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Regeneration of N.W. African *Pinus halepensis* forests following fire

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Abstract

Pinus halepensis forests of N.W. Algeria are subjected to frequent fires. During the fire the aboveground parts of plants are completely burned but only a few species are killed. Most perennial herb and shrub species survive owing to their underground organs and regenerate vegetatively in the next moist period. The semi-shrubs regenerate both vegetatively and from seeds. The most intensive growth of the shrub layer occurs during the first 2 years and in the 5th year, it reaches a height of 1–1.5 m. *Pinus halepensis* is completely killed by the fire and it regenerates from seeds only. The regeneration is retarded during the first 2–3 years, apparently by competition of the rapidly developing shrubs and semi-shrubs with *P. halepensis*. In the following years, there is a more rapid increase in both density and height, although by the 5th year after fire, the height does not exceed 0.5 m. The young trees overtop the shrub layer between 10 and 15 years after fire. The increase in density and cover supress the lower layers, in particular the herb layer. The reduction in density of trees in the following decades enables the herb layer to reconstitute its composition and cover.

This process of regeneration resembles forest growth cycles rather than a secondary succession. The shrub and herb layers maintain their identity as they are mostly formed of the same individuals as before the fire; they merely regenerated their aboveground organs. Only the tree layer regenerates anew after the fire.

Introduction

Vegetation dynamics comprises different processes which should be distinguished according to their nature. Postfire changes of vegetation are often called succession (cf. e.g. many authors in West, Shugart & Botkin (eds.) 1981). However, succession should be characterized not just by quantitative or structural changes in the vegetation but primarily by qualitative changes in the floristic composition. This is not always the case in forest regeneration following fire as is shown in this paper.

Pinus halepensis is a mediterranean species occurring in disjunct areas in the forest zone of Northern Algeria (cf. Quèzel et Santa 1962–1963). In the Oran district it forms large forests in the tabular branch of the Little Atlas Mountains situated to the south of Sidi-Bel-Abbès (Alcaraz 1977 – see Fig. 1). These forests reach as far as the steppe zone at the contact of the Little Atlas with the High Plains. The forests

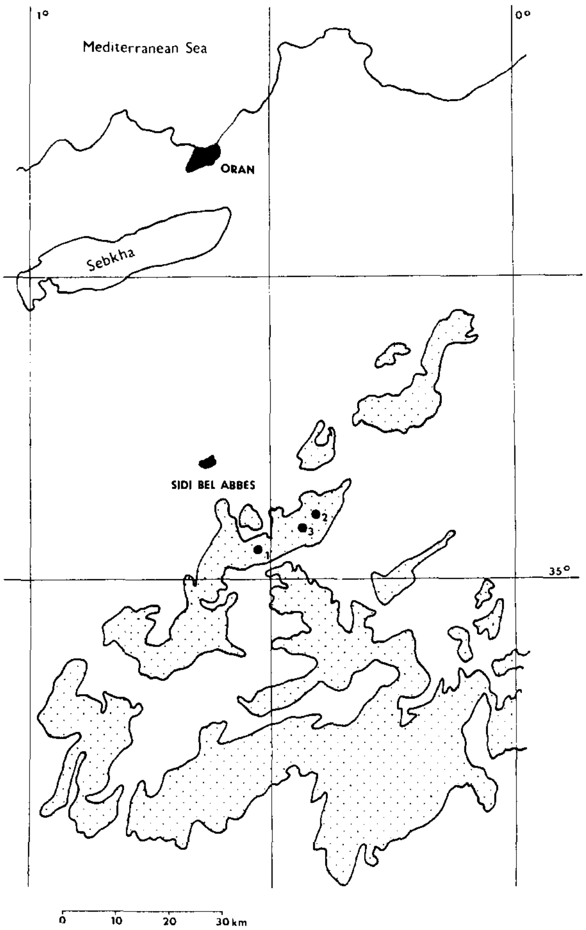

Fig. 1. Distribution of Pinus halepensis forests in the Oran district, N.W. Algeria (after Alcaraz 1977).

