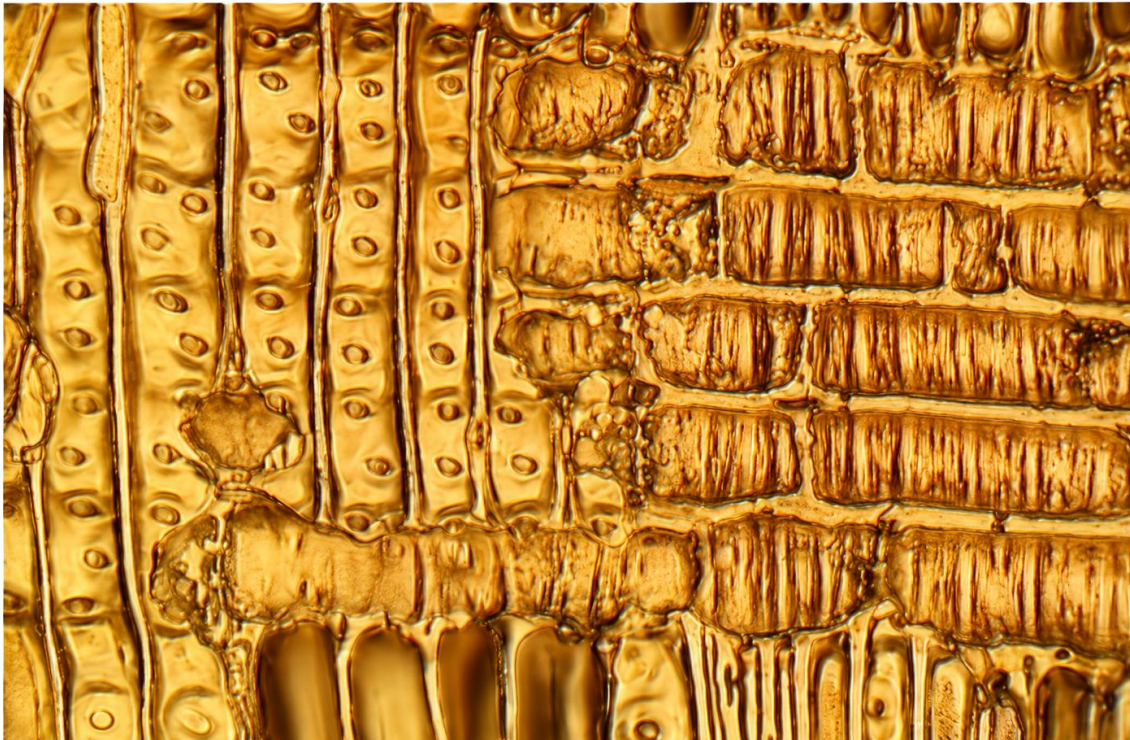


UNIVERSITY OF LAW, ECONOMICS AND SCIENCES OF AIX-MARSEILLE III

Faculty of Sciences and Technology of Saint-Jérôme
Mediterranean Institute of Ecology and Paleoecology
Laboratory of Botany and Mediterranean Ecology
Postgraduate Diploma (DEA)
Environmental Biosciences, Chemistry and Health
Continental Environments Option



Charcoal of *Juniperus excelsa*, cross-field (digital tomosynthesis, $\times 1000$).

Comparative Study of the Population Dynamics of Two Vicariant Juniper Species
(*Juniperus thurifera* L. and *Juniperus excelsa* Bieb.)
in France and Syria.
A Pedoanthracological Approach.

Presented by Marwan CHEIKH AL BASSATNEH

Under the supervision of Michel THINON

Academic Year 2000–2001

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1. INTRODUCTION

Juniperus thurifera L. (Spanish juniper), endemic to the western Mediterranean Basin, and *Juniperus excelsa* Bieb. (Syrian juniper), distributed in the eastern Basin (Figure 1), are regarded as geographical vicariant species (Quézel, 1980). Both species play an important role in the degradation stages of high-altitude Mediterranean forests, both in the Maghreb and in Anatolia and the Near East, particularly within coniferous formations such as cedar, black pine, and other juniper communities (Quézel et al., 1980; Quézel, 1981; Barbero et al., 1994). They may also constitute the highest-elevation arboreal stands. The degradation of these forests leads to xerophytic spiny shrub formations that are physiognomically similar (Quézel, 1957; Abi-Saleh, 1978; Gauquelin, 1988; Cheikh-Al-Bassatneh, 1997). In Spain and France, climatic, orographic, and phytogeographical factors place *J. thurifera* communities at intermediate elevations (Rivas-Martínez, 1985; Barbero & Quézel, 1986; Costa Tenorio et al., 1993).

In France, the Spanish juniper, long regarded as a rare species, is in fact relatively abundant in the Southern Alps and Pre-Alps, occurring either as scattered individuals or in small stands (Offner & Breistroffer, 1948; Barbero & Quézel, 1986). The largest and best-known population is located in the upper Durance Valley at Saint-Crépin (Hautes-Alpes).

The position and ecological role of *J. thurifera* within the vegetation structure of the Southern Alps have been the subject of several contradictory interpretations. Archiloque and Borel (1965) considered the Spanish juniper woodlands to constitute a vegetation series, with those of the Southern Alps belonging to a marginal series in the sense defined by Rey (1960), i.e., conditions favorable for the full development of the series occur only in a few geographically restricted areas. The optimum development zone of the “central” series would be located in Morocco, whereas the Spanish populations would represent a “lateral” series. Ozenda (1966) assigned these juniper woodlands the status of rupicolous communities within the sub-Mediterranean downy oak series. Barbero and Quézel (1986) distinguished several types of *J. thurifera* woodlands. According to these authors, the Saint-Crépin stand corresponds to a pre-steppe pre-forest community belonging to the internal Scots pine series.

Only a diachronic study of the stand over a long period can provide information allowing a better understanding of the evolution of the floristic composition of such a community, which has long been subjected to strong anthropogenic pressure. In the past, this pressure underwent major

fluctuations related to demographic variations caused by disease and insecurity (Lathuillière, 1994). Under such conditions, vegetation dynamics may then have been expressed, and certain woody species of the successive stages more advanced stages of ecological succession may have begun to establish (Thinon, 1992). Until recently, information concerning past vegetation dynamics was mainly derived from pollen analysis (Beaulieu, 1977). However, this type of analysis provides only broad-scale information over relatively large territories and poorly discriminates altitudinal zonation. In recent years, a new discipline, pedoanthracology (Thinon, 1978, 1992), has emerged. Owing to its high spatial precision and relatively good taxonomic resolution, this approach is particularly well suited to local-scale investigations. It is based on the systematic recovery, identification, and dating of charcoal fragments preserved in most soils worldwide. These charcoals may originate from natural fires, but they were mainly produced through the use of fire by humans since the Neolithic period for the management of agro-pastoral landscapes (Thinon, 1992).

We applied this discipline to the study of past vegetation in the *J. thurifera* woodland of Saint-Crépin and in a *Juniperus excelsa* stand located in the Anti-Lebanon range (Ras-Al-Maara), Syria. These data should make it possible, at both sites, to detect the possible presence of forest taxa corresponding to more advanced successional stages than those observed today. Finally, comparison of the results obtained should confirm or refute the vicariant relationship between these two juniper species.

2. MATERIALS AND METHODS

2.1 – Species description

Juniperus thurifera L. and *Juniperus excelsa* Bieb. are gymnosperms belonging to the family Cupressaceae, order Coniferales. This family is divided into two subfamilies: Cupressoideae and Callitrioideae Li (1953). The Cupressoideae are further subdivided into three tribes: Cupresseae, Junipereae, and Thuyopsidae. The tribe Junipereae includes only the genus *Juniperus*. According to Gaussen (1968), this genus is divided into three subgenera: *Caryocedrus*, *Oxycedrus*, and *Sabina*. *Juniperus thurifera* and *Juniperus excelsa* belong to the latter subgenus. Within this subgenus, *J. thurifera* is classified in the section *Chinensioides*, whereas *J. excelsa* belongs to the section *Excelsoides*. However, based on an analysis of the concentration of a phenolic compound

(prodelphinidin), Barbero et al. (1994) suggested grouping the two species within the same section, *Excelsoides*.

Species of the genus *Juniperus* differ from *Cupressus* mainly by their cones with imbricated fleshy scales, resembling a small berry (galbule) containing wingless seeds, whereas the cones of *Cupressus* are dry, with peltate scales and winged seeds. The origin of the genus *Juniperus* appears relatively recent: the oldest known fossil is a wood specimen of *Juniperoxylon pachyderma* (Göppert) Kräusel from the European Tertiary (Boureau, 1956).

2.1.1 – *Juniperus thurifera* L.

Juniperus thurifera L. is a species of the western Mediterranean Basin, occurring in North Africa and southwestern Europe. Based on morphological and biochemical criteria, Gauquelin et al. (1988) distinguished two subspecies.

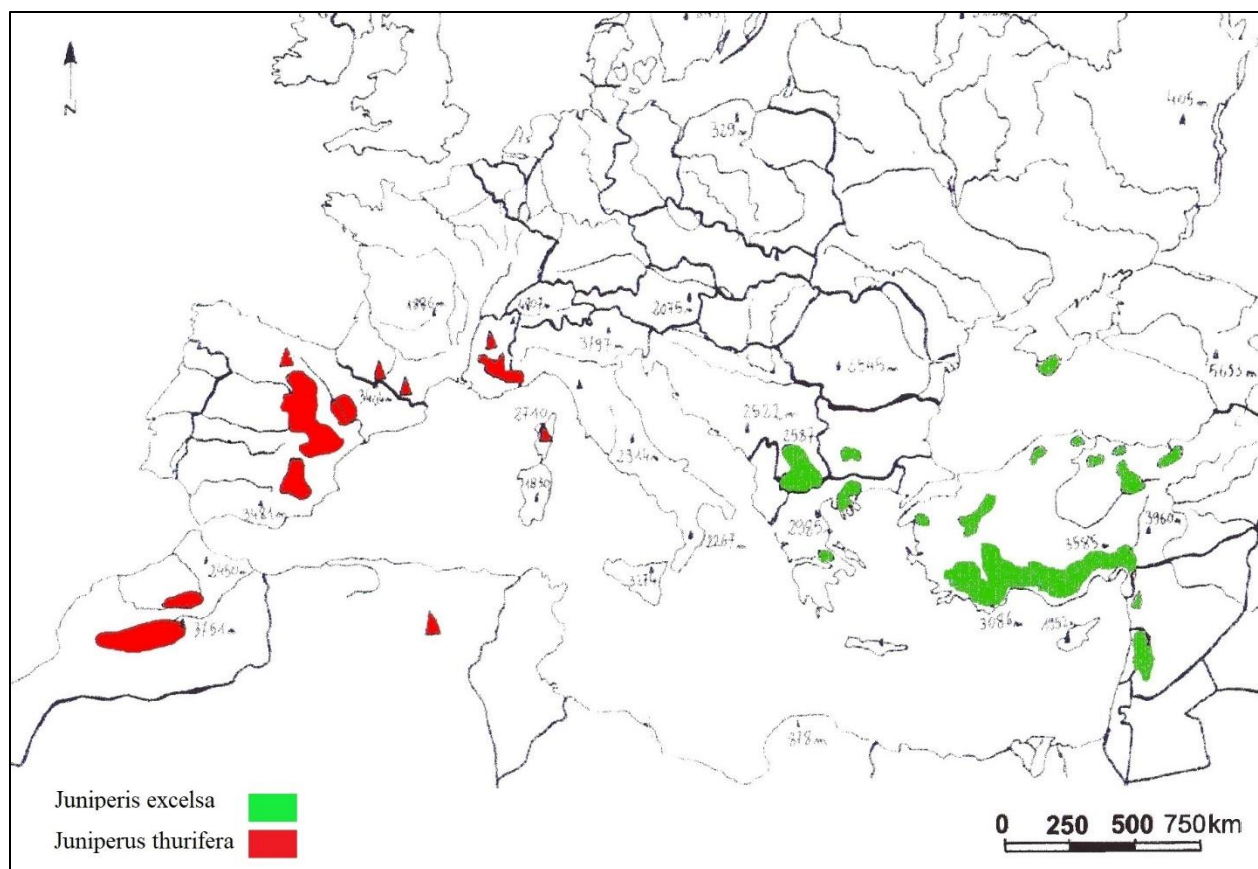


Figure 1. Distribution ranges of *Juniperus thurifera* and *Juniperus excelsa* (after Lathuillière , 1994)

Juniperus thurifera subsp. **africana** (Maire) Gauquelin et al. occurs in North Africa. This subspecies is found mainly in Morocco, in the Middle Atlas and High Atlas Mountains, between 1,700 and 3,100 m a.s.l. Small and fragmented populations also occur in Algeria, in the Aurès Massif, at approximately 2,200–2,300 m elevation.

