ANNALES DE L'UNIVERSITÉ DE PROVENCE

BIOLOGIE - ÉCOLOGIE MÉDITERRANÉENNE

tome VIII - numéro 3-4 - 1981

Extrait

éditions de l'université de provence

Biologie - Ecologie méditerranéenne
Tome VIII, n° 3-4, 1981, pp. 119-128

EARLY STAGES OF REGENERATION AFTER FIRE IN A PHRYGANIC ECOSYSTEM (EAST MEDITERRANEAN). I. REGENERATION BY SEED GERMINATION

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ABSTRACT : *The first post-fire year a burned phryganic ecosystem in Greece is typified by a flush of seed germination and seedling growth not seen in the unburned area.*

Applications of various heat treatments to unburned phryganic soil indicated that the seeds of some species, resident in it, especially Cistus spp., are released from dormancy by a direct - mechanical rather - effect.

Bioassays with heated and unheated soil samples and planted seeds appeared no effect of inhibitors possibbly present in the unheated soil.

RESUMÉ : *La première année après le feu, l'écosystème des phrygana incendié est caractérisé par une augmentation de la germination des semences et de la croissance des plantules.*

Les applications des différents traitements de chaleur au sol non incendié démontrent que les semences des quelques espèces présentes dans le sol, spécialement Cistus spp, sont libérées de la dormance par une action mécanique directe.

Les bio-essais avec échantillons chauffés et non-chauffés, et semences plantées n'ont démontré aucune action des inhibiteurs probablement présents dans le sol incendié.

INTRODUCTION

The severe summer drought combined with high temperatures has a result the frequent fires in Mediterranean-type ecosystems. Long ago (SHANTZ, 1947) these ecosystems were characterized as "fire-type" or "fire climax" because of their long subjection to recurring fires. The numerous adaptations of plants dominating such habitats indicate that this factor has been a strong selective force for many years and systems can be considered also as "fire-induced" or

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"fire-adapted" (JEPSON, 1930 ; NAVEH, 1973 ; BISWELL, 1974). Plant adaptations are therefore homeostatic responses of the ecosystems, following fire-induced disturbances.

According to NAVEH (1975) positive feedback responses are those which help in overcoming the fire hazard and its after-effects by increased physiological activity. This is expressed by vegetative, fire-stimulated resprouting and/or fire-stimulated seed germination and post fire flower and seed production. As negative feed back responses, on the other hand, can be regarded all those defense mechanisms which enable the avoidance of the fire hazard, either by direct fire tolerance of seeds or plant organs or by their reduced physiological activity during critical fire period.

Information available today on homeostatic responses of mediterranean-type ecosystems are mainly coming from California (CHRISTENSEN and MULLER, 1975 ; HANES, 1971 ; etc...), Israel (NAVEH, 1973, 1974) and S. France (TRABAUD, 1973). Possibly the explanation for this defficiency can be found in the general feeling that fire is always something criminal and catastrophic, and this idea has not permitted search for other more sound ecological aspects.

Working during last years on a broader project on structure, function and management of greek phryganic ecosystems, we consider of interest to study their positive feedback responses to fire, and in this paper we present our first data on fire's effect on seed germination.

Experimental site

A phryganic ecosystem found at Mount Hymettus, near Athens University Campus is the area under study. It burned accidentally in July 1976. Some data on structure and function of the system before fire are already published (MARGARIS, 1976).

A.- MATERIALS and METHODS

I.- Field observations

Throughout a two years period burned and unburned sites were frequently surveyed. Seedlings of woody plants dominating the ecosystem were counted in ten 1 m^2 plots randomly selected in burned site.

II.- Laboratory experiments

Two series of experiments were planned. By the first one we checked the effect of high temperatures on seeds resident in the unburned soil. With the second series we checked the effect of high temperatures on possible soil toxicity with a bioassay.

a) Effect of heat on seeds resident in the soil

The effect of uniform heat applied to soil collected from the unburned site was examined in the following way : Ten separate soil samples of about 500 g each, were collected in June 1977, from the upper 5 cm of soil excluding the litter layer. Samples were thoroughly mixed and screened through 0,4 cm sieve. Forty five subsamples of the main sample (each 110 g) were placed in aluminium containers and separated in 7 groups of 6 samples each. The 7 groups were devided into 2 subgroups of 3 samples each. The seven groups were corresponding to the seven heat treatments tested, while the subgroups to the heating duration. These were 60, 80, 100, 120, 40, 150, and 200°C for 30 and 60 minutes. Three of the 45 samples were not heated for control (Table 1). After the heat treatment the samples were layered over a 4 cm bed of sand in plastic containers of 15 cm diameter and watered as needed. The plastic containers were placed in a short day room (8 hrs light-16 hrs darkness) with a temperature gradient of 18-24°C.

