the greatest number of germinated species was always in the surface layer, not in the deeper one.

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