Juniperus thurifera subsp. *thurifera* occurs in Europe and includes three varieties:

Juniperus thurifera subsp. *thurifera* var. *thurifera* in Spain, where populations locally form relatively extensive forest stands in the central part of the country (Costa Tenorio et al., 1993). Its ecological optimum is considered to lie between 1,000 and 1,100 m elevation (Gonzalez & Candas, 1991). To these populations may be added those of the French Pyrenees, in Haute-Garonne (Coste & Soulié, 1913; Dupias, 1960) and Ariège (Guerby, 1993).

Juniperus thurifera subsp. *thurifera* var. *gallica* occurs in six French Alpine departments, from the Alpes-Maritimes to Savoie, where the northernmost locality of the species is found (Breistroffer, 1946). A synthesis of the distribution of Spanish juniper in the Alps is provided by Garraud and Villaret (2000). This latter taxon was also reported by Barbero et al. (1987) on the Italian slope of the Ligurian Alps.

Juniperus thurifera subsp. *thurifera* var. *corsicana* Gauquelin et al. occurs in Corsica, in the Monte Cinto region: the Pinnera valley near Asco, and the Niolu region in the Rudda and Prunicia valleys (Gamisans, 2000).

Throughout its present distribution range, *J. thurifera* occurs within numerous vegetation belts, as shown in Table I below (Barbero et al., 1988). In Morocco, it forms the highest-elevation arboreal stands, colonizing semi-arid to sub-humid bioclimatic zones, from cold to extremely cold variants (Achal et al., 1980; Barbero et al., 1994).

Table I. Ecological Position of *Juniperus thurifera* in Vegetation Belts (Barbero et al., 1988)

Morocco	Spain	Mediterranean Vegetation Belts	Digne Prealps	Verdon & Vaire	Tinée	Roya	Saint-Crépin	Alpine Vegetation Belt
+		Oromediterranean						Subalpine
+	+	Montane-Mediterranean		+	+	+	+	Internal Montane
+	+	Supramediterranean and Upper Mediterranean	+	+	+	+	+	Internal Colline
		Mesomediterranean			+			

2.1.2 – *Juniperus excelsa* Bieb.

This juniper species (Syrian juniper), is considered the eastern geographical vicariant (or geovicariant) of *J. thurifera*. It is distributed throughout the mountainous regions of the eastern Mediterranean Basin (Quézel, 1980), from the Balkans to the mountain ranges of Lebanon (Figure 1). Some authors also include within this group *J. isophyllos* Koch, *Juniperus polycarpus* Koch., *Juniperus turcomanica* Fedtsch., eastern taxa, as well as *Juniperus procera* Hochst., from the southern Arabian Peninsula and eastern Africa (Barbero et al., 1994).

In the high mountains of the eastern Mediterranean, this hardy species exhibits a very wide altitudinal range. On Mount Ak Dag in Lycia (Turkey), for example, it occurs from 1,100 to 2,500 m elevation. On other massifs, it forms open woodlands reaching up to 2,700 m and characterizing degraded substrates associated with pre-steppe landscapes (Abi-Saleh, 1978).

In the Near East, particularly on Mount Lebanon and Anti-Lebanon, it occurs under very similar ecological conditions, where it forms the highest arboreal stands. At lower elevations, however, it may be associated with various other more or less dominant species such as *Quercus calliprinos*, *Q. infectoria*, *Abies cilicica*, *Cedrus libani*, and *Juniperus drupacea* (Abi-Saleh, 1978). In Syria, *J. excelsa* occurs in the northeastern part of the Anti-Lebanon range, at Issal-Al-Ward, Gabal-al-Btnein, Talaet-Moussa, Gabal-Al-Zamrani, and on the summits of Gabal-Halimet, covering a total area not exceeding 10,000 ha.

2.2 – Description of the Study Sites

2.2.1 – The Saint-Crépin Site

The largest French populations of *J. thurifera* are found in the Hautes-Alpes region, among which the Saint-Crépin stand is the most characteristic and best known. This locality is situated in the upper Durance Valley, between Briançon and Guillestre, within the natural region of Guillestrois or Haut-Embrunais (Figure 2).

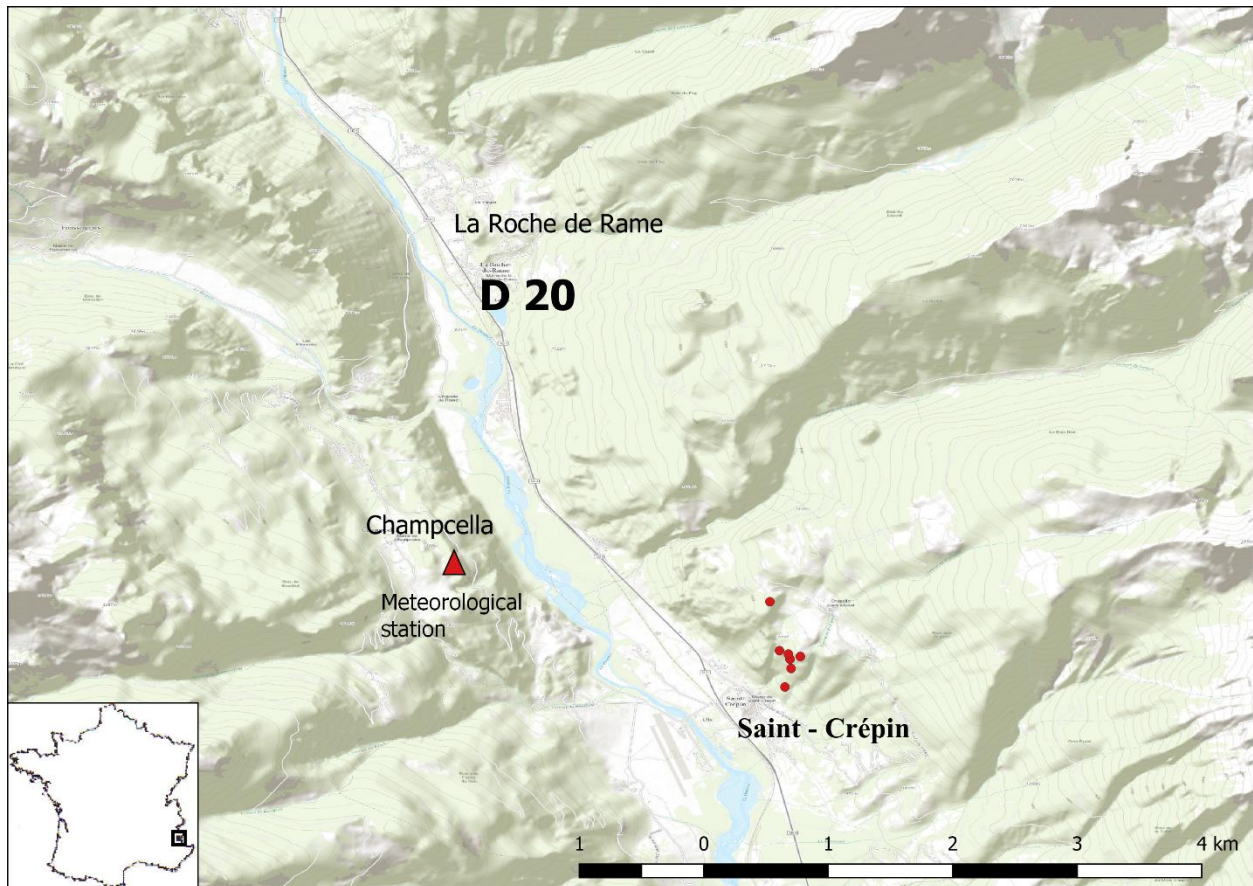


Fig. 2. Location of the Saint-Crépin juniper woodland, the Champcella weather station, and the pollen core from Roche de Rame.

The climate of the upper Durance Valley is characterized by generally low precipitation (approximately 600–800 mm annually) compared with the regional average, and by a wide thermal amplitude, with strong annual, seasonal, and daily variability in both factors (Meyer, 1981). The climate is dry and sunny, with exceptional luminosity owing to the powerful mountain barriers of

the Pelvoux massif to the west and the Queyras–Mont Viso massif to the east, which “deplete” cloud systems before they reach the north–south oriented valley.

Mediterranean influences moving up the Durance Valley are clearly perceptible in both the landscape and flora. However, there is no true dry month in the sense of Bagnouls and Gaussen (1957), i.e., $P < 2T$, but rather a sub-dry month where $P < 3T$ (Lathuillière, 1994).

The Saint-Crépin *J. thurifera* woodland (Figure 7) develops on the left bank of the Durance River, between 970 and 1,370 m elevation, on a steep west- to southwest-facing slope at the foot of the Crousas ridge, which culminates at 2,901 m approximately 3 km to the east. The calcareous substrate is composed at its base of Upper Cretaceous strata (slab marble) and, at the summit, Upper Jurassic formations (Guillestre marble); the lower part of the slope is covered with scree derived from both geological levels (Pourtet, 1975). The soil is rocky and very shallow, with only a few pockets of stony earth between massive blocks. In 1922, Pons described the *J. thurifera* woodland as a very open, pure, and homogeneous forest, intensively grazed and almost completely devoid of herbaceous and shrubby vegetation. The situation has since evolved, particularly with the expansion of Scots pine (*Pinus sylvestris*) and pioneer shrubs following the abandonment of grazing. Nevertheless, the central part of the stand still provides an image of what the woodland looked like at the beginning of the last century.

The nearest meteorological station, Champcella, is located only 1,500 m from the *J. thurifera* stand, at an elevation of 1,200 m.

The mean annual precipitation (P), calculated for the period 1961–1966, is 714.1 mm.

The mean maximum temperature of the warmest month (July) is 24.6°C.

The mean minimum temperature of the coldest month (January) is –7.1°C.

Calculation of Emberger’s pluviothermic quotient gives a value of 78.8. The stand is therefore situated within a subhumid bioclimatic zone with an extremely cold (or glacial, according to Akman and Daget, 1971 terminology) variant. Emberger’s pluviothermic climagram is presented in Figure 4 (the limits of the bioclimatic belts and variants correspond to those adopted by these authors).

$$Q = \frac{2000P}{(M^2 - m^2)}$$

Where P = mean annual precipitation, M = mean maximum temperature of the warmest month in K, and m = mean minimum temperature of the coldest month in K.

2.1.2 – The Ras-Al-Maara Site

Ras-Al-Maara is a Syrian village located in the Anti-Lebanon range, culminating at 2,616 m at Talaet-Moussa. The Syrian–Lebanese border follows the crest line of this mountain chain. The massif extends almost parallel to the Lebanon range, lying to its east along a northeast–southwest axis approximately 170 km long and averaging 25 km in width. The Lebanon range, which rises above 3,000 m and is higher than the Anti-Lebanon range, intercepts the maritime influences responsible for precipitation. Rainfall distribution is characteristically Mediterranean, with a large proportion occurring as snow.

Our pedoanthracological study was conducted at the Al Khashaa site, approximately 6 km from Ras-Al-Maara, at around 2,300 m elevation, with an additional floristic *relevé* carried out at Juret Al-Sahen, 2,200 m elevation (Figure 3).

There is no meteorological station in the Ras-Al-Maara region. However, Rahali (1987), using the work of Combier (1933), proposed precipitation and temperature values extrapolated from regional meteorological stations (Issal-Al-Ward, 1,625 m, for precipitation, and Rankous, 1,400 m, for temperature). These values are presented in Table II. The calculation of Emberger's pluviothermic quotient (Figure 4) yields a value of 77.1, remarkably close to that obtained for Saint-Crépin, corresponding to a very cold variant because m is higher than at that locality.