Table 1.- *Heating treatment to the main soil sample*

MAIN SAMPLE							
	Heating temperatures °C	Subgroup 1 Heating time 30 min			Subgroup 2 Heating time 60 min		
GROUPS	60	+	+	+	+	+	+
	80	+	+	+	+	+	+
	100	+	+	+	+	+	+
	120	+	+	+	+	+	+
	140	+	+	+	+	+	+
	150	+	+	+	+	+	+
	200	+	+	+	+	+	+

Seedlings counts were carried out every day during a month till their numbers became constant.

b) Bioassay for soil toxins inactivation by heat

Part of the initial sample soil collected for the above experiment was treated separately in the following manner. A subsample of it was heated at 100°C for 60 min and an other was the control. Both were separated in three groups of three samples each, of about 100g soil and placed in alluminum containers of 6 x 17 cm. Twenty five seeds of *Zea mays*, *Pisum sativum* and *Citrullus lanatus* were sown in each of the three groups respectively. The incubation was run in a long day room (16 hrs day and 8 hrs darkness) with a temperature gradient of 28-22°C. At the end of a 20 days period we measured the dry weight of shoots and roots as well as the total length of shoot (Table 2).

Table 2.- *Plan for the bioassay treatments*

TREATMENTS	GROUPS		
	Zea mays	*Pisum sativum*	*Cutrullus lanatus*
HEATED	+	+	+
SAMPLE	+	+	+
(100°C, 60 min)	+	+	+
UNHEATED	+	+	+
SAMPLE	+	+	+
(Control)	+	+	+

B.- RESULTS AND DISCUSSION

a) Field observations

Six months after fire, and three months after first autumn rains, seedlings started appearing. In most places they appeared in groups. Figure 1 contains data on seedling appearance and survival. It is obvious that the greater seedling numbers are that of *Cistus* spp followed by those of *Sarcopoterium spinosum* (L) and by the much lower numbers of *Phlomis fruticosa* (L) and *Euphorbia Euphorbia acanthothamnos* (Heldr. & Sart ex Boiss). Of course after some time gradual decrease in the total seedling numbers happened.

Comparing numbers of seedlings from burned site with those from the unburned given by ARGYRIS (1977) *S. spinosum* and *Cistus* spp appear a multiplication in their numbers 10 and 20 times respectively after fire while *P. fruticosa* and *E. acanthothamnos* decreased them by 7 and 60 times.

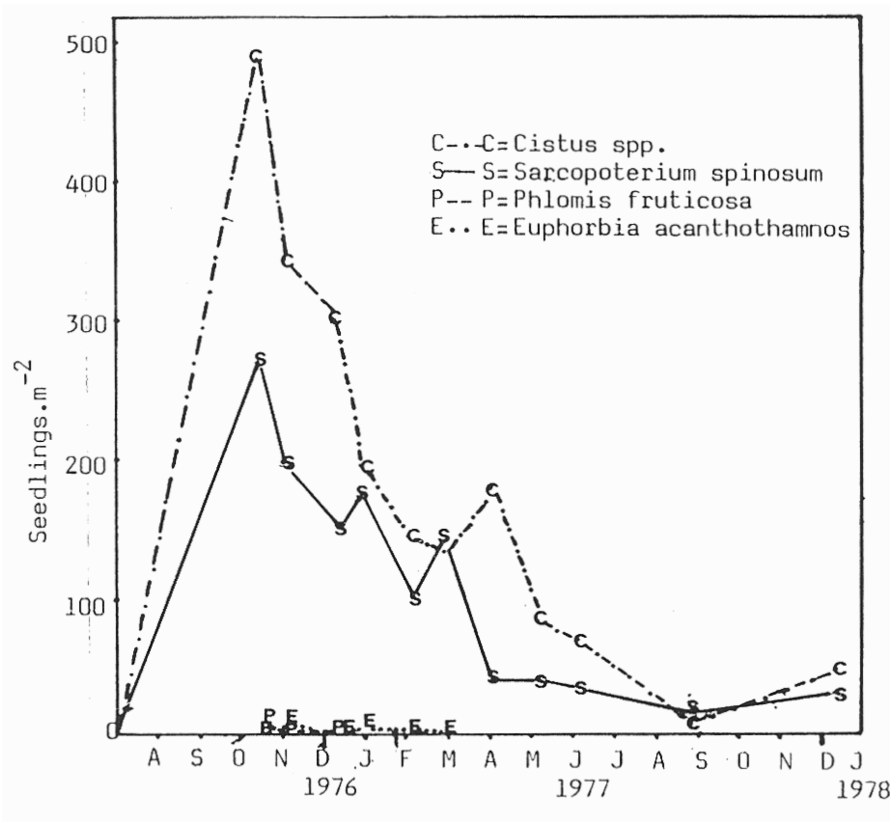

FIGURE 1.- SEEDLING NUMBERS PER M² OF THE DOMINANT PHRYGANIC SPECIES.