of *P. halepensis* are subjected to frequent fires usually during the dry season, May to October (Fig. 2), as is the case in the European part of their distribution – cf. Trabaud, Grosman & Walter 1985, Trabaud, Michels & Grosman 1985. The author had the opportunity to observe the regeneration of these forests during his stay at the University Center of Sidi-Bel-Abbès and attention was also given to this problem by his students (Hadjam 1986; Kourdassi 1986; and Salem 1986).

Observation area

The observations were confined to the large forest area of the 'Forêt de Tenira' and 'Forêt de Caïd Belarbi', which cover continuously a flat mountain chain more than 700 m high at the southern and south-eastern boundaries of the basin of Sidi-Bel-Abbès. The climate of this region is semi-arid (see Fig. 2). The geological substrate is made up mostly of sandstones and conglomerates of Cretaceous or Miocene origin. Sandy soils predominate, enriched with $CaCO_3$.

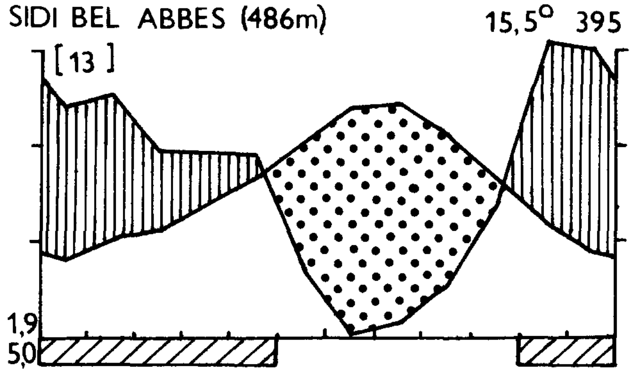

Fig. 2. Climate diagramm of Sidi-Bel-Abbès (after Walter et Lieth 1960, etc.).

Methods

Regeneration of *P. halepensis* forests after fire was deduced from synchronous observations made in sample plots in stands of known age of regeneration after fire as well as in nearby undamaged forests, which had also regenerated after fire but about 50 years earlier – according to tree ring counts. Vegetation relevés, according to the Braun-Blanquet procedure, were taken in the spring of 1986 by Miss Z. Hadjam, Miss K. Kourdassi and Miss N. Salem under the author's supervision.

Three study sites were chosen (see Fig. 1 and Table 1).

1. Area burned in April 1984 ('Forêt de Tenira') – relevés **a** and **b** and reference relevés **A** and **B** of undamaged forests (about 50 years old).
2. Area burned in September 1981 ('Forêt de Caïd Belarbi') – relevés **c** and **d** and reference relevé **C** (a stand about 60 years old).
3. Area burned in 1966 ('Forêt de Caïd Belarbi') – relevé **e** and reference relevé **E** (a stand about 40 years old).

Table 1. Comparison of regeneration phases (**a-e**) with undamaged reference stands of Pinus halepensis (**A-E**) (nomenclature follows Quèzel et Santa 1962–1963; species occurring in one relevé only are not included); abundance-dominance of species in the Braun-Blanquet scale (cf. Mueller-Dombois et Ellenberg 1974. 59–60).