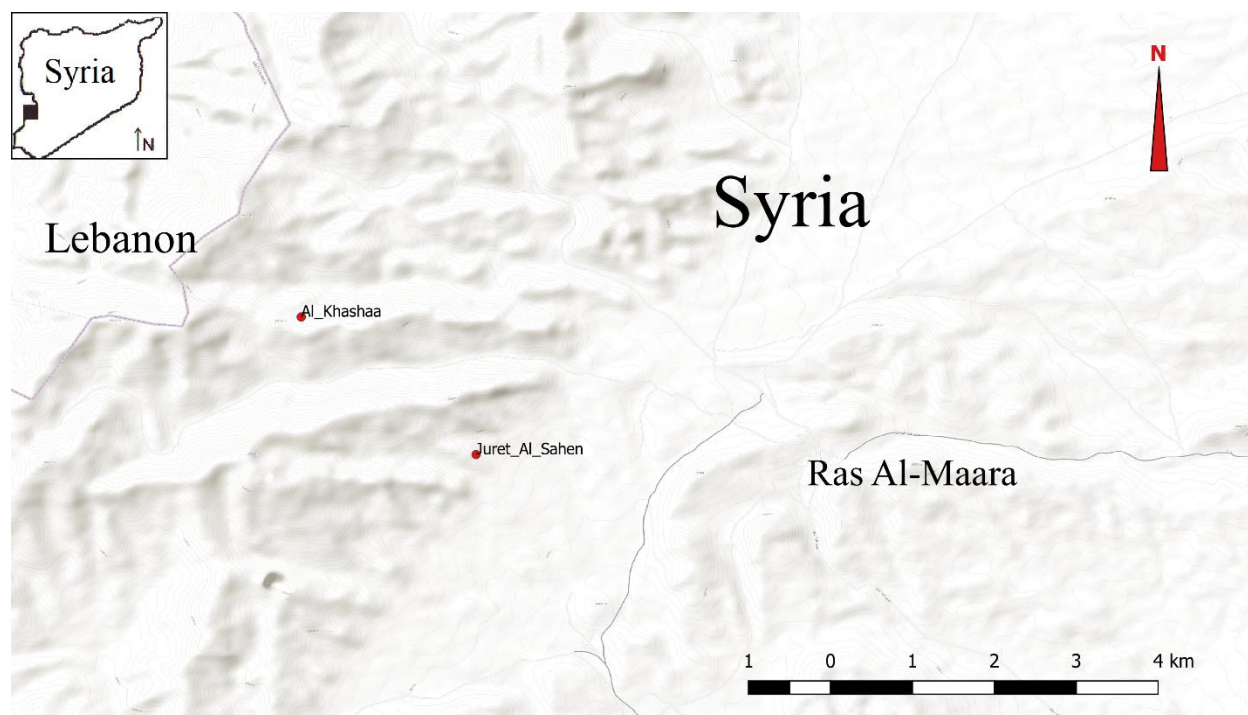


Fig. 3. Location of the station and vegetation relevés at Ras-Al-Maara.

Table II. Estimated Annual Temperatures and Precipitation Proposed by Rahali (1987)

Geographic Areas	Issal-Al-Ward	Mountain Regions of Ras-Al-Maara		
		Amashka (2,000 m)	Juret Al-Sahen (2,200 m)	Al-Khasha (2,300 m)
Mean minimum temperature of the coldest month (m°C)	-1.6	-2.4	-2.6	-4.2
Mean maximum temperature of the warmest month (M°C)	27.0	24.8	22.6	23.0
Mean annual temperature (T°C)	10.3	10.2	9.1	8.5
Mean annual precipitation (P mm)	263	445	544	593

2.3 – Floristic Methodology

Floristic *relevés* were carried out according to the Zürich–Montpellier method (Braun-Blanquet et al., 1951). Each species was assigned an abundance–dominance index (from 1 to 5, with “+” for

very rare species) characterizing the area occupied by individuals, and a sociability index (from 1 to 5) characterizing the spatial distribution of individuals (Appendix). Plant nomenclature follows Flora Europaea (Tutin et al., 1964–1980) for European taxa and the flora of Mouterde (1966) for Syria.

Each floristic *relevé* includes the complete list of species present, together with the location and general characteristics of the site, namely altitude, slope, exposure, and substrate type. When several vegetation strata are present, percentage cover is provided for each stratum.

Five *relevés* were conducted at the Saint-Crépin site. In contrast, at the Syrian site (Ras-Al-Maara), it proved difficult to obtain floristic *relevés* representative of the entire region because of problems of accessibility. Only two *relevés* were therefore conducted at this latter site.

2.4 – Pedoanthracological Methodology

The different stages of the pedoanthracological method were conceived and subsequently developed by Thinon (1978, 1992) in order to isolate and identify charcoal fragments originating from soils more or less rich in organic matter (Figure 5).

2.4.1 – Selection of Sampling Sites

Following phytosociological considerations, edaphic characteristics, particularly soil depth, play a fundamental role in the selection of sampling sites. Various important requirements must be respected:

1. Disturbed or reworked soils resulting from excavation, trenching, or filling operations must be avoided. If a soil has been covered by spoil deposits or overturned by ploughing, it may still be studied provided that only the undisturbed levels are sampled.
2. Topography also plays a major role, since low-lying areas accumulate material transported by runoff and air currents; charcoal fragments may therefore originate from any upstream location within the catchment basin, depending on the presence of watercourses or pronounced relief. Recently deposited colluvial soils or highly eroded soils should be avoided, as should soils located on very steep slopes. Upslope transport of wood charcoal

(in the anatomical sense of the term) by ascending air currents above fires at high elevation appears negligible, as it concerns only extremely small particles, smaller than the finest sieve mesh used (Clark, 1988; Thinon, 1992). Moreover, these charcoal particles are subsequently subjected to fragmentation processes.

2.4.2 – Sampling Protocol

The first stage of sampling consists of digging a soil pit or refreshing a pre-existing section, if possible down to the bedrock. A second phase of soil observation and description aims to match, as closely as possible, the pedoanthracological sampling levels with the natural soil horizons in situ. Horizons of substantial thickness (>30 cm) are subdivided in order to maintain relative uniformity in the thickness of sampled levels. Sediment is sampled from bottom to top in order to prevent contamination by material from upper levels that could modify the floristic composition of the anthracological assemblage. Before being bagged, the sediment undergoes an initial sieving (20 mm mesh) to remove the largest stones. In this way, approximately 10 liters of sediment are collected per level, corresponding to a mass of 8–15 kg depending on horizon density.

2.4.3 – Extraction and Preparation of Charcoal Fragments

Samples are dried either in open air or in an oven (maximum temperature 50°C). This step increases the resistance of charcoal fragments, which become fragile upon humidification, and allows the mass of extracted charcoal to be related to the dry soil mass. Charcoal extraction is partly based on the flotation principle: the sediment is first mixed in a rotating tank filled with water (approximately 20–25 L), the liquid phase cushioning the impacts generated during agitation. Fine aggregates are progressively broken down and the smallest particles placed into suspension. In soils displaying strong structural stability, a deflocculating agent ($\text{Na}_2\text{P}_2\text{O}_4$, NaOCl) may be added to promote disaggregation.

The supernatant, composed mainly of organic matter (primarily roots) and the lightest charcoal fragments, is poured through a sieve corresponding to the smallest mesh size used (0.4 mm). This mesh size represents a suitable compromise between the risks of allochthonous (extra-local) inputs

of tiny fragments smaller than 0.4 mm transported by wind, the possibilities for anatomical identification, and the effort required for extraction from soil constituents.

The study of charcoal grain-size distributions indeed shows that most of the anthracomass is composed of particles larger than 400 µm, both in temperate and tropical soils (Thinon, 1992). The residue remaining at the bottom of the tank (sands) is then poured onto a column of three sieves (5 mm, 2 mm, and 0.4 mm). The largest charcoal fragments (4–5 mm) are collected directly from the sieves and immersed for several dozen hours in a deflocculating solution of sodium hexametaphosphate ($\text{Na}_2\text{P}_2\text{O}_4$). The remaining aggregates are then gently dispersed on the sieves so that only isolated mineral particles remain. The residues retained on the different sieves are treated in the same way with the deflocculating solution, then rinsed and dried. An automatic elutriation device for separating charcoal mixed with sand (Thinon, 1992) reduces by more than 90% the quantity of sediment that must otherwise be sorted manually under a binocular microscope.

The charcoal fragments directly extracted are then individually cleaned of the residual clay and silt coating by means of an ultrasonic generator. Smaller charcoal fragments, extracted from the “roots” and “sand” fractions, may, if necessary, be cleaned using concentrated hydrofluoric and hydrochloric acid solutions. This procedure improves the quality of microscopic observations. The charcoal fragments are then ready for identification.

2.4.4 – Identification of Charcoal Fragments

Charcoal identification is carried out through microscopic examination of wood anatomical structures preserved during carbonization. It is therefore necessary to use anatomical reference works describing wood structure (Greguss, 1955, 1959; Jacquot, 1955; Jacquot et al., 1973; Schweingruber, 1990). The identification of small charcoal fragments requires recognition of characters not described in these works, which deal with only a limited number of species. The establishment of a reference collection of carbonized woods is therefore essential in order to build a specific database taking into account numerous anatomical characters and criteria observable on charcoal fragments (Thinon, 1992, 1994a, 1994b, 1994c).

2.4.4.1 – Reference Collection

For French species, we used the IMEP collection established by Thinon. For Syria, we collected several dominant woody species from the region of the pedoanthracological survey: *Juniperus excelsa*, *Prunus prostrata*, *Rhamnus libanotica*, *Acer syriacum*, *Berberis libanotica*, *Noaea mucronata*, *Astragalus colluotoides*, *Astragalus angustifolia*, *Cotoneaster nummulariifolia*, and *Onobrychis cornutis*.

After drying, part of the wood samples was carbonized in an electric furnace at approximately 550°C. To prevent combustion through contact with atmospheric oxygen, the wood was placed in a metal container and covered with 4–5 cm of siliceous sand (Fontainebleau sand). Pyrolysis lasted approximately 1 h 30 min, until smoke and flammable gases ceased to be released.

2.4.4.2 – Anatomical Description of Samples

The various anatomical structures were observed on fractures made along the woody planes. Anatomical analysis of the samples was carried out according to the standardized descriptive system of the anatomical characters of carbonized wood established by Thinon (1994b, 1994c). This description makes it possible to build a relational database managed using the software 4D.

2.4.4.3 – Microscopic Study and Identification

Microscopic examination was carried out in episcopy on the three anatomical planes of wood (transverse, tangential, and radial). The use of polarized light and Nomarski differential interference contrast (Thinon, 1990) allows access to the finest anatomical details, such as pit ornamentation. Anatomical description and identification were performed using the same microscope. Identification was based on information provided by anatomical reference works and by the reference collection.