The second post-fire year there is not so great seed germination. Only 10 seeds per m^2 *Cistus* spp and 3 seeds per m^2 *S. spinosum* appeared in November 1977.

It seems that in the second post-fire year there was not such great seed offer since resprouts of *E. acanthothamnos* and *S. spinosum* flourished and fruited in very low numbers while *P. fruticosa* flourished on the second year. *Cistus* spp seedlings flourished from the first year, but in low levels. So, we can attribute seedlings appearance in the second year mainly to seeds resident and dormant in the soil before fire.

Our data are in good agreement with those previously published. So, in our observations seedling mortality of *Cistus* spp and *S. spinosum* was about 90%. Same percentage is given by ARGYRIS (1977) for the unburned site. PAPANASTASIS (1977) working in North Greece gave the numbers of 1900 seedlings per m^2 in *S. spinosum* 5 months after fire and 200 seedlings per m^2 of *Cistus salviifolius* and *C. monspeliensis* after 9 months. *Sarcopoterium* populations decreased 73% 4 months later, while *Cistus* spp by 31% on the second 3rd post-fire year.

NAVEH (1974) refers that *Cistus* species on Israel garrigue show a peak in seedling appearance after fire followed by a strong decrease in their density probably because of the drought and competition. In the Californian chaparral, MONTGOMERY and STRID (1976) observed the same phenomenon for the *Cistus* species.

Increased seed germination after fire was observed also in other mediterranean-climate systems. CHRISTENSEN and MULLER (1975) working on Californian chaparral cited many data about *Adenostoma fasciculatum* after a fire. According to them the richness of ash in nutrients favoured seedling growth, while their survival under the shrub cover was inhibited by the toxins produced from the shrubs. VOGL and SCHORR (1972) concluded that the patterns of distribution, the succession and especially the appearance of seedlings of herbs and shrubs is mainly defined by the presence or absence of ash and the relative changes on pH.

PURDIE (1977) working on Mediterranean ecosystems of Australia reports that all species, except the geophytes, regenerated from seeds the first post-fire year. Although many seeds destroyed by fire's action, the germination in the majority of the species was higher after fire. This was attribued to the direct thermal action on seed and the removal of some inhibitors existing in the unburned site.

WHITTAKER and GIMINGHAM (1963) observed an increase in germination of *Calluna vulgaris* (heathland) seeds after fire.

Table 3 contains some data with features about seedlings presence and survival in California and Greece (Hymettus Mt.), from which we can see that some species have a full success in their seedling establishment, some a moderate one, while other disappear from the site.

TABLE 3.- QUALITATIVE CONCLUSIONS ABOUT LIFE HISTORY FEATURES OF THE DOMINANT SPECIES OF CALIFORNIAN CHAPARRAL AND THE PHRYGANIC ECOSYSTEM STUDIED IN GREECE (HYMETTUS).
Numbers refer to the following investigators : 1. HORTON and KRAEBEL (1955) ; 2. PLUMB (1961) ; 3. PLUMB (1963) ; 4. PATRICK and HANES (1964) ; 5. KINUCAN (1965) ; 6. HANES and JONES (1967) ; 7. SPECHT (1969) ; 8. HANES (1971) ; 9. VOGL and SCHORR (1972) ; 10. BRADBURY (1974) ; 11. DODGE (1975).

