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Post-fire regeneration in *Pinus brutia* forest ecosystems of Samos island (Greece): 6 years after

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Abstract

Post-fire regeneration of pine (*Pinus brutia*) forest of Samos island was investigated 6 years after the great wildfire of August 1983. Results and observations concerning floristics of woody plants and pine sapling demography are presented and discussed in relation to those gathered during the first two post-fire years and already reported in a previous publication.

By 1989, most of the burnt area was dominated by two species of *Cistus*, the vegetation being a dense shrubland of phryganic and evergreen species. The overall density of 6-year-old pine saplings was around 0.15 plants m^{-2}, adequately high for natural reforestation in most sites. The survival of saplings was considerable: 43% of the pine seedlings tagged in May 1984 were found alive. The height of 6-year-old pine saplings was largely variable with an overall average around 60 cm.

The striking discovery of numerous, very short (10-20 cm) saplings, evidently suppressed by neighboring vegetation, led to the postulate that a pine sapling bank may be formed during the early post-fire recovery stage. Since pine seed supply during this stage is absent or scarce, a pine sapling bank may be proven an important or indispensable adaptative strategy for the regeneration of a burnt Mediterranean forest.

Keywords: fire, growth, Mediterranean forest, *Pinus brutia*, regeneration, sapling bank, survival.

Résumé

La régénération de la pinède (*Pinus brutia*) de l'île de Samos a été étudiée 6 ans après le grand incendie d'août 1983. Les résultats et observations relatifs à la floristique des ligneux et à la démographie des jeunes pins sont présentés et discutés en relation avec ceux qui avaient été rassemblés au cours des 2 années suivant l'incendie et consignés dans une publication antérieure.

En 1989, la plus grande partie de la zone brûlée est dominée par deux espèces de *Cistus*, la végétation étant un maquis dense d'espèces phryganiques et persistantes. La densité globale de jeunes pins de 6 ans est d'environ 0,15 plant par mètre carré, ce qui est habituel, dans la plupart des sites, pour une reforestation naturelle. La survie des jeunes plants est très importante : 43 % des jeunes pousses de pins marquées en mai 1984 ont été retrouvés vivants. La hauteur des jeunes pins de 6 ans est très variable, la moyenne générale étant d'environ 60 cm.

La découverte surprenante de nombreux petits plants de 10 à 20 cm, manifestement réprimés par la végétation environnante, amène à supposer qu'une banque de jeunes pins peut se former au cours du stade de reprise suivant immédiatement l'incendie. Dans la mesure où le stock de graines est absent ou rare au cours de ce stade, une banque de jeunes pins peut constituer une stratégie adaptative importante voire indispensable à la régénération d'une forêt méditerranéenne brûlée.

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INTRODUCTION

The eastern Mediterranean pine (*Pinus brutia* Ten.) is a tree of great ecological and economic importance for the eastern Mediterranean rim (Panetsos, 1981; Nahal, 1983, 1984). Its heliophilous nature has been well known since Theophrastus: "the pine likes the sun and does not grow at all in shady places or grows there poorly" (*De Causis Plantarum*, Book II.7.2). It is only found in the Mediterranean Basin and participates in various bioclimatic associations (Nahal, 1983, 1984). *P. brutia* dominates most of the forests of Samos, a large island of Greece at the eastern-central part of the Aegean Sea. The shrub understorey of the forest ecosystems of Samos differs from site to site but is always floristically rich, mainly comprised by numerous evergreen sclerophylls (maquis) and phryganic subshrubs.

Similar to the other two groups of Mediterranean-type ecosystems (namely maquis and phrygana), pine forests in the Mediterranean rim are well known to be highly flammable. Recurrent wildfires are natural events and are considered as an integral part of the Mediterranean-type environment. Moreover, it is already well established that many plant species dominating these fire-prone ecosystems have evolved numerous adaptation mechanisms, particularly concerning post-fire regeneration (Naveh, 1975; Kruger, 1983; Trabaud, 1987).

In a previous work, the early regeneration of pine forest ecosystems of Samos island was followed during the first two years after the destructive wildfire of 7-9 August 1983 (Thanos *et al.*, 1989). In that work both post-fire floristics and pine seedling demography were investigated. The major conclusion reached was that pine seedling emergence, establishment and survival were significant and predictably adequate for complete natural reforestation, for most of the sites of the area burnt. It was also found that ecosystem recovery was additionally characterized by both a prolific resprouting and a massive seed germination of *Cistus* spp. (and of numerous legumes, as well). The present investigation is an update on the *P. brutia* forest regeneration 6 years after the fire, with particular emphasis on growth, density and survival of pine saplings.