Years after fire	(undamaged)						2	2		5	5		20
	A	**B**	**C**	**E**	**A**	**B**	**a**	**b**	**C**	**c**	**d**	**E**	**e**
Tree layer (> 5.5 m)													
cover degree (%)	30	45	35	50	30	45	0	0	35	1	1	50	0
Pinus halepensis	3	3	3	4	3	3	·	·	3	+	+	4	·
Shrub layer (0.75–2.50 m)													
cover degree without Pinus halepensis (%)	10	20	40	33	10	20	5	15	40	15	10	33	10
Quercus coccifera	2	2	2	2	2	2	1	2	2	1	1	2	2
Pistacia lentiscus	1	+	2	1	1	+	+	+	2	1	1	1	1
Phillyrea angustifolia	+	+	+	1	+	+	·	1	+	+	+	1	·
Tetraclinis articulata	·	1	+	2	·	1	·	+	+	·	+	2	+
Arbutus unedo	+	·	·	·	+	·	+	1	·	+	·	·	·
cover degree of Pinus halepensis (%)	0	0	0	0	0	0	0	0	0	70	5	0	80
Pinus halepensis	·	·	·	·	·	·	·	·	·	4	2	·	5
Semi-shrub sublayer													
cover degree (%)	10	20	10	15	10	20	35	15	10	15	15	15	15
Rosmarinus tournefortii	1	1	2	1	1	1	+	r	2	1	1	1	2
Cistus villosus	1	1	1	+	1	1	3	2	1	2	2	+	1
Fumana thymifolia	1	+	+	·	1	+	1	1	+	1	2	·	·
Globularia alypum	+	+	1	r	+	+	r	+	1	·	+	r	·
Helianthemum cinereum	+	+	+	·	+	+	·	1	+	2	1	·	+
Helianthemum racemosum	+	r	+	·	+	r	1	+	+	+	+	·	r
Cistus sericeus	+	·	1	r	+	·	·	·	1	1	+	r	+
Asparagus acutifolius	·	r	r	r	·	r	r	·	r	r	·	r	r
Bupleurum gibraltaricum	r	1	·	r	r	1	·	+	·	·	·	r	·
Cytisus arboreus	+	·	1	·	+	·	+	+	1	1	·	·	+
Calycotome villosa	·	2	·	1	·	2	·	1	·	·	·	1	r
Thymus ciliatus	·	2	+	·	·	2	r	r	+	r	·	·	·
Thymelea nitida	r	·	r	·	r	·	·	r	r	r	r	·	r
Genista quadriflora	2	2	·	·	2	2	+	r	·	·	·	·	·
Linum suffruticosum	+	r	·	·	+	r	·	+	·	·	·	·	·
Coronilla minima	r	+	·	·	r	+	·	r	·	·	·	·	·
Fumana ericoides	r	·	·	·	r	·	1	r	·	·	·	·	·
Herb sublayer													
cover degree (%)	10	15	15	15	10	15	10	10	15	10	10	15	10
Ampelodesma mauritanicum	2	3	1	1	2	3	1	1	1	+	2	1	+
Stipa tenacissima	+	1	2	2	+	1	+	+	2	+	1	2	·
Teucrium pseudochamaepitys	+	1	+	+	+	1	1	1	2	+	1	2	·
Carex halleriana	1	+	1	+	1	+	r	+	1	+	·	+	·
Asperula hirsuta	·	r	+	+	·	r	·	r	+	·	r	+	·
Koeleria vallesiana	·	r	·	+	·	r	·	·	·	·	·	+	·
Scleropoa rigida	·	r	+	·	·	r	1	+	+	·	r	·	·
Vulpia ligustica	+	+	·	·	+	+	+	·	·	·	r	·	·
Bupleurum rigidum	r	·	1	·	r	·	·	r	1	1	r	·	·
Leuzea conifera	r	·	+	·	r	·	·	·	+	r	·	·	·
Rubia peregrina	·	·	·	+	·	·	·	·	·	·	·	+	+
Hippocrepis scabra	·	·	+	·	·	·	·	·	+	1	·	·	·
Coronilla juncea	·	·	r	·	·	·	·	·	r	r	+	·	·
Lotophyllus argenteus	·	·	+	·	·	·	·	·	+	+	·	·	·
Psoralea bituminosa	·	·	+	·	·	·	·	·	+	r	·	·	·
Hippocrepis multisiliquosa	·	·	r	·	·	·	·	·	r	r	·	·	·
Serratula cichoracea	·	·	r	·	·	·	·	·	r	r	·	·	·
Bromus rubens	·	·	·	·	·	·	+	+	·	+	+	·	·
Cirsium acarna	·	·	·	·	·	·	r	r	·	r	·	·	r
Knetranthus calcitrapa	·	·	·	·	·	·	r	·	·	r	·	·	·