(R) : Resprouting *(NR) : Nonresprouting*

SPECIES		Adult mortality after fire	Relative seedling establishment after fire	Early seedling mortality	Mortality of shrubs later in succession
Arctostaphylos glauca	(NR)	complete[1,8]	high[1]	moderate[1]	low[1]
A. glandulosa	(R)	very low[2]	low[1,6,9]	high[1,9]	low[1]
Ceanothus gregii	(NR)	complete[8,9]	very high[9]	low to moderate[9]	moderate to high[8,10]
C. leucodermis	(R)	moderate[8]	moderate [1,9]	low[1,9]	moderate to high[1,7,8]
Adenostoma fasciculatum	(R)	moderate to high[1,2,5,8,11]	high[1,6,9]	moderate[1]	moderate[4,8]
Quercus dumosa	(R)	very low[3,5]	none[1]	unknown probably high	low[4]
Phlomis fruticosa	(R)	low	very low	high	
Sarcopoterium spinosum	(R)	low	high	low to moderate	
Euphorbia acanthothamnos	(R)	low	low	high	
Cistus spp.	(NR)	complete	very high	low to moderate	
Thymus capitatus	(NR)	complete	very low	very high	

Increased seed germination observed after a fire can be attributed in three, at least, different reasons (see review by MARGARIS, 1981). The first, fire acts mechanically rupturing seed coats, second the inactivation of heat-sensitive inhibitors present in the soil and third an indirect mode of action through the activation of the phytochrome system. In our paper we cheked, with laboratory experiments, the first two hypotheses.

b) Laboratory experiments

Results dealing with the effect of uniform heat treatment to seeds resident in unburned soil are presented in Fig. 2 and 3. In Fig. 2 are plotted data concerning with *Cistus* spp germination which shows that a moderate heat treatment activates germination. So, in the temperature of 100°C for 30 min the germination increased 7 times. In 80°C for 60 min the germination was lower, while in 100°C for 60 min and 80°C, 100°C for 30 min the increase was between 5 and 4 times. Higher temperatures resulted in a decrease in numbers of seedling appearance (e.g. in 140°C for 30 min fewer seedlings than the blank, 140°C for 60 min and 200°C for 30 min or 60 min no germination) or remained at the same levels (120°C for 60 min). Soil heating in 60°C for 30 or 60 min showed no significant difference in the percentages of seed germination comparing with that of the blank. There was a fluctuation in the beginning of germination, but a convergence in the period of the highest one, between 4th and 12th day for all the treatments.

Seeds of other species, than *Cistus* spp (Fig. 3) showed negative relations with soil heating, as far as seedlings numbers in the blank were higher than those in any other test, except that in 60°C for 30 min, where germination is triplicated.

Out results are in accordance with those relatives of other investigators. So, PAPANASTASIS and ROMANAS (1977) tested the effects of various heat treatments on phryganic seeds (50-75-100-125 and 150°C for 1-30 min). They concluded that the germination increased by heating at 100-125°C in the *S. spinosum* in samples taken from N. and S. Greece respectively. Seeds of *P. fruticosa* germinated at 50°C for 5 min, temperature which normally occours on soil surface during the summer months.

McPHERSON's and MULLER's (1969) experiments have shown significant differences on germination in seeds of *Adenostoma fasciculatum* by soil heating in 80°C, while those of CHRISTENSEN and MULLER (1975) 3-4 times increase in temperatures of 100-120°C for 60 minutes.

Concerning with the present data, the first hypothesis, according to which fire acts mechanically rupturing seed coat, seems to apply in our case, especially for *Cistus* spp since under laboratory conditions artificial rupture of seed coats promotes maximum germination (ARGYRIS, 1975). Also in California, according to CHRISTENSEN and MULLER (1975) seeds of *Emmenanthe penduliflora, Eucrypta chrysanthemifolia, Phacelia grandiflora* and *Allophylum glutinosum* rarely germinate under the shrub cover, but are common in artificial clearings and burned areas. Furthemore, germination of fresh seed without any pretreatment, even under favourable moisture conditions, was quite low. This was true inspite of their being fully imbibed. By carefully exposing the radicle, however, 60%-100% of the seed were made to germinate.

The poor germination of seeds of these species may be due to mechanical restriction of the embryo by the surrounding tissues. Germination may then be dependent on gradual deterioration of these tissues in the soil. When decomposition is sufficient to allow germination, subsequent dormancy may result from other factors (e.g. to toxins). For this reason we checked with a bioassay the possible effect of heat on toxins present in soil. According to our data (Table 4) no inhibitors are present in soil which are inactivated by heat at least for the growth of the bioassay plants *Zea mays, Pisum sativum* and *Citrullus lanatus*.