MATERIALS AND METHODS

Observations and measurements were carried out during October and November 1989 at various sites of Samos island, in the area that had been burnt during the great wildfire of 7-9 August 1983. All five sites visited in this study were among those investigated previously (Thanos *et al.*, 1989; tab. V) and their characteristics are given in table I. The botanical nomenclature of this work follows *Flora Europaea* (Tutin *et al.*, 1964-1980).

Table I. — *Site description. All sites at least* 1 *ha large, on calcareous rocks, at the south-western ranges of Mt Ambelos (in the region surrounded by the villages Pyrgos, Platanos, Koumeika and Neohorion).*

Site	Altitude (m)	Slope (°)	Exposure
A	400-600	25	NE (A_1)-N (A_2)
B	350-600	30	S-SW
C	300-350	15	S
D	200-250	20	E-NE
E	350-500	20	S-SE

The meteorological data of Samos island were furnished by the National Meteorological Service of Greece. Figure 1 shows the Gaussen (GAUSSEN, 1954) ombrothermic climatic diagram (pooled data

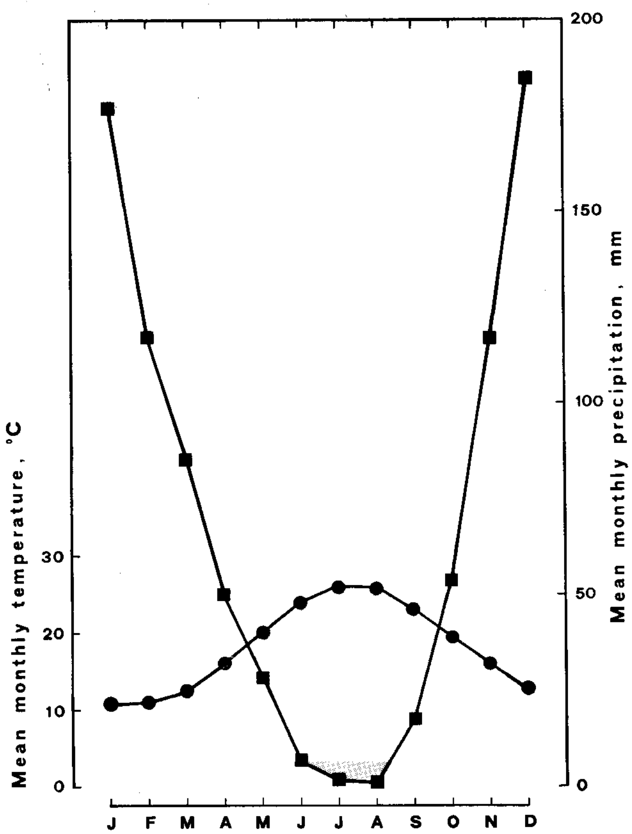

FIG. 1. – The ombrothermic climatic diagram (Gaussen diagram) of Samos island. The xerothermic period is shown shaded.

for the period January 1953-August 1983). The mean yearly precipitation is 836.6 mm and the xerothermic season of Samos is shown to occur (to a varying extent) during the period May-September. According to the formula of Emberger (EMBERGER, 1971), a value of 139.6 was computed for the pluviothermic quotient Q and the Mediterranean-type climate of Samos can be further characterized as mild and subhumid. However, it must be taken into account that the meteorological station of Samos is situated at sea level, at the local airport (in the rather dry, south-eastern part of the island). A comparison of the rainfall data, for the period September 1983-August 1984, to those of a rather rudimentary station located at the village Vourliotes (altitude ca. 400 m) showed a dramatic increase of 69% in the latter site (the total precipitation being 1,753.0 mm) due to the considerably higher amounts of rain during the wet months.

Height and cover measurements were carried out on a number of randomly taken young pine plants. The density of pine saplings was determined with randomly sampled areas (circles of 1 m radius, i.e. 3.14 m^2 each). Values are generally reported as means ±SE (standard error). The number *n* of individual saplings measured and areas surveyed in each case are properly indicated in the appropriate tables.