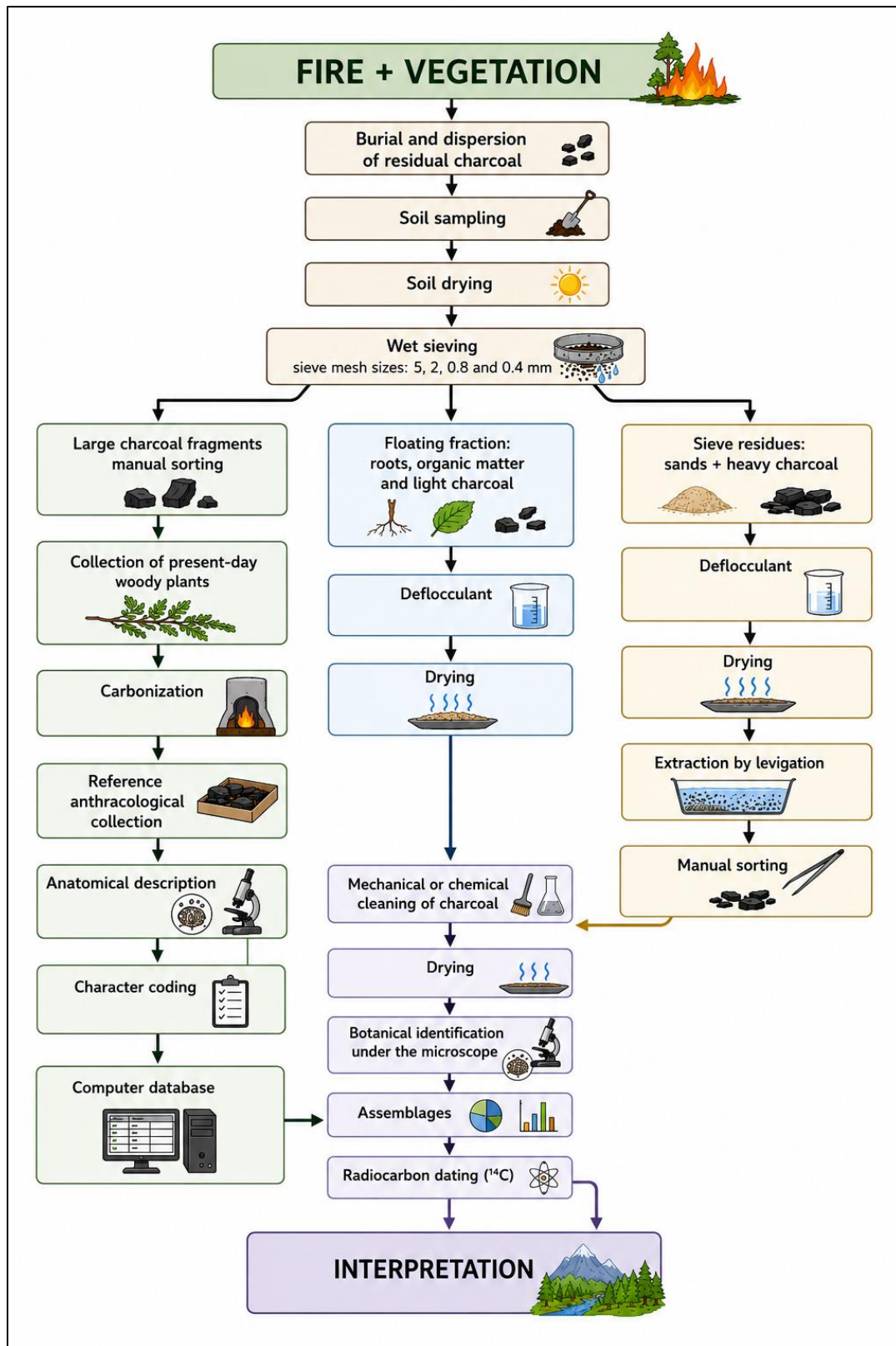


Fig. 5. Synthetic diagram of the pedoanthracological method (after THINON, 1992, modified).

2.4.5 – Expression of Results

Anthracological assemblages are established from the presence data of taxa within the different sampled levels. This qualitative approach is the only truly objective one, ecological conditions being inferred from the ecological requirements of the different taxa (Thinon, 1992). From a quantitative point of view, the charcoal richness of a sediment may be represented by its specific anthracomass (Thinon, 1992), defined as the ratio between the total mass of extracted charcoal retained on a sieve of given mesh size and the mass of dry soil particles smaller than 5 mm. Since charcoal mass is measured in milligrams and sediment mass in kilograms, the specific anthracomass is expressed in mg kg^{-1} , i.e., in ppm.

One may distinguish the specific anthracomass per level (ASN) and the mean specific anthracomass (ASM), the latter referring to all levels studied within a soil profile. This mode of expression makes it possible to compare different levels within the same soil as well as different soils.

Variations in charcoal mass corresponding to the different identified taxa within a given level may be expressed as relative anthracomass (ARN), defined as the ratio between the charcoal mass of a given taxon in a pedoanthracological level and the total charcoal mass examined within the same level.

Finally, changes in the anthracomass of a given taxon between different levels are represented by the specific anthracomass of the charcoal belonging to that taxon. Carcaillet and Talon (1996) proposed calling this value taxonomic specific anthracomass (AST), whereas Thinon preferred the term partial specific anthracomass (ASP), since unidentified or unidentifiable charcoal fractions do not represent any particular taxon.

It should be noted that these latter two forms of anthracomass express quantitative variations among identified taxa. The origin of these variations remains unclear and difficult to interpret. It is highly probable that neither of these two methods of expression provides a perfectly faithful image of past vegetation, owing to the many factors involved in the formation of the anthracological signal: initial biomass, combustibility, frequency and intensity of fires, charcoal dispersion, fragmentation processes, preservation, and sampling and extraction artefacts, etc. (Thinon, 1992). Only major differences appear to be significant.

By comparing vegetation *relevés* conducted before fire events with charcoal assemblages collected after burning, Thinon (1992) observed that the frequency of taxa within anthracological assemblages from several surface samples taken within the same site corresponded to the abundance of these same taxa within the phytocoenoses. It therefore appears that a direct relationship may exist between the abundance of taxa within phytocoenoses and the frequency of occurrence of these taxa within anthracological assemblages. This relationship still requires further investigation, particularly because of the complex problem of anthracological assemblage modification over time and during burial.

The pedoanthracological diagram (Carcaillet & Thinon, 1996), inspired by the conventional relative representations used in palaeoecology, provides a clear and rapid visual interpretation of results as well as of the main characteristics of the sampled profile. We selected this mode of representation while taking into account the limitations previously discussed regarding quantitative representations. Relative representations also raise additional problems, which may be partially resolved by reasoning in terms of partial specific anthracomass.

2.4.6 – Dating

Certain charcoal fragments of ecological or stratigraphic interest may be submitted to specialized laboratories for dating. The extremely small mass of pedoanthracological charcoal samples, ranging from fractions of a milligram to a few tens of milligrams, requires the use of Accelerator Mass Spectrometry (AMS). This relatively expensive method (approximately 3,000 French francs per date) is practiced in only about a dozen laboratories worldwide, and processing times are rather long (from more than six months to over one year). Within the framework of this study, dating analyses could not be carried out.

3 – RESULTS

3.1 – Anatomical Description of *J. thurifera* and *J. excelsa*

The different juniper species exhibit extremely similar anatomical characteristics, making species discrimination difficult, if not impossible. However, consideration of very precise characters observable on charcoal fragments, such as those retained by Thinon (1992, 1994c), may sometimes allow reliable discrimination within a given geographical region. In the present study, we restricted

ourselves to establishing diagnostic criteria distinguishing *J. thurifera* from *J. excelsa*. These criteria mainly concern the wood rays.

- Maximum ray height

Less than 10 cells in *J. thurifera*; between 10 and 15 cells in *J. excelsa*.

- Thickness of the transverse walls of radial cells

Generally thin ($<1\ \mu\text{m}$) in *J. thurifera*; of intermediate thickness ($1\ \mu\text{m} \leq x < 2\ \mu\text{m}$) in *J. excelsa*.

- Thickness of the tangential walls of radial cells

Thinner than the transverse walls in *J. thurifera*; equally thick in *J. excelsa*.

- Cross-field pits

Up to 3 pits per field in *J. thurifera*; up to 4–5 pits in *J. excelsa*.

Marginally positioned in the inner ray cells of *J. excelsa*.

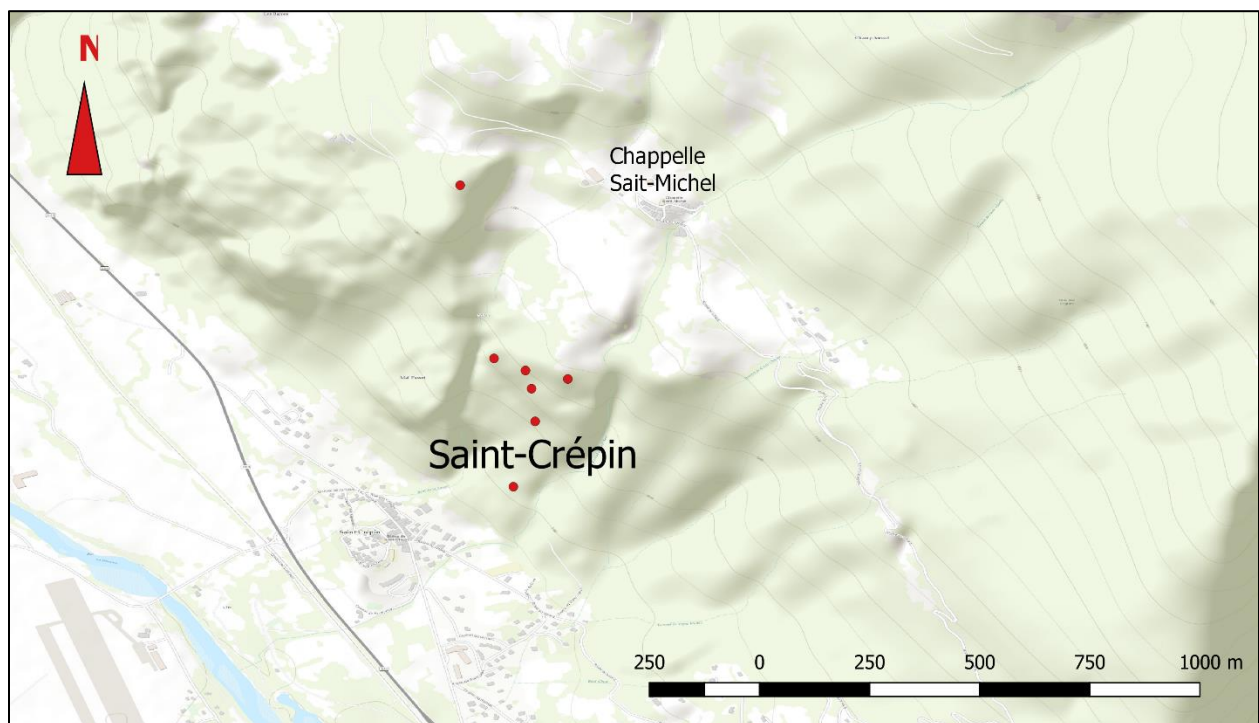


Fig. 6. Location of the boreholes (1 and 2) and *relevé* points (1 to 7) in Saint-Crépin.

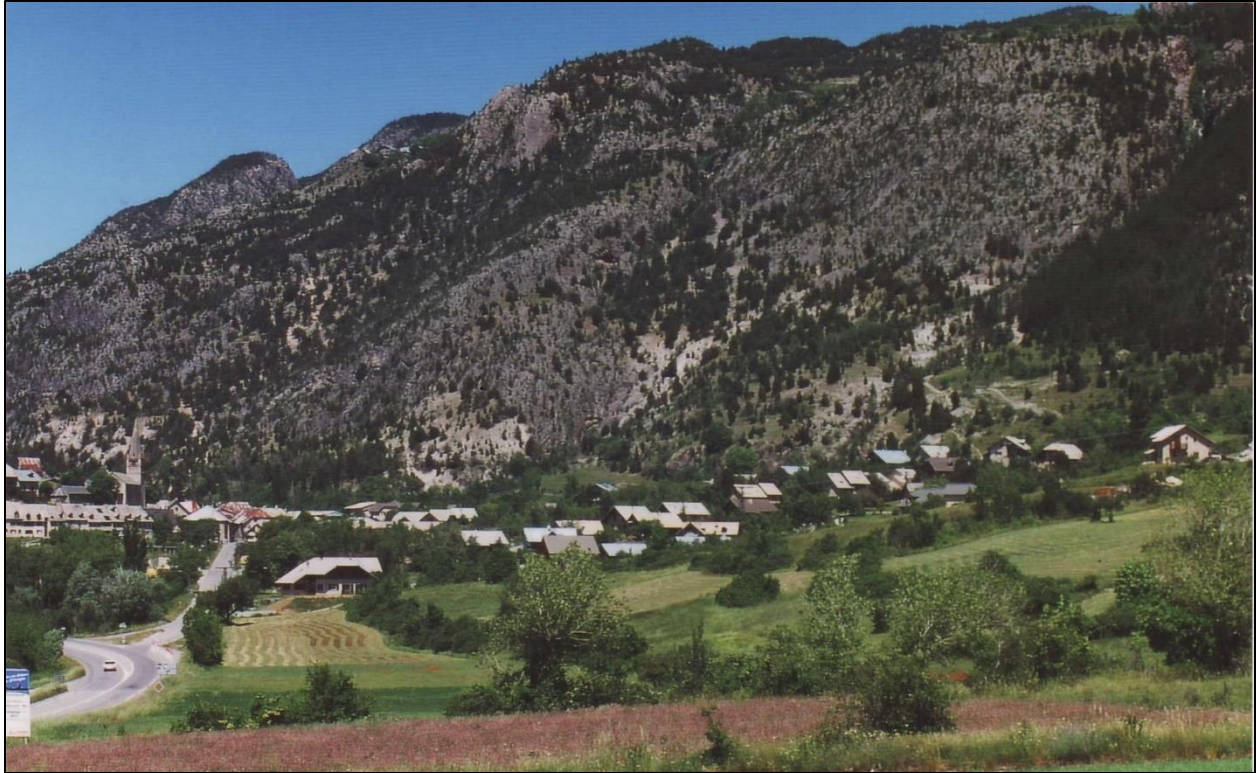


Fig. 7. General view of the Saint-Crépin site.