Pinus halepensis forests

The present state of *P. halepensis* forests of the Oran district does not permit to reconstruct the features of the original forest which have not been influenced by long-lasting human activity and repeated fires. No stands older than 60–70 years could be found. The present tree layer is formed exclusively of *P. halepensis* (see Fig. 3). *Tetraclinis articulata* probably originally accompanied *P. halepensis* as a tree but now constitutes the shrub layer together with *Pistacia lentiscus*, *Quercus coccifera* and *Phillyrea angustifolia*. Semi-shrub species, such as *Rosmarinus tournefortii*, *Globularia alypum*, *Cistus villosus*, *C. sericeus*, *Helianthemum racemosum*, *H. cinereum* (subsp. *roseum*), *Fumana thymifolia* and *Asparagus acutifolius*, form a semi-shrub sublayer.

In the herb sublayer, only few herb species show a higher degree of presence; the grasses *Ampelodesma mauritanicum* and *Stipa tenacissima* reach a higher dominance, accompanied by *Carex halleriana*, *Teucrium pseudochamaepytis* and *Asperula hirsuta*. Some annuals occur irregularly and with a low dominance on bare soil surface (e.g. *Scleropoa rigida* or *Vulpia ligustica*). The reference relevés (Table 1) give a rough idea on the floristic composition of these forests.

According to Trabaud, Michels & Grosman (1985), two types of *P. halepensis* forests were

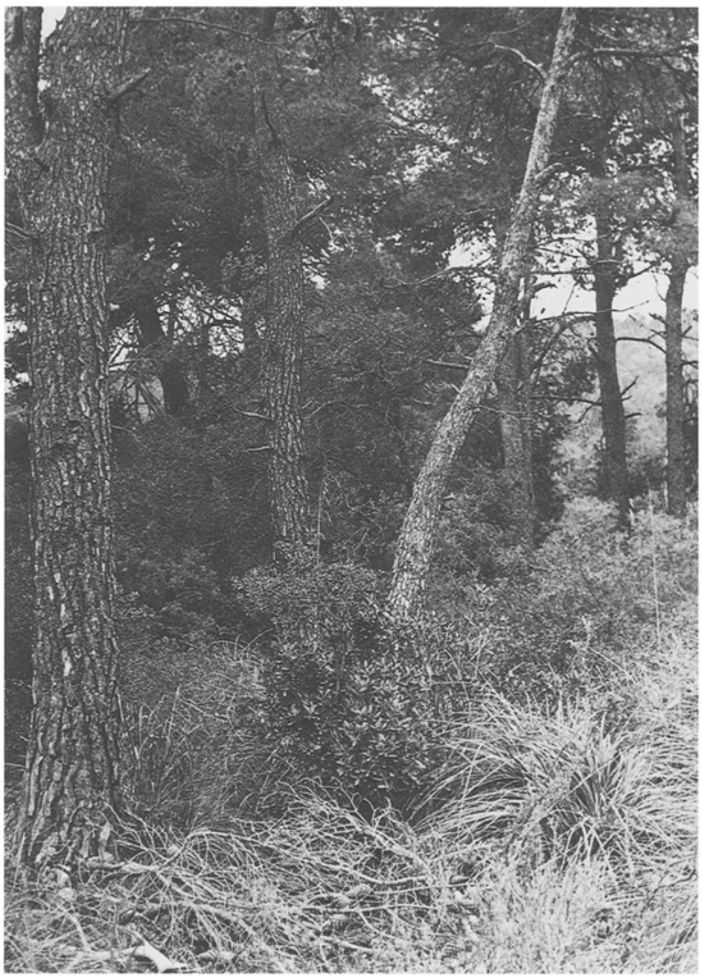

Fig. 3. Undamaged Pinus halepensis forest (Forêt de ténira).