Survival measurements were performed by counting the same seedlings which had appeared during the first post-fire rainy season and had subsequently been tagged with plastic rings, in the spring of 1984 (THANOS *et al.*, 1989). Due to the great difficulty of respotting the particular plots, only 3 of the 12 burnt sites, initially established, were surveyed. Nevertheless, these sites were the most important ones since they comprised about 63% of the pine seedlings marked (288 out of a total of 452); thus the survival estimate refers to that particular part of the initial seedling population.

RESULTS

The climatic conditions that prevailed throughout the post-fire period 1983-1989 are illustrated on a monthly basis in figure 2. In comparison with the pre-fire

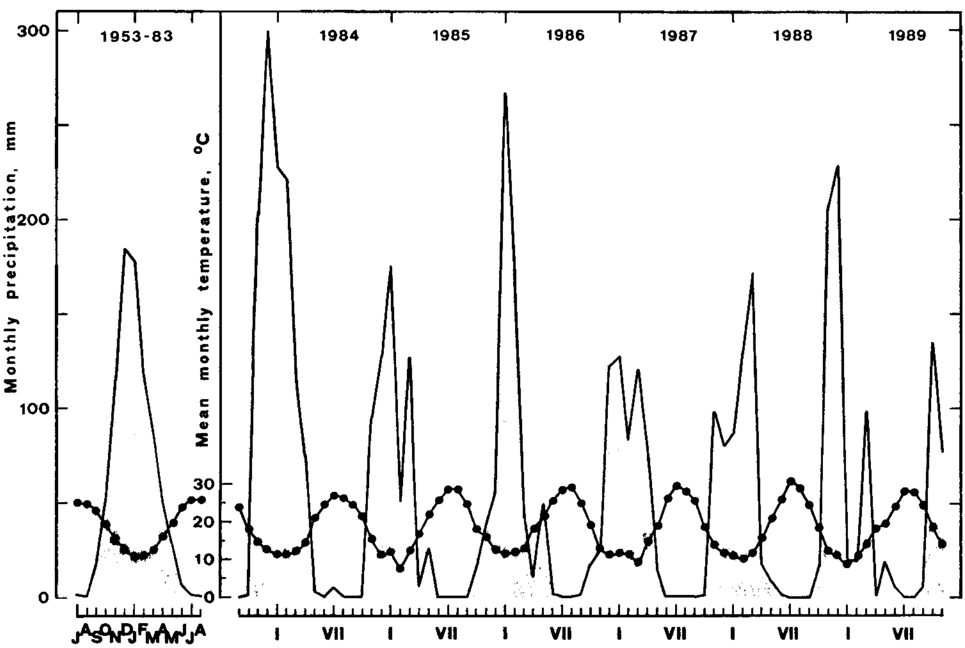

FIG. 2. – Monthly precipitation and mean air temperature for the post-fire period September 1983-November 1989. On the left, the average monthly values for the pre-fire period 1953-1983.

average conditions it is rather evident that nothing very unusual happened during this 6-year long period (at least with regard to the high unpredictability and variability of the Mediterranean climate). Nevertheless, mean annual precipitation for the period September 1983-August 1989 was 699.0 mm, a considerably lower value than the overall average (836.6 mm). No signs of grazing were observed in the burnt areas, consistent with the virtual absence of sheep and goat husbandry in most parts of the island.

The vegetation type of the particular sites, and of the whole burnt area in general, was a very dense (total cover nearly 100%) mixed (phrygana and maquis) shrubland. Table II contains floristic data for the sites of the 1983 wildfire investigated in this study (tab. I); since sampling was performed once (in the autumn),

TABLE II. – *The woody plant vegetation of the experimental sites.* *: *dominant* (>25% *cover*), *C: common* (5-25% *cover*), *R: less common or rare* (<5% *cover*). – *: not observed*.