3.2 – The Saint-Crépin Site

3.2.1 – Current Floristic Data

The five floristic *relevés* carried out at Saint-Crépin are presented in the Appendix. These *relevés* provide an overview of the present floristic assemblage of the *J. thurifera* woodland at different points within the stand (Figure 6). *relevés* 1 and 2 correspond respectively to the Saint-Crépin 1 and Saint-Crépin 2 sampling pits.

Because pedoanthracological investigations require soils of sufficient depth and gentle slope, it is logical that the corresponding floristic *relevés* are those showing the greatest herbaceous cover. The other *relevés* were conducted on relatively steep slopes with more or less extensive rocky outcrops, favorable to various saxicolous taxa or species associated with very shallow soils, such as *Anthyllis* spp., *Sedum* spp., *Sempervivum*, *Paronychia*, *Asplenium*, etc.

It may be noted that five out of seven *relevés* include *J. thurifera* in the low shrub layer, indicating that the species regenerates satisfactorily. It can also be observed that few trees exceed 5 m in height; apart from a few very old individuals, the stand is composed mainly of relatively young trees. Among all the taxa recorded, a significant proportion (indicated in green in the original surveys) belongs to the floristic assemblage of deciduous oak forests.

3.2.2 – Results of the Pedoanthracological Analysis

A first soil profile (Saint-Crépin 1) was sampled near the upper part of the stand, at 1,240 m elevation, at the edge of a hay meadow and immediately above the main escarpment (Figure 8). Four levels were sampled (Figure 9), down to a depth of 1.2 m (Table III).

Saint-Crépin 2 is located at the base of this escarpment, at 1,020 m elevation, above the last agricultural terraces (Figure 10). Because the soil was shallower, only three levels were sampled (Figure 11).

Comparison of these two profiles (Figure 12) shows that Saint-Crépin 1 is markedly richer in wood charcoal than Saint-Crépin 2 (mean specific anthracomass = 91.8 versus 33.2). The figure also shows that wood charcoal quantities generally decrease with depth, although increases occur at certain intermediate levels. This phenomenon is consistent with observations reported in other studies (Thinon, 1992; Ouédraogo, 1995).

Table 3. Depth of Each Sampling Level and Mass of Soil (Elements < 5 mm) Collected at Each Site.

Profiles	Level I		Level II		Level III		Level IV	
	Soil Mass (kg)	Depth (cm)	Soil Mass (kg)	Depth (cm)	Soil Mass (kg)	Depth (cm)	Soil Mass (kg)	Depth (cm)
Saint-Crépin 1	7.860	15–30	9.980	40–55	7.223	70–85	13.560	85–120
Saint-Crépin 2	9.115	15–25	11.050	30–45	9.830	50–65	—	—
Al-Khasha	7.145	5–20	7.560	30–50	—	—	—	—

3.2.2.1 – Granulometric Sampling and Fragmentation

As previously observed, the mass (and number) of charcoal fragments to be studied varies among soils and even within a single soil profile. For Saint-Crépin 1 and 2, the number of charcoal fragments larger than 500 μm reached 3,363 and 2,057 respectively. Under these conditions, identifying all charcoal fragments would require excessive time, making it necessary to carry out a rational sampling strategy.

We therefore performed a granulometric segregation of charcoal fragments within each level, separating them into four size classes: ≥ 1.25 mm, < 1.25 –1 mm, < 1 –0.8 mm, and < 0.8 –0.5 mm. Figure 14 shows the distribution of anthracomass among these classes throughout the entire profile of soil 1. The first two classes contain a large proportion of the charcoal mass.

Furthermore, comparison of anthracomass and charcoal fragment number within each soil level (Table IV, Appendix, and Figure 14) indicates that identification effort is optimal when restricted to the first two classes. The smaller classes may essentially result from fragmentation of charcoal fragments belonging to larger classes. However, identifying only charcoal fragments larger than 1 mm could lead to overlooking taxa producing fragile charcoal, which may undergo stronger fragmentation. Consequently, for each level of both soils, all charcoal fragments ≥ 1 mm were identified, and a random sample of 40 charcoal fragments was taken from each of the two smaller size classes (see Appendix, Table IV).



Fig. 8. Saint-Crépin 1 station with *Juniperus thurifera* on the right side.



Fig. 9. Soil profile of the Saint-Crépin 1 station.



Fig. 10. Saint-Crépin 2 station at the base of the escarpment, with regeneration of *Juniperus thurifera*.



Fig. 11. Soil profile of the Saint-Crépin 2 station.

Wood charcoal fragments contained within soils have undergone, and continue to undergo, fragmentation due to various factors (Thinon, 1992). Some fragmentation originates during carbonization itself, as pyrolyzed elements undergo contraction stresses leading to the appearance of more or less orthogonal fissures characteristic of carbonized wood and oriented according to the structural organization of woody tissues.

Other fragmentation processes, mainly mechanical in origin, occur during the residence time of charcoal at the soil surface and later within the soil: action of atmospheric and biological agents (freeze–thaw cycles, trampling), volumetric changes in clays, compression and displacement induced by root growth, activity of soil fauna, etc.

This fragmentation, which continues over time, explains the decrease in specific anthracomass with depth (Figure 12). Likewise, Figure 14, comparing charcoal number and anthracomass for each soil level, shows that deeper horizons contain an increasing proportion of smaller fragments.

3.2.2.2 – Pedoanthracological Diagrams

The general results are summarized in the diagrams presented in Figures 15 and 16, where three taxa clearly dominate in both sampled profiles: *Pinus type sylvestris* (Scots pine anatomical group), *Larix decidua* (European larch), and *Juniperus* sp. (juniper species undetermined).

The indeterminate identifications result from anatomical difficulties. Three French pine species belong to the same anatomical group as *Pinus sylvestris*: besides the latter, *Pinus uncinata* (mountain pine) and *Pinus nigra* (black pine sensu lato) are extremely similar and, according to current knowledge, often impossible to distinguish anatomically.

Within the framework of this study, and considering the ecological characteristics of the investigated sites, these remains most probably correspond to *Pinus sylvestris*.

For junipers, which are also anatomically extremely similar, the condition and size of the charcoal fragments only rarely allowed identification at the species level. Three juniper species occur at the site (*J. thurifera*, *J. communis*, and *J. sabina*), and although *J. thurifera* appears to be the dominant species, all juniper charcoal fragments were grouped together.

Secondly, six additional taxa appear in both sampled profiles: deciduous *Quercus sp.* (deciduous oak), *Acer sp.* (maple), *Berberis vulgaris* (barberry), *Prunus spinosa* (blackthorn), *Rosa sp.* (wild rose), and an unidentified Fabaceae. Other taxa were observed only in one soil profile, sometimes

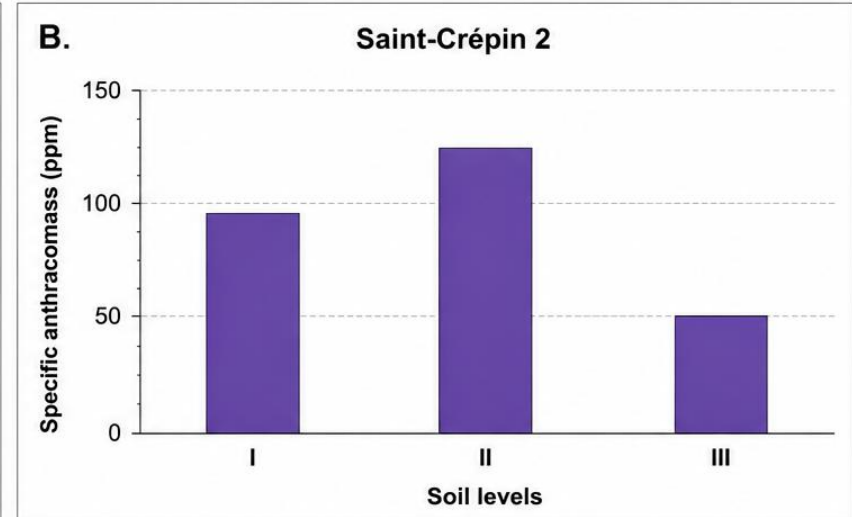
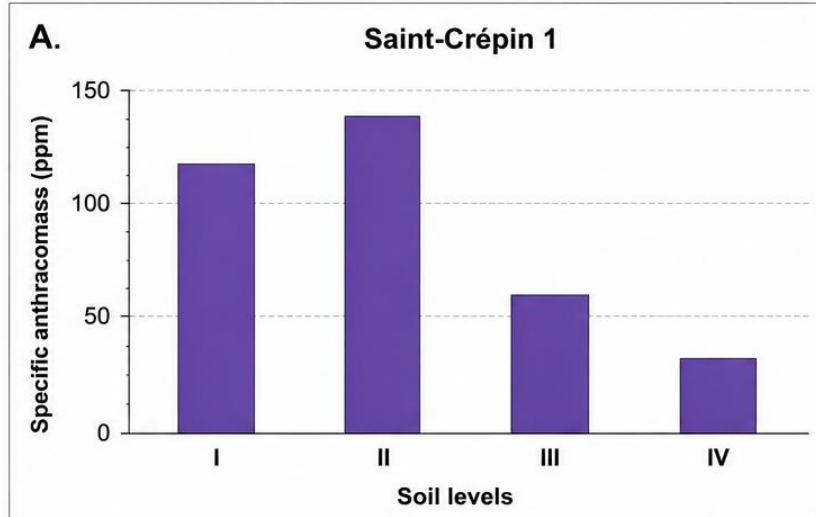


Figure 12. Specific anthracomass by soil level for charcoal fractions larger than 0.5 mm.

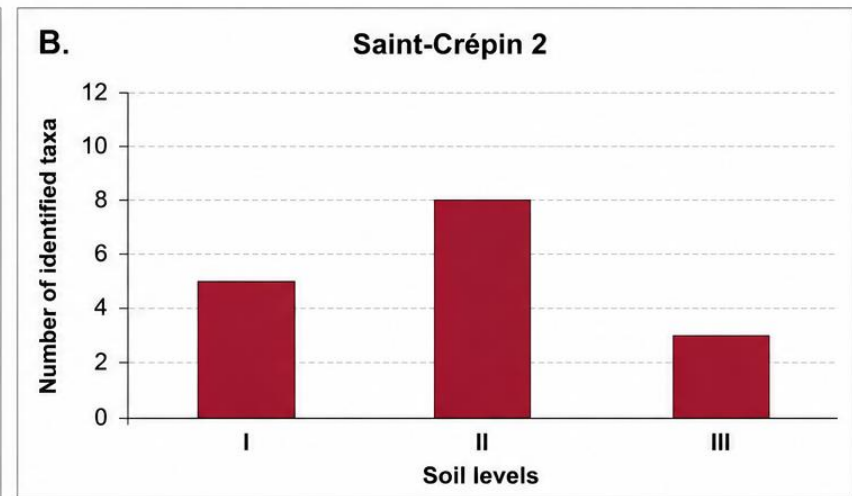
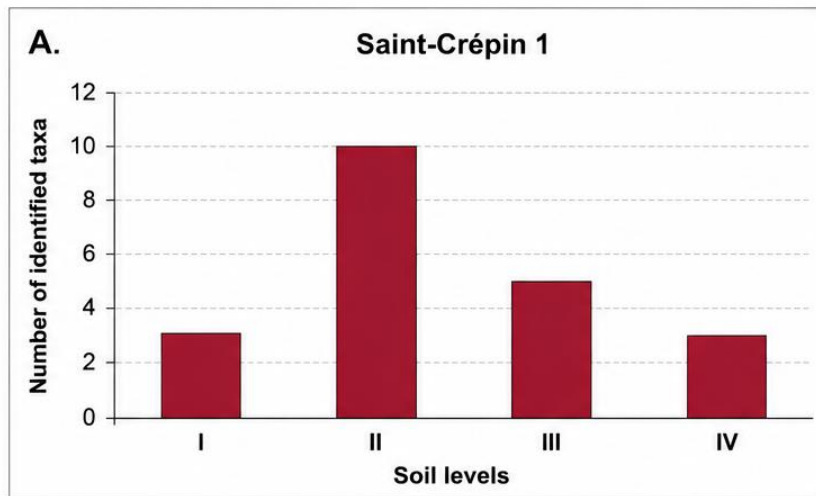


Figure 13. Number of identified taxa at the different soil levels of Saint-Crépin.