distinguished in S. France by Grosman (1981) and Michels (1982): the rosemary-pine type (dominated by *Rosmarinus officinalis* – rosemary) and the kermes-pine type (dominated by *Quercus coccifera* – kermes scrub oak). *P. halepensis* forests of the Sidi-Bel-Abbès region are not identical with the above types. *Rosmarinus* (not *R. officinalis* but *R. tournefortii*) occurs together with *Quercus coccifera*, and further differences can be found in the floristic composition.

To protect the forests from fire, deforested belts of different widths (up to 100 m) have been made through the stands. These belts are ploughed at irregular intervals of several years to prevent the re-establishment of woody plants and the accumulation of dry litter on the soil surface.

Dead branches, cones and needles of *P. halepensis*, rich in resins, are easily inflammable and highly combustible. The same is true for the litter produced by shrubs and some perennials. Some species also produce volatile aromatic essences (e.g. *Rosmarinus tournefortii*) which are very inflammable. This, together with a low water content in plants during the dry period, makes even living plants combustible.

The action of fire

In most cases man starts the fires, but natural causes cannot be excluded. The spread of fire is highly facilitated on days of the sirocco, a hot and dry wind blowing from the Sahara. Fire spreads very quickly especially through the forest canopy (cf. Trabaud 1970). Whirls of hot air blowing over the burning forest are able to transport whole burning branches across the protection belts over a distance of more than 100 m setting fire to areas of several hectares within a short time.

Fire completely destroys the aboveground plant organs as well as the litter. However, the underground organs of most shrubs, some semi-shrubs and perennial plants survive. *P. halepensis* is completely killed by fire. Only isolated trees within an open vegetation, where the fire had a low intensity, can survive. The soil does not change, except that the surface layer of 2–4 cm is slightly hardened by fire. The burned area remains bare and subject to wind erosion till the rainy season starts in autumn.

Results

The regeneration of the forest of *Pinus halepensis* after fire is illustrated in Table 1. It started during the next moist period following the fire (see Fig. 4). Different species show different strategies of regeneration, with most shrubs, perennial herbs and some semi-shrubs regenerating vegetatively from their underground organs. Thus the life of the shrub layer and of a great part of the herb layer continues. No stage essentially different in qualitative floristic composition from the undamaged forest could be observed.

Regeneration after 2 years

The shrub layer plays a leading role in the forest regeneration during the first years after fire. The most intensive growth occurred in the first two years, when the shrub layer reached a height of about 1 m (Salem 1986). As shown in Table 2, *Pistacia lentiscus, Quercus coccifera* and *Phillyrea angustifolia* had a similar growth rate. They reached more than 60% of the maximum mean height found in undamaged reference stands. *Tetraclinis articulata* grew more slowly.

The herb layer also regenerated rapidly during this period, partly vegetatively from underground organs, partly from seeds stored in the soil. The two leading species of the semi-shrub sublayer – *Rosmarinus turnefortii* and *Cistus villosus* – regenerated from seeds. *Cistus villosus* regenerated very quickly, probably being favoured by higher light levels. Within two years after fire, it reached the highest cover degree within the regeneration cycle: values 2 to 3 in the Braun-Blanquet scale of abundance-dominance (see Table 1). However, *Rosmarinus tournefortii* and *Genista quadriflora* regenerated much more slowly. The semi-shrub sublayer reached the cover of 15–35%, especially owing to the dominance of *Cistus*