	A	B	C	D	E
Evergreen sclerophylls (maquis elements):					
Arbutus andrachne L.	–	R	–	–	–
Arbutus unedo L.	C	C	C	R	C
Ceratonia siliqua L.	–	R	–	R	–
Erica manipuliflora Salisb.	–	C	–	R	–
Myrtus communis L.	–	R	–	–	–
Olea europaea var. *sylvestris* (Miller) Lehr.	–	–	–	R	R
Phillyrea latifolia L.	–	–	–	–	R
Pistacia lentiscus L.	–	R	C	R	C
Quercus coccifera L.	R	–	R	R	C
Deciduous shrubs (associated with maquis vegetation):					
Crataegus monogyna Jacq.	–	R	–	–	–
Pistacia terebinthus L.	C	R	R	R	–
Quercus pubescens Willd.	R	–	–	–	–
Vitex agnus-castus L.	–	R	–	–	–
Low shrubs (associated with phrygana):					
Anthyllis hermanniae L.	C	C	–	C	–
Cistus incanus ssp. *creticus* (L.) Heywood	*	*	*	*	*
Cistus salvifolius L.	*	*	*	*	*
Dittrichia viscosa (L.) W. Greuter	C	C	R	–	–
Genista acanthoclada DC.	C	C	R	C	C
Hypericum empetrifolium Willd.	–	C	–	R	–
Lavandula stoechas L.	–	R	–	–	R
Sarcopoterium spinosum (L.) Spach	C	C	–	C	R
Satureja thymbra L.	–	C	–	C	–
Spartium junceum L.	–	R	R	R	–
Thymus capitatus (L.) Hoffmanns. & Link	C	–	–	R	–

only the perennial, woody plants have been included in the list. The canopy height was variable, roughly between 50 and 150 cm, depending on soil, elevation and exposure. From table II it is evident that the two species of *Cistus* were by far the dominant plants (50-80% cover) while various proportions of phryganic and maquis elements were encountered. All the maquis members had obviously resprouted immediately after the fire and therefore the resproutings were 6 years old. Only very few young saplings of maquis elements (notably of *Arbutus unedo* in site A and of *Pistacia terebinthus* in site D) were observed established from seed, their age being indeterminate (but between 2 and 5 years). The phryganic plants were represented mainly by young plants that had germinated and established during the first rainy season after the fire of 1983, thus being (most of them, at least) 6 years old.

Height and canopy cover of pine saplings are given in table III. Although the variability within each site was very wide (indicated in the range column) the average height was around 60 cm; the significantly deviating values obtained in sites C and D can be attributed to the soil conditions (the soil being rather rich at the former site which is adjacent to an olive grove but very poor, due to erosion, in the latter).

TABLE III. — *Growth measurements of 6-year-old pine saplings.*

Site	Mean height (cm, ± SE)	Height range (cm)	Mean plant cover (m^2, ± SE)	*n*
A_1	57.0 ± 2.3	15-110	0.08 ± 0.01	61
A_2	59.9 ± 2.9	20- 95	0.08 ± 0.01	36
B	52.8 ± 2.7	10-115	0.09 ± 0.01	65
C	76.8 ± 3.2	35-125	0.15 ± 0.02	60
D	22.8 ± 2.8	10- 65	0.02 ± 0.01	20
E	59.6 ± 6.6	20-160	0.11 ± 0.03	27

TABLE IV. — *Density of 6-year-old pine saplings. Small case letters following values indicate statistically significant differences* ($P = 0.05$).

Site	Density (plants m^{-2})	*n*
A	1.79 ± 0.31 [a]	36
B	0.10 ± 0.04 [c]	63
C	0.42 ± 0.12 [b]	45
D	0.02 ± 0.01 [c]	41
E	0.03 ± 0.01 [c]	70

The pine sapling density measured at the five sites visited is shown in table IV. The variability was once more very high, but if site A is not taken into account, a gross average of 0.15 plants per m^2 is reached (0.47 plants m^{-2}, with all sites included).

The survival curve of the pine seedlings and saplings is shown in figure 3. Time 0 has been set at the start of the observation period, in May 1984, at the end of the first rainy season when no additional germination was expected. The seedlings marked were 1-5 months old though most were, presumably, 2-3 months old and were forming their primary needles at that time. Figure 3 is actually an update of a previous one (fig. 1; THANOS *et al.*, 1989). The surviving percentage of pine saplings by November 1989 (after 6 growing seasons) was markedly high: 42.6%. The negative exponential curve previously fitted (continuous line) is obviously very steep and several efforts to obtain a new curve were unsuccessful. Thus, the stippled line in figure 3 was drawn by hand.

Cypress (*Cupressus sempervirens* L.) seedlings tagged in 1984, as well, were also examined in this study. Surprisingly enough, all 10 survivors of the last survey (November 1985) at a particular location of site A were found safe and thriving. The mean height and plant cover ($n = 13$) were estimated to be 86.5 ± 5.7 cm and 0.07 m^{-2}, respectively.