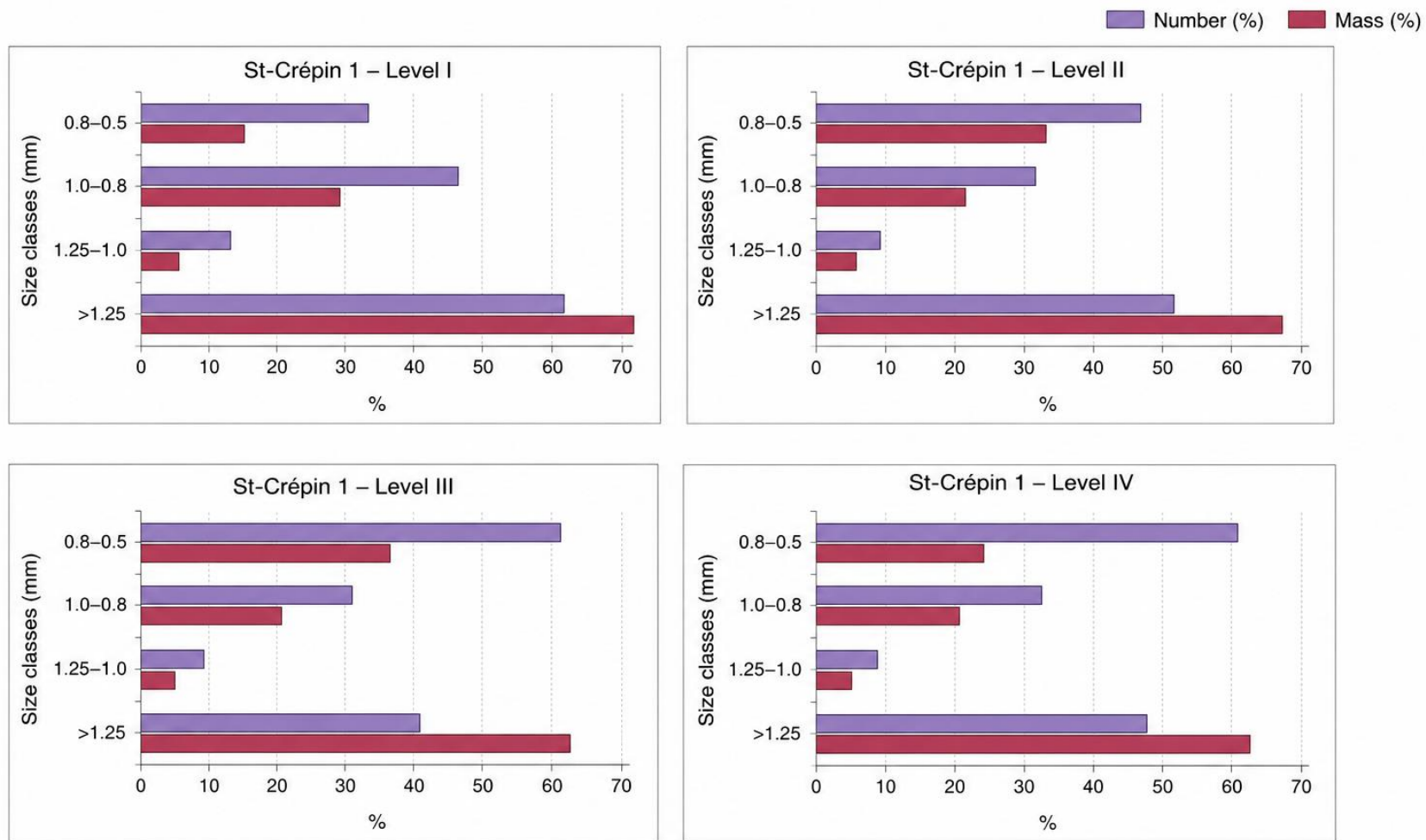


Fig. 14. Comparison of mass and number according to size classes for each level of Saint-Crépin 1.

restricted to two levels, such as *Fraxinus excelsior* (European ash) and *Salix* sp. (willow). Finally, *Alnus incana* (grey alder), *Populus* sp. (poplar), *Amelanchier ovalis* (serviceberry), and *Astragalus* sp. were recorded only in a single level. The same difficulties in species-level identification apply to deciduous oaks, poplars, willows, and, to a lesser extent, maples.

A certain fraction of the charcoal remains indeterminable because of the absence of diagnostically relevant anatomical information. This concerns mainly vitrified and scoriaceous charcoal fragments and, to a lesser extent, parenchymatous or cortical masses, often attributable to herbaceous plants.

Qualitative Interpretation

Saint-Crépin 1

From a qualitative point of view, the lower levels are richer in taxa (Figure 18). In level IV, in addition to *Pinus*, *Larix*, and *Juniperus*, the presence of deciduous *Quercus*, *Acer*, *Populus*, *Berberis*, and an unidentified Fabaceae is recorded. All these taxa indicate a relatively mesophilous environment with a certain degree of openness. *Berberis vulgaris* (and to a lesser extent *Juniperus*) is a heliophilous residual species associated with grazing pressure, thus reflecting pastoral activity.

In level III, the arboreal deciduous taxa *Quercus* and *Populus* disappear, while only *Acer* remains. *Berberis* is replaced by *Prunus spinosa* and *Rosa*, which have similar ecological significance.

With regard to the species currently present in the region, *Quercus* may correspond to *Q. petraea* (Mattuschka) Liebl. and/or *Q. pubescens* Willd.; *Populus* to *P. nigra* L. or *P. tremula* L.; and *Acer* to *A. monspessulanum* L., *A. opalus* Miller, *A. campestre* L., or *A. pseudoplatanus* L.

The two upper levels are less diversified; apart from the triad *Pinus–Larix–Juniperus*, only the thorny shrub *Berberis* persists in level II. It should be noted that this level contains a high proportion of indeterminable charcoal fragments, most often vitrified. This level also exhibits the highest specific anthracomass (Figure 12), and may therefore correspond to a phase of intensified burning.

St-Crépin 1
1240 m

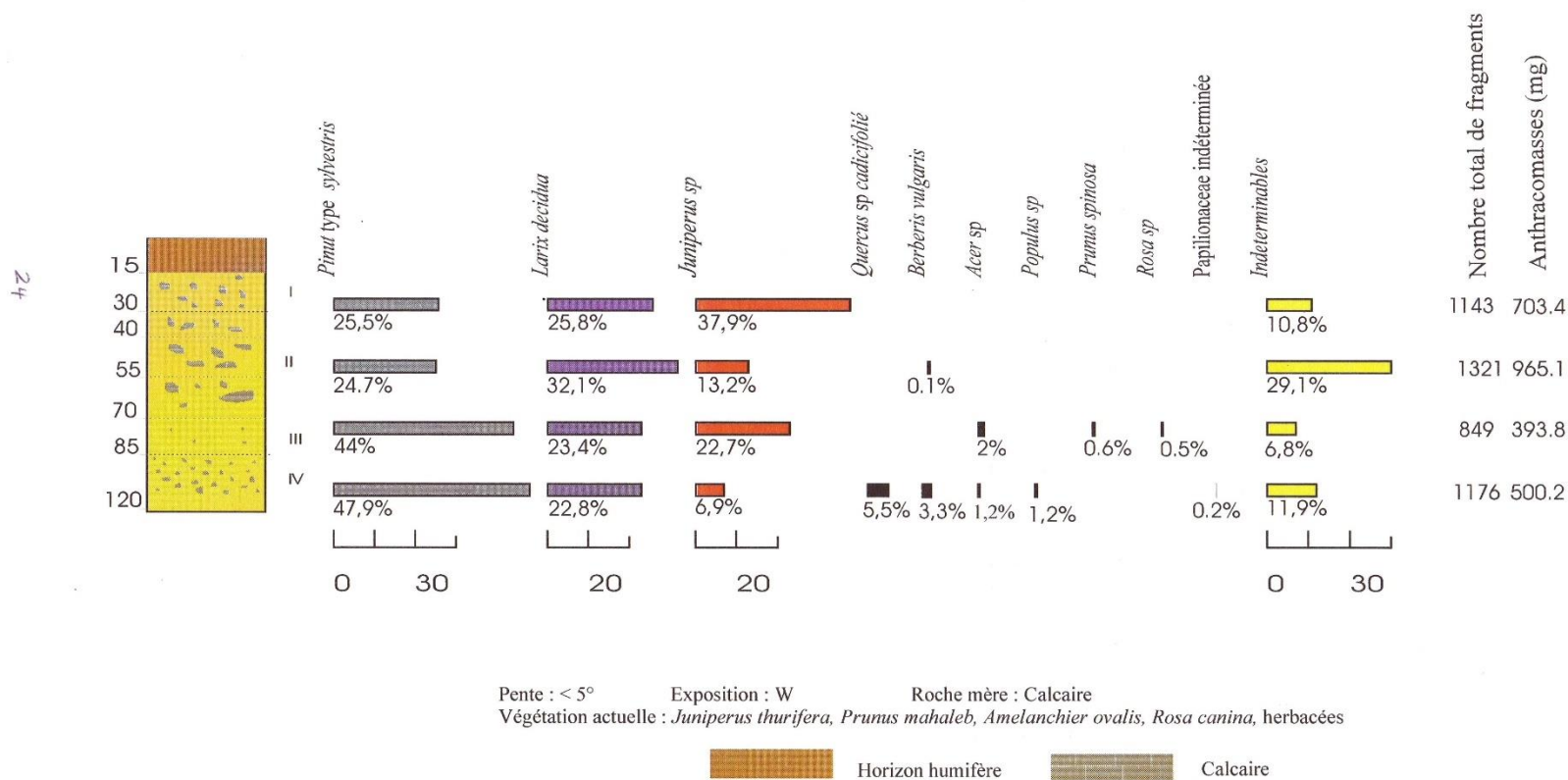


Fig. 15. Results of the pedoanthracological analysis of Saint-Crépin 1 expressed as relative anthracomass by level (ARN%).