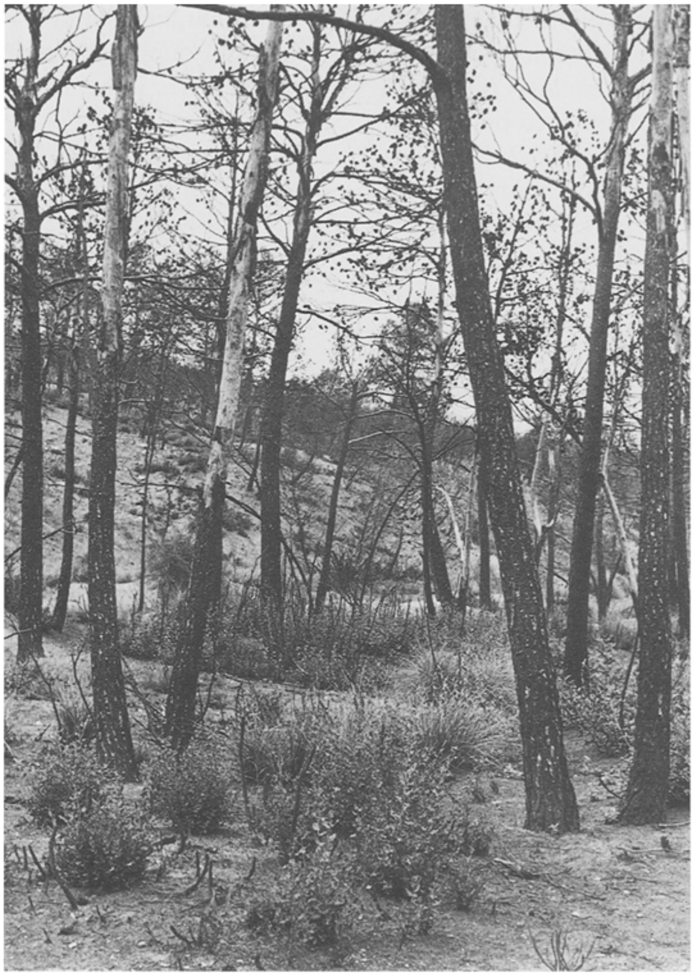

Fig. 4. Vegetative regeneration of the shrub and herb layers 10 months after fire (Forêt de Ténira).

Table 2. Mean heights (in cm – after Salem 1986) of the shrub-layer species in the regeneration phases and in corresponding undamaged reference stands of Pinus halepensis (r) and the relative heights given in per cent of the mean maximum shrub height in reference stands (r_{max}).

Years after fire	2/r	5/r	20/r	r_{max}
		Mean height in cm		
Pistacia lentiscus	1.37/1.35	1.31/0.20	1.16/1.66	1.66
Quercus coccifera	1.17/1.87	1.03/1.50	1.70/1.61	1.87
Phillyrea angustifolia	1.06/1.27	0.75/1.00	1.50/1.74	1.74
Tetraclinis articulata	0.75/2.50	1.67/1.60	2.10/2.50	2.50
		Relative height in %		
Pistacia lentiscus	83	79	70	
Quercus coccifera	63	55	91	
Phillyrea angustifolia	61	43	86	
Tetraclinis articulata	30	67	84	

villosus. This value was higher than that found in undamaged forests.

The two main species of the herb sublayer – the grasses *Ampelodesma mauritanicum* and *Stipa tenacissima* – regenerated vegetatively from their underground organs. New tillers did not restore the original cover degree during the first two years. Some annuals, absent in undamaged forests, such as *Bromus rubens, Cirsium acarna* and *Kentranthus calcitrapa*, encroached onto bare places form the deforested protection belts but with only a low abundance. The high similarity of the herb layer of the regeneration phase after 2 years with the herb layer of undamaged reference stands is shown by the values of 50 and 69 (**a**/**A** and **b**/**B**, respectively) of the Sørensen's floristic similarity index (Hadjam 1986).

Despite their relatively low degree of cover, the shrub and herb layers of this regeneration phase effectively protect the soil against wind erosion, retarding the wind at the soil surface. They also protect the soil surface against sheet erosion.