DISCUSSION

The woody plant floristic composition of the regenerated forest ecosystems was quite similar, as expected, to the one recorded during the previous study (THANOS *et al.*, 1989). Besides *P. brutia*, the presence of *Cistus* spp. and *Anthyllis*

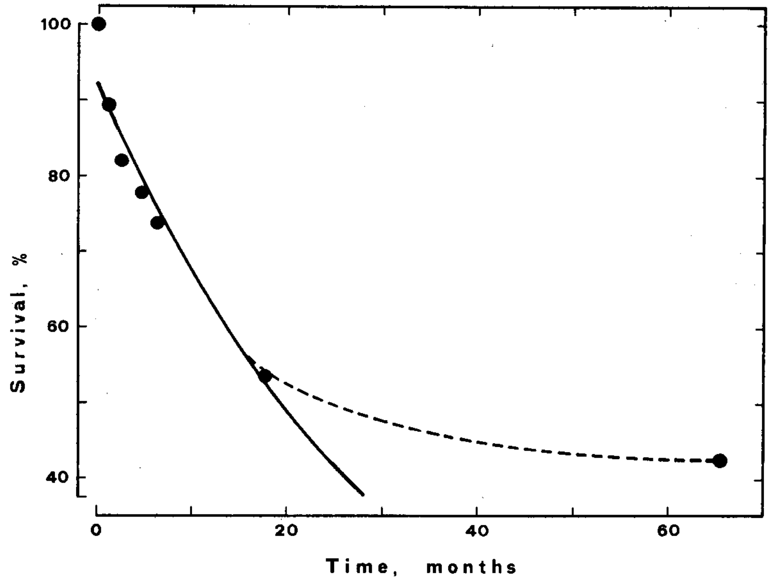

FIG. 3. – The survival curve of *P. brutia* saplings for the period May 1984 (time 0)-November 1989.

hermanniae is due to the fire-induced seed coat "softening" (probably through the "opening" of hilum, CORRAL *et al.*, 1989) which leads to massive germination (ARIANOUTSOU & MARGARIS, 1981; THANOS & GEORGHIOU, 1988), although according to NAVEH (1975) both *Cistus* spp. and *A. hermanniae* can regenerate vegetatively as well. Nevertheless, the two modes of regeneration seem to account for post-fire establishment of most of the phryganic subshrubs (*Genista acanthoclada*, *Hypericum empetrifolium*, *Lavandula stoechas*, *Sarcopoterium spinosum* and *Satureja thymbra*); on the other hand, it is evident that all the maquis elements have resprouted. Finally, *Dittrichia viscosa* (Compositae) is a very aggressive weed known to colonize disturbed areas thanks to its numerous, wind-dispersed seeds.

The average height of the 6-year-old pine saplings (which germinated after the wildfire of 1983) falls into the class 50-60 cm. This value compared to those for 1- to 4-year-old plants (THANOS *et al.*, 1989) indicates a somewhat decreased growth rate, this slowing being either inherently determined or environmentally controlled (by climate and/or neighboring vegetation). However, this same deceleration of the growth curve has also been observed for *P. halepensis* during 5 and 10 years after various wildfires in southern France (TRABAUD *et al.*, 1985). The actual average height in the latter case had increased from about 0.7 at year 5 to only 1.1 m at year 10. Moreover, heights attained by both species during their early development seem rather similar, though the Aleppo pine is supposed to grow much faster than the Brutian one (PANETSOS, 1981). In nursery tests of six Greek provenances, the average height of 7-year-old *P. brutia* trees varied between 3.02 and 3.81 m (provenances of Samaria, western Crete and Thasos island, respectively). This considerable deviation in height values in comparison to those measured in the present study should be attributed to favorable soil conditions and/or cultivation techniques of the former report. In a similar study in Italy (Eccher *et al.*, 1987), the height average of up to 17 provenances of *P. brutia* grown for 10 years in plantations located at Rome (Ovile), Rome (Castel di Guido), Forli and Taranto ranged very widely, due to the different soil and climatic conditions: 8.45, 5.84, 2.95 and 1.95 m, respectively.

Density measurements of pine saplings, though highly variable from site to site, may offer an overall insight to the general situation of the burnt area. The average density of the five sites is 0.47 plants m^{-2} and if site A is excluded from calculations, the average of the remaining four sites is 0.15 plants m^{-2} or 1,500 stems ha^{-1}, a very satisfactory value for an average pine forest (*cf.* Trabaud *et al.*, 1985). Nevertheless, as a matter of fact, a vegetation patchwork, due to the varying extent of regeneration among sites, has already started to emerge in the burnt area. In our previous study (Thanos *et al.*, 1989) we predicted a density of 0.13 plants m^{-2} at year 5, a value strikingly close to the actual situation.