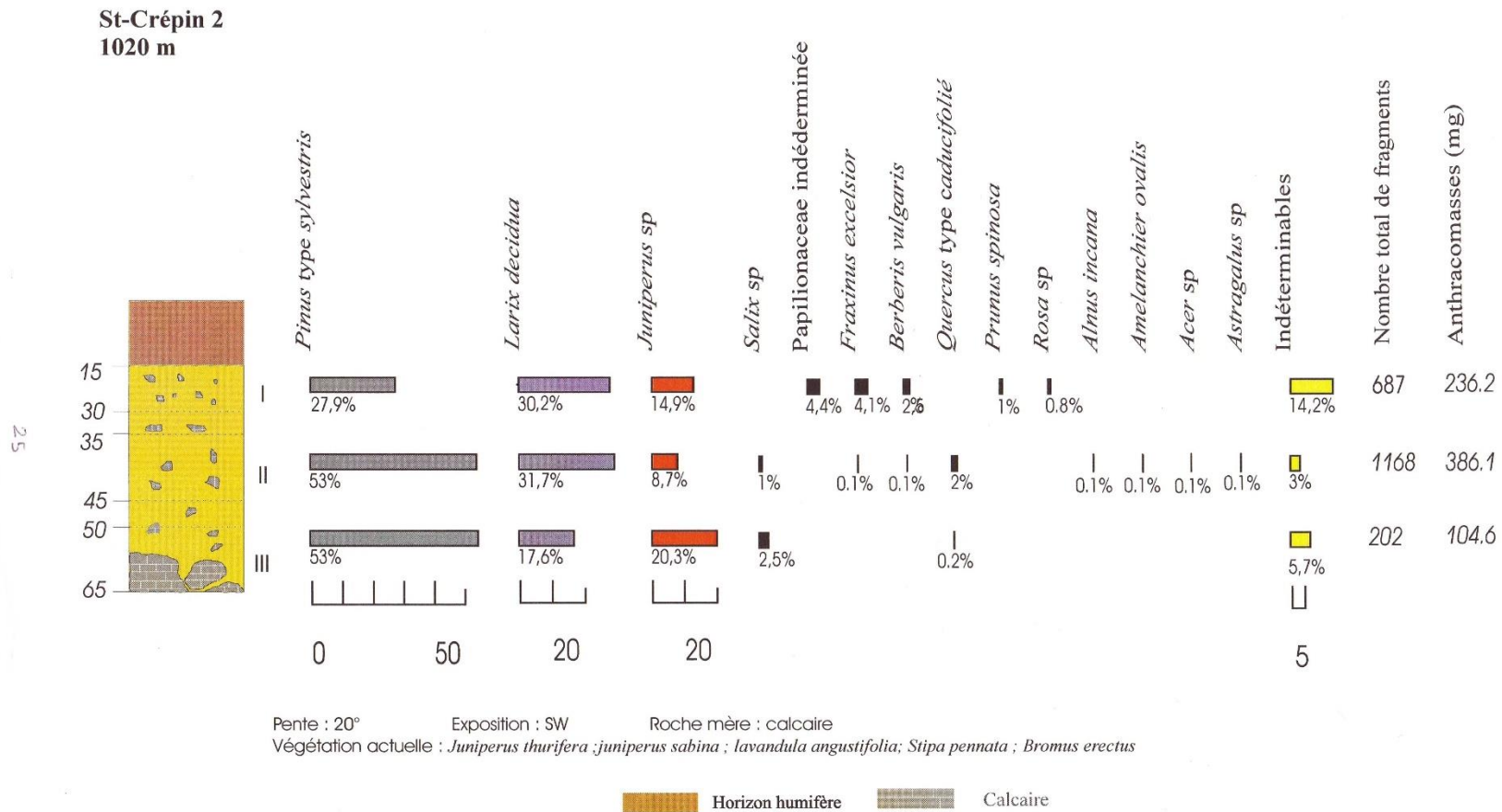


Fig. 16. Results of the pedoanthracological analysis of Saint-Crépin 2 expressed as relative anthracomass by level (RAN%).

The disappearance of angiosperms and the persistence of heliophilous conifers indicate increasing opening and degradation of the environment, reaching a maximum in level I.

Saint-Crépin 2

In contrast to the previous soil profile, the two upper levels display greater taxonomic richness (Figure 13), even exceeding that of Saint-Crépin 1. Certain taxa such as *Salix*, *Alnus*, an *Fraxinus* (as well as *Populus* in soil profile 1) indicate a certain degree of edaphic humidity. About thirty meters south-east of the sampling site lies the ravine of the Lauze stream and, on the opposite side at approximately the same distance, a small spring maintains humid soil conditions. Nevertheless, a few young individuals of *Fraxinus excelsior* were observed growing on rocky ledges outside these humid zones, as well as old *Populus nigra* individuals established on soils similar to those of profile 1, near the upper limit of the escarpments.

Level III contains charcoal fragments of the three constant taxa found in the previous soil profile: *Pinus*, *Larix*, and *Juniperus*, together with deciduous *Quercus* and *Salix*. Except for *Quercus*, which is a forest species but may tolerate relatively open conditions, all these taxa are heliophilous and indicate an open environment.

In level II, *Fraxinus*, *Acer*, *Alnus*, *Amelanchier*, *Berberis*, and *Astragalus* are added. This level, the most diversified, remains relatively open but appears distinctly more wooded.

Level I, slightly less diverse, is characterized by the disappearance of deciduous arboreal taxa (*Quercus*, *Acer*, *Alnus*) and the appearance of thorny shrubs such as *Prunus spinosa* and *Rosa*. All taxa present are heliophilous, and the occurrence of thorny shrubs reflects pastoral activity.

It should be noted that the foliage of *Fraxinus excelsior* is frequently used as fodder through pollarding practices, which may explain the tolerance or even promotion of this species.

Quantitative Interpretation

Quantitative data must be used with caution and should remain subordinate to the qualitative approach, since no invariant relationship is known between the vegetation affected by fire and the quantity of charcoal ultimately observed under the analyst's microscope.

Saint-Crépin 1

Among the three dominant taxa, *Pinus* and *Juniperus* show generally opposite trends, whereas *Larix* remains relatively stable (Figure 15).

At greater depth, *Pinus* is largely dominant (47.9%), whereas *Juniperus* reaches its lowest value (6.9%), only slightly higher than that of *Quercus* (5.5%). The other taxa display very modest percentages, compatible with the vegetation landscape reconstructed from the anthracological assemblage and consistent with their disappearance in the overlying level.

If one considers that, among the three dominant taxa, *Juniperus* is the most resistant to environmental degradation, its dominance in level I is entirely consistent with the previous qualitative interpretation.

Saint-Crépin 2

In this pedoanthracological profile, the same three taxa are also clearly dominant (Figure 16). Contrary to profile 1, *Juniperus* is more strongly represented in the deepest level (20.3%).

In this same level III, *Larix* displays a similar proportion (17.6%), whereas *Pinus* clearly dominates (53%).

In level II, *Pinus* remains constant, while *Larix* increases (31.7%), in contrast to *Juniperus*, which reaches its lowest value (8.7%). It is in this level that *Quercus* appears, although at a low percentage (2%), together with seven additional taxa, three of which may be arboreal.

In level I, *Pinus* decreases (27.9%), *Larix* remains stable (30.2%), whereas *Juniperus* increases markedly (14.9%), while three deciduous arboreal taxa disappear.

The increase of *Larix* and the regression of *Juniperus* in level II, together with the appearance of four arboreal taxa, seem to reflect a certain closure of the environment. This level displays the greatest taxonomic richness (Figure 13). The increase of *Juniperus* at the expense of *Pinus* in level I, accompanied by a decrease in deciduous arboreal taxa, appears to be correlated with a phase of degradation that nevertheless remained moderate. *Fraxinus* is relatively well represented (4.1%), which supports the previously proposed hypothesis of pastoral use.

Synthetic Interpretation

Comparison of the qualitative and quantitative data leads essentially to the same conclusions. The comparison between the two profiles reveals a relative similarity, although the history of each soil appears different.

In Saint-Crépin 1, the greatest taxonomic richness (Figure 13), which seems to correspond to minimal disturbance, occurs in the deepest levels. The history of this soil would therefore indicate a constant increase in degradation leading to the present-day state, which is almost completely deforested (floristic *relevé* no. 1).

The Saint-Crépin 2 profile appears to have a more complex history. The upper levels, particularly level II, are the richest in taxa. In this respect, there is a marked discontinuity between levels II and III that only dating analyses could explain.

This soil lies directly upslope from agricultural terraces, and it may be assumed that the area, which is relatively steep (20°), underwent strong erosion during a period of pastoral exploitation, followed by relative stabilization associated with more agricultural land use after the establishment of the village of Saint-Crépin, already mentioned in the 11th century (Lathuillière, 1994).

The same author reports a non-negligible viticultural activity. Braun-Blanquet (1922) noted in the Haute-Durance region “a relative abundance of broadleaved species near inhabited places and cultivated fields, depending largely on human practices which, in this conifer-dominated region, protect and favor broadleaved trees.”

However, descriptions of the *J. thurifera* woodland during the first half of the 20th century (Pons, 1922; Guinier, 1931) indicate an environment subjected to intense grazing and almost entirely devoid of vegetation other than juniper, suggesting that this degraded state represented only the culmination of much earlier degradation processes.

At both stations, a very clear dominance is observed, in the same order of abundance, of *Pinus*, *Larix*, and *Juniperus*, accompanied by six other common taxa appearing in at least one level (*Quercus* deciduous type, *Acer* sp., *Berberis vulgaris*, *Prunus spinosa*, *Rosa* sp., and an unidentified Fabaceae), i.e., 9 common taxa out of 15.

Among the six remaining taxa, three are associated with seepage areas or humid soils. These nine common taxa may therefore be considered as belonging to the vegetation dynamics of areas currently occupied by *J. thurifera*.

3.3 – The Ras-Al-Maara Site

3.3.1 – Current Floristic Data

The two floristic *relevés* from Ras-Al-Maara are presented in the Appendix. The first was conducted at the pedoanthracological sampling station at Al Khashaa, approximately 6 km from Ras-Al-Maara, at around 2,300 m elevation. The second *relevé* comes from the same area, at Juret Al-Sahen, around 2,200 m elevation.

Relevé 1 is very poor in species (12 taxa), half of which are represented by low woody plants dominated by two *Astragalus* species, spiny xerophytes selected by grazing pressure (Figure 17). The rare herbaceous species are likewise grazing-resistant remnants. *Relevé 2* is richer, but two-thirds of the taxa are woody species (Figure 18). In their overwhelming majority, the species present are thorny, toxic, or otherwise repellent.

3.3.2 – Results of the Pedoanthracological Analysis

The soil at Al Khasha was sampled at two levels: 5–20 cm and 30–50 cm, corresponding respectively to sediment masses of 7.145 kg and 7.560 kg. Level II proved sterile with regard to wood charcoal, whereas level I yielded only 71 very small charcoal fragments totaling 11.2 mg. All these charcoal fragments were attributable to *Juniperus excelsa*. A posteriori landscape analysis from photographs and soil examination showed that the sampled sediment corresponded to the lower horizon of a much thicker soil profile that had been severely truncated by erosion. The spiny xerophytes, largely dominant at the site, represent the ultimate stage preceding mineral desertification, and bedrock is extensively exposed. These xerophytes generally occur in highly degraded *J. excelsa* stands (Figure 17).

During a phase of relative stabilization of erosion, *J. excelsa* may have recolonized the site, and its charcoal fragments may have been preserved within the surface horizon, this horizon being devoid of older charcoal because such remains would have been buried too deeply within the original soil profile. Radiocarbon dating would be necessary to test this hypothesis.

These highly disappointing results appear to be explained by the characteristics of the soil itself. The survey was conducted under unfavorable conditions (a military border zone difficult to



Fig. 17. Al-Khashaa station: *Juniperus excelsa* and cushion thorn vegetation on highly eroded soil.



Fig. 18. Structure of the woody vegetation at the Juret Al-Sahen station.

access), the region being extremely degraded and every small patch of soil (sometimes less than 1 m²) being used for cultivation, making it difficult to locate suitable soil for sampling.

Furthermore, this sampling campaign was carried out before our departure from Syria, following the instructions of our internship supervisor, at a time when we lacked the practical experience that, in retrospect, would probably have led us to select a different type of soil.

4 – Discussion

The results obtained for *Juniperus excelsa* in Syria do not allow direct comparison with those concerning *Juniperus thurifera* at Saint-Crépin. The latter, however, clearly demonstrate the former presence of deciduous arboreal taxa (*Quercus*, *Acer*, *Fraxinus*) that are still encountered today within the *thurifera* juniper woodland zone. Present-day individuals show good vitality and are generally young, in agreement with historical descriptions of the site (Pons, 1922; Guinier, 1931).

The expansion of broadleaved species is a direct consequence of the abandonment of traditional agro-pastoral practices, a process observable throughout industrialized Europe. Study of the floristic *relevés* indicates that a very large proportion of species can be assigned to communities belonging to, or derived from, deciduous oak forests.

At Saint-Crépin, juniper is currently often associated with Scots pine (*Pinus sylvestris*) (Barbero & Quézel, 1986; Lathuillière, 1994), which is also clearly reflected in the pedoanthracological data. This pine readily colonizes degraded stages of deciduous oak forests, extending into the mesomediterranean zone, as illustrated by the population of the Chaîne de l'Étoile at north of Marseille. By contrast, the soils contain a substantial proportion of *Larix* charcoal, although this species is not currently associated with *J. thurifera* and has not been reported by previous authors. European larch (*Larix decidua*) is known for its colonizing behavior and can descend to relatively low elevations. We observed it growing together with Scots pine at 890 m altitude, approximately 5 km southwest of Saint-Crépin, between Mont-Dauphin and Saint-Clément-sur-Durance. Lavagne (1964) refers to *mélèze per descensum* in the Ubaye Valley, where it is sometimes associated with pubescent oak. Sandoz (1987) likewise reports its occurrence at only 240 m

altitude in the southern Alps. In any case, the abundance of larch at Saint-Crépin is a genuine feature and should not be surprising, since this species is widespread in the region and associated with several other taxa.