The regeneration of *P. halepensis* was retarded during this period. Only 16 and 23 seedlings (per 100 m^2), hardly reaching a height of 10 cm, were found in the sample plots **a** and **b** respectively (Kourdassi 1986). This can be explained by intensive competition of the rapidly growing shrubs and semi-shrubs with *P. halepensis*. On the protection belt adjacent to the sample plot **a**, ploughed some years before, more seedling were found, 1584 individuals per 100 m^2 with a mean height of 23 cm (Kourdassi 1986).

Regeneration after 5 years

The growth rate of *Pistacia lentiscus, Quercus coccifera* and *Phillyrea angustifolia* had decreased considerably, 5 years after burning. The shrub height was actually lower than in stands two years after the burning (see Table 2). Only *Tetraclinic articulata* continued to grow and overtop the other species. The qualitative floristic composition remained the same.

In the semi-shrub sublayer, *Cistus villosus* remained dominant but *Rosmarinus tournefortii* and *Cistus sericeus* had almost returned to the level of dominance recorded from undamaged forests. The main herbs – *Ampelodesma mauritanicum* and *Stipa tenacissima* also increased the dominance and the annuals *Bromus rubens* and *Cirsium acarna* were still present. The qualitative floristic similarity with the undamaged reference stand (88 for **c**/**C** and 58 for **d**/**C**) was higher than that found in stands two years after burning (Hadjam 1986).

The regeneration of *P. halepensis* was accelerated, probably owing to the decreasing growth rate of the shrubs. The density of saplings can be locally elevated in the proximity of fruiting trees (cf. also Abbas, Barbero & Loisel 1985; Barbero *et al.* 1988 and, on the sample plot **c** with 358 individuals per 100 m^2 and a mean height of 48 cm). *P. halepensis* had not overtopped the shrub layer but it had a cover value of up to 70% (Kourdassi 1986).

Regeneration after 20 years

During the ensuing years, *Pinus halepensis* became dominant. It increased faster in height and overtopped the shrub layer between 10 and 15 years after the fire. Young trees increased the degree of cover, thus helping to suppress the lower layers. The relevé **e** (Table 1) shows this situation. It represents a dense stand of young trees (225 individuals per 100 m^2) with a mean height of 2.2 m and cover of 80% (Kourdassi 1986).

The floristic composition of the shrub layer and semi-shrub sublayer was practically the same as in regenerating stands 5 years after fire. The herb layer was poorer in species with a low degree of cover. This is shown by the low floristic similarity index (only 31) between the herb layer 20 years after fire and the undamaged reference stand (**e**/**E** – Hadjam 1986).

Further development of *P. halepensis* forests is characterized by their continued increase in height and diminishing density. The concurrent increase in irradiance to lower layers allows the stabilization of their qualitative and quantitative floristic comoposition (as occurs in undamaged forests). Local deviations from the general course of regeneration described above are most likely to be the result of more frequent fires.

Conclusions

The regeneration of *P. halepensis* forests in N. Algeria resembles forest growth cycles rather than a secondary succession. Trabaud, Michels et Grosman (1985) came to similar conclusions for *P. halepensis* forests and Trabaud et Lepart (1980) for garrigue communities of S. France. The shrub and herb layers maintain their identity as they are mostly formed of the same individuals as before the fire, merely regenerating their above-ground organs. Thus, the regenerated shrub and herb layers should be considered as a regeneration phase of the forest rather than as an initial stage of secondery succession. Only the tree layer regenerates anew from seeds. This is similar to the regeneration of the tree layer in a forest after timber cutting or damage by storm. The continuity of the herb layer (and, in some cases, also of the moss or shrub layer) after destruction of the tree layer is particularly typical of light forests without a dense tree canopy, often composed of conifers, which occur on nutrient-poor and acid soils in humid regions (see Heinselman 1981) and on nutrient-rich ± neutral soils in semiarid regions.

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