Concerning the survival curve of pine saplings, it seems that, eventually, mortality has greatly slowed. By applying the exponential function fitted for the data of the first 18 months (Thanos *et al.*, 1989) the survival expected after 65.5 months would be only 11%, instead of the actual 43%. However, since it is evident that exponential mortality is applicable only during the vulnerable seedling and early sapling stages of development, we adopted in our previous work a so called "moderate" annual survival probability of 90% from the third year onwards. The actual data show that this prediction has been really moderate: the estimated annual survival value has been 93%. In conclusion, mortality of pine seedlings could be described briefly as follows: 25% of the seedlings established at the end of the first post-fire spring perished during the first summer, 25% of the remaining ones perished during the next 12 months and, finally, 25% of the survivors perished during the next 4 years.

According to Nahal (1983) mature cones are produced by *P. brutia* at an average age of 10 years, in contrast to Panetsos (1981), who concluded that it starts flowering 1-2 years later than *P. halepensis*, i. e. at year 4 or 5, thus producing mature cones at year 7 or 8. It is worth remarking that only one young (several months old) female cone was encountered in one pine sapling at site B out of several thousand examined during the field survey, in the present study. Therefore, in the post-fire grown pines of Samos island, no cones at all will have matured by the age of 8 (since cone maturation requires 3 growing seasons after initial formation).

Concerning form plasticity of pine saplings, it should be noted that in numerous occasions, particularly amidst resproutings of *Arbutus unedo* and *Pistacia lentiscus*, tall and slender young pines were seen emerging through the canopy of their bushy neighbors. However, the dramatic observation of the present study was the number of very short (10-20 cm) pine saplings found in the burnt sites investigated (50% of total saplings in site D, ca. 5% in the other sites). These young plants were beyond doubt 6 years old since most of the sites were far away from unburnt pine stands and thus seeding during the second or subsequent years after the wildfire was highly improbable. In addition, the actual surveys during the second growing season (THANOS *et al.*, 1989) did not reveal any appreciable emergence of new seedlings. This absence was expected not only because of the distance from the potential seeders but also as a result of the already established, quite dense, herbaceous vegetation which would certainly inhibit most germination of the pine seeds that might happen to land in the area (THANOS & SKORDILIS, 1987). However, indisputable evidence in support of the 6-year age was the discovery of many short (some of them as short as 5 cm) saplings tagged in the previous study, in 1984. Certain of these saplings were single-stemmed while in others several axillary long shoots had formed. All of them had of course secondary needles but in a few saplings secondarily developed juvenile needles were also observed. These suppressed saplings were found everywhere and most strikingly in site D, where the majority of them were completely outgrown and covered by dense *Cistus* stands.

Only recently has the concept of sapling bank emerged as a regeneration pathway in addition to soil or canopy seed bank and vegetative regrowth (SIMPSON *et al.*, 1989). Sapling banks have been reported mostly in tropical rain forests and to a certain degree for temperate deciduous forest species (PARKER *et al.*, 1989). The suppressed trees are suggested to be, like seeds in the ground, awaiting the removal of inhibition of their development; light, water and nutrients being the possible limiting factors. The postulated advantages of a sapling bank over the seed bank are lower predation losses (particularly for the large-seeded species) and the detection (and exploitation as well) of a small opening in the shading canopy by a suppressed young plant (impossible for a seed in the soil) (PARKER *et al.*, 1989). Both these advantages seem to fit nicely into the case of *P. brutia*.

Therefore, it is suggested that in certain cases, and to a varying extent, a post-fire sapling bank of *P. brutia* may be formed under the dense canopy of *Cistus* shrubs (and under other fire followers, as well). These particular *Cistus* stands are composed by plants of virtually the same age and since maximum longevity is around 10-15 years (MARGARIS, 1976; ROY & SONIE, personal communication) senescence may start well before year 10 after fire. Therefore, the stand decline will eventually relieve sapling suppression and permit normal growth of the pine understorey. The pine sapling bank postulate requires, undoubtedly, further and rigorous studies towards the determination of both the degree of its occurrence and related factors, as well as in regard to the ecophysiological mechanisms pertaining to the suppression and resumption of sapling growth.

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