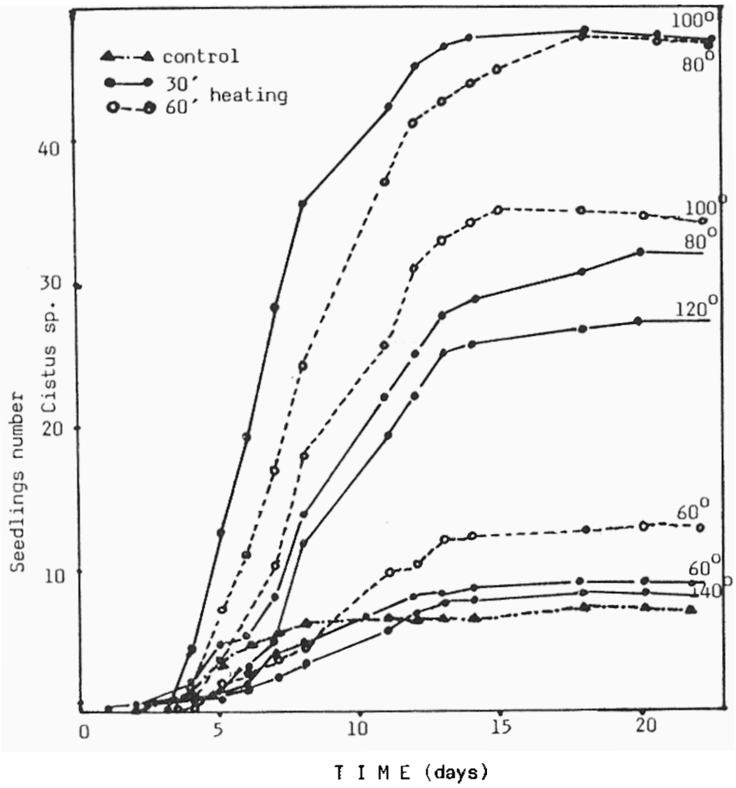

FIGURE 2.- CISTUS SPP SEEDLINGS GERMINATED FOR A PERIOD OF 25 DAYS IN SOIL HEATED FOR 30 OR 60 MIN AT 60, 80, 100, 120, AND 140°C.

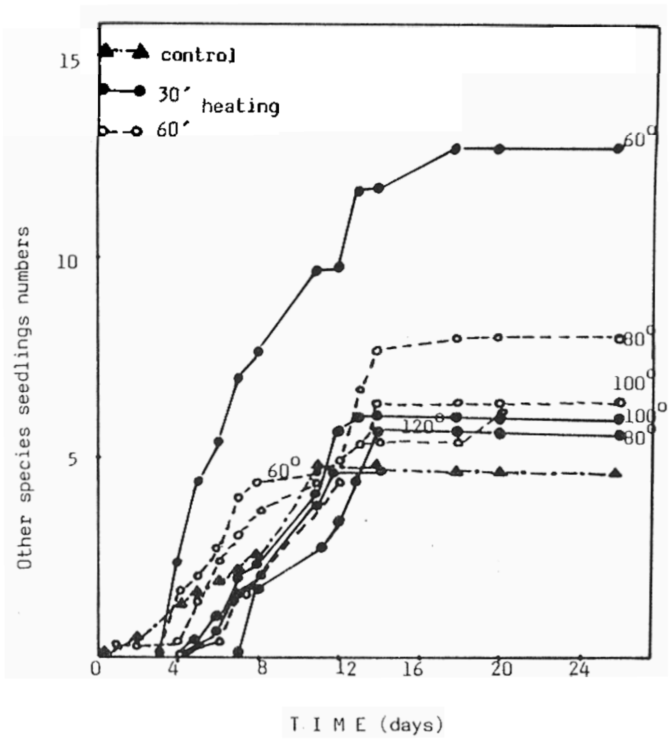

FIGURE 3.- OTHER SPECIES SEEDLINGS GERMINATED FOR A PERIOD OF 25 DAYS IN SOIL HEATED FOR 30 OR 60 MIN AT 60, 80, 100, 120, AND 140°C.

So, the second hypothesis based on the presence of toxins seems not to apply to our system.

TABLE 4.- SEEDLING GROWTH FEATURES, EXPRESSED AS SHOOT LENGTH AND WEIGHT, OF ZEA MAYS, PISUM SATIVUM AND CITRULLUS LANATUS SPECIES IN HEATED AND UNHEATED SOIL.

SPECIES	SEEDLING SHOOT LENGTH (cm)		SEEDLING SHOOT WEIGHT (g)	
	HEATED SOIL	UNHEATED SOIL	HEATED SOIL	UNHEATED SOIL
Zea mays	36,90 ± 0,93	35,69 ± 0,93	0,12 ± 0,005	0,11 ± 0,006
Pisum sativum	10,62 ± 0,41	11,50 ± 0,96	0,05 ± 0,002	0,05 ± 0,004
Citrullus lanatus	15,54 ± 0,46	13,52 ± 0,41	0,06 ± 0.003	0,04 ± 0,003

Reçu pour publication en Juin 1981.

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