In this regard, Braun-Blanquet (1922) considered larch forest (*Larix*) to represent the terminal stage in the evolution of grazed grasslands on acidic rocks and deep calcareous soils, whereas in very dry sites he regarded Scots pine woodland with *Astragalus* as more characteristic.

Archiloque and Borel (1965) linked the Saint-Crépin thurifera juniper woodland to a marginal series of the southern Alpine thurifera formations, embedded within the range of pubescent oak forest. Ozenda (1966) argued that more than three-quarters of the preferential species identified by these previous authors actually belong to communities closely associated with the submediterranean pubescent oak forest (today generally termed supramediterranean). Consequently, he considered Alpine thurifera woodlands to be merely “simple rupicolous communities characteristic of the submediterranean pubescent oak series, especially in its lower stage.” Following this interpretation, the Saint-Crépin thurifera woodland, where *Buxus sempervirens* and *Genista cinerea* are absent, should be regarded as a rupicolous community of the internal pubescent oak series. Ozenda himself included this section of the Durance Valley within that series.

More recently, Barbero and Quézel (1986) distinguished several types of thurifera woodlands and assigned that of Saint-Crépin to a preforest community of the internal Scots pine series. These authors considered the thurifera woodland to be a pre-steppe formation in the sense of Abi-Saleh, Barbero, and Quézel (1976): a “community lacking its own true forest species because of thermal and edapho-hydric constraints, and in which the same species are found in both the potential vegetation and the degradation shrublands.”

The pedoanthracological results support Ozenda’s interpretation because, despite climatic conditions that may appear severe, deciduous taxa were present. Their charcoal remains show that even during periods of strong disturbance, evidenced by the use of fire, these taxa were able either to persist or to establish themselves. The abundance of larch also demonstrates that the climatic and edaphic conditions are favorable to this species, which is far more demanding with respect to water availability than Scots pine. This latter observation argues against integrating the stand into the internal Scots pine series.

The first results of a pedoanthracological study conducted in high-altitude non-forest regions of Morocco (Thinon, personal communication) show that charcoal fragments of *Juniperus thurifera* there are frequently associated with those of deciduous broadleaved taxa and oaks.

Chronological aspects, which are of major importance, are unfortunately lacking. A palynological study carried out by Beaulieu (1977) at the small lake of Roche-de-Rame, situated at 950 m altitude approximately 5 km north-northwest of Saint-Crépin (Figure 2), nevertheless allows some comparisons.

The presence of pollen in this isolated lake is related not only to the proximity of pollen-producing taxa, but also to the dispersal capacities of their pollen and to the direction and intensity of winds during the flowering period. The pollen diagram provides a rather regional picture since *Fagus*, which does not occur in the valley, is represented, whereas *Berberis* and *Rosaceae* (*Prunus*, *Amelanchier*, *Rosa*) are absent. Figure 19 presents the upper portion of this reference diagram, covering approximately the last four millennia.

If the presence of *Acer* in the charcoal assemblages is taken into account, the pedoanthracological profiles would be contemporaneous with this upper section (Subboreal and Subatlantic periods), during which *Acer* is most strongly represented. All the arboreal taxa identified in the charcoal assemblages are also present in the pollen record, with *Pinus*, an overrepresented pollen producer, being dominant and deciduous *Quercus* occupying second place. *Juniperus* (including *J. thurifera*) is currently well established in the immediate vicinity of the lake, and its pollen was also well represented in the past. Anthropogenic influence is reflected by cereals (especially at the base of the Subatlantic period) and by the development of *Plantago* and *Artemisia* (grasslands and pastures).

This comparison with palynological data suggests that the pedoanthracological profiles date back at least to the last two millennia. Only chronological dating methods will be able to confirm this hypothesis.

5 – Conclusion

The very marked disparity between the results obtained at the Saint-Crépin site in France, occupied by *Juniperus thurifera*, and those from Ras-Al-Maara in Syria, colonized by *Juniperus excelsa*, does not permit direct comparison between the stands of these two species, although they are considered vicariant taxa.

Only the results from Saint-Crépin provide insight into the historical development of *thurifera* juniper woodland, at least over the last millennium, and probably over a much longer period. Despite the absence of chronological markers, the changes recorded by disturbance indicators (particularly fire) are essentially of anthropogenic origin.

The study of the two stations, Saint-Crépin 1 and Saint-Crépin 2, selected according to the altitudinal range of the stand, provides comparable information concerning the constitution of the burned vegetation communities. The essential result is the presence of deciduous arboreal taxa, especially *Quercus* and *Acer*, which form the structural basis of deciduous forests. These are accompanied by other heliophilous deciduous trees such as *Fraxinus excelsior*, *Populus*, *Salix*, and *Alnus incana*, the latter three being more or less associated with seepage zones and humid soils. Other thorny deciduous shrubs and small trees, including *Berberis vulgaris*, *Prunus spinosa*, and *Rosa*, are indicators of pastoral activity.

The floristic study of the present-day vegetation demonstrates a more or less abundant occurrence of most of these taxa, together with the accompanying herbaceous flora. These plants appear to be expanding following the abandonment, or strong decline, of pastoral practices.

Secondly, the constant and abundant presence of larch (*Larix decidua*) can be noted as the only deciduous conifer. Although abundant in the region, it does not appear to occur today within the various *thurifera* juniper woodlands of the Alps. Its presence also indicates that the xeric character of the environment, so often emphasized, is only apparent and that vegetation may evolve beyond xeric Scots pine woodland.

The past and present occurrence of these various taxa makes it possible to regard the *Juniperus thurifera* woodland of Saint-Crépin as a degradation facies, more or less rupicolous, of deciduous oak forest. This interpretation supports the view of Ozenda (1966) and opposes other conceptions that consider the various *Juniperus thurifera* stands either as a distinct entity (Archiloque & Borel,

1965) or as several distinct entities (Barbero & Quézel, 1986) determined by natural climatic and edaphic conditions.

Our results concern only the Saint-Crépin thurifera woodland and do not prejudge the situation of other stands, which could be investigated further through additional soil coring. This study demonstrates that the status of the various *Juniperus thurifera* formations should not rely solely on floristic and climatic-edaphic analyses, but must also take into account the historical trajectories of these stands. Owing to its high spatial precision, pedomorphology proves to be a particularly valuable tool for this type of investigation.

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Appendices



Figure X. Charcoal of *Juniperus excelsa*, cross-field (3D digital tomosynthesis, ×1000)

Description

Three-dimensional view of a charcoal fragment of *Juniperus excelsa* in cross-field, obtained by 3D digital tomosynthesis at ×1000 magnification.

Anatomical features

- Left (radial section): rows of bordered pits on the tracheid radial walls.
- Right (tangential section): uniseriate ray parenchyma composed of procumbent cells with smooth to finely nodular walls.
- Bottom: longitudinal section showing tracheids with thick walls and helical thickenings.

Interpretation

The combination of uniseriate rays (one cell width), the presence of bordered pits in the radial walls of tracheids, and helical thickenings is diagnostic of the Cupressaceae, genus *Juniperus*.

Scale

Scale bar = 10 μm (micrometres).

Relevé of Saint-Crépin	1	2	3	4	5	6	7
Slope (°)	>5	20	50	35	20	25	25
Altitude (m)	1240	1020	1125	1120	1190	1300	1300
Exposure	W	SW	W	SW	SW	SW	SW
Substrate	Calcareous	Calcareous	Calcareous	Calcareous	Calcareous	Calcareous	Calcareous
Tree layer > 5 m							
Percentage cover (%)	0	5	0	5	<5	0	0
<i>Juniperus thurifera</i> L.	–	1.1	–	1.2	+1	–	–
Low tree layer (2–5 m)							
Percentage cover (%)	10	20	25	5	<10	10	30
<i>Juniperus thurifera</i> L.	2.2	2.2	2.2	1.1	+1	2.2	3.3
<i>Quercus pubescens</i> Willd.	–	–	1.2	–	–	–	–
<i>Pinus sylvestris</i> L.	–	–	1.1	–	–	1.1	–
<i>Juniperus communis</i> L.	–	–	–	–	1.1	–	–
Upper shrub layer (between 0.5 and 2 m)							
Percentage cover (%)	20	10	35	15	15	10	15
<i>Amelanchier ovalis</i> Medik.	+1	–	2.2	1.1	+	–	+1
<i>Juniperus thurifera</i> L.	–	1.2	3.2	2.1	1.1	+	–
<i>Juniperus communis</i> L.	–	–	–	+1	+1	1.1	2.2
<i>Prunus mahaleb</i> L.	3.3	+	1.2	–	–	–	–
<i>Rosa canina</i> L.	1.1	+	+	–	+1	–	–
<i>Berberis vulgaris</i> L.	–	+	–	–	+1	–	–
<i>Sorbus aria</i> (L.) Crantz	–	–	–	–	+	–	+
<i>Viburnum lantana</i> L.	–	–	–	–	1.1	+	+
<i>Crataegus monogyna</i> Jacq.	–	–	–	–	+1	–	–
<i>Fraxinus excelsior</i> L.	+	–	–	–	–	–	–
<i>Pinus nigra</i> Arnold	–	–	–	–	+1	–	–
Lower shrub layer (< 0.5 m)							
Percentage cover (%)	10	15	15	10	10	10	10
<i>Lavandula angustifolia</i> Miller subsp. <i>Angustifolia</i>	1.1	2.2	+	1.1	1.1	1.1	+
<i>Amelanchier ovalis</i> Medik.	1.1	+	1.2	–	+1	–	–
<i>Juniperus thurifera</i> L.	+1	1.1	1.1	1.1	+1	–	–
<i>Juniperus communis</i> L.	+	+	+	+1	–	–	–
<i>Prunus mahaleb</i> L.	+1	+1	1.2	–	–	–	–
<i>Rhamnus saxatilis</i> Jacq.	–	–	–	–	+1	1.1	1.1
<i>Hippophae rhamnoides</i> L.	–	–	–	–	1.1	1.1	+
<i>Juniperus Sabina</i> L.	–	2.5	–	–	–	–	1.1
<i>Artemisia alba</i> Turra.	+	+1	–	–	1.1	–	–
<i>Ligustrum vulgare</i> L.	–	1.1	+	–	–	–	–
<i>Berberis vulgaris</i> L.	–	–	–	–	+	+	+
<i>Prunus spinosa</i> L.	1.3	–	–	–	–	–	–
<i>Arctostaphylos uva-ursi</i> (L.) Sprengel	–	–	–	–	–	–	2.1
<i>Cornus sanguinea</i> L.	–	+	–	–	–	–	–
<i>Coronilla minima</i> L.	–	–	–	–	–	–	2.1
<i>Cotoneaster nebrodensis</i> (Guss.) C. Koch	–	–	–	–	–	–	+
<i>Fumana procumbens</i> (Dunal) Gren. & Godron	–	–	+	1.2	–	–	–
<i>Rhamnus alpina</i> L.	–	+	–	–	–	–	–
<i>Rosa canina</i> L.	+	+	–	–	–	–	–
Herbaceous layer							
Percentage cover (%)	70	80	15	45	15	20	–
<i>Sedum sediforme</i> (Jacq.) Pau	1.1	+	+	1.2	1.2	–	–
<i>Bromus erectus</i> Hudson	4.4	4.4	+	1.2	–	–	–
<i>Stipa pennata</i> L.	2.2	2.2	+	1.2	–	–	–
<i>Vincetoxicum officinale</i> Moench	1.1	–	1.1	1.2	1.2	–	–
<i>Thymus serpyllum</i> L.	+1	–	–	+1	+	+	1.1
<i>Odontites luteus</i> (L.) Clairv.	–	+	–	–	+1	1.1	1.1
<i>Anthyllis montana</i> L.	–	–	+	1.3	–	1.1	+
<i>Aristolochia pistolochia</i> L.	–	–	+1	+1	–	1.1	1.1
<i>Teucrium chamaedrys</i> L.	–	1.2	1.2	1.2	1.2	–	–
<i>Hippocrepis comosa</i> L.	1.2	1.2	–	1.2	–	–	–
<i>Koeleria vallesiana</i> (Honckeny) Gudln	–	1.1	–	1.2	+2	–	–
<i>Trinia glauca</i> (L.) Dumort.	–	2	–	1.1	–	+	–
<i>Lotus corniculatus</i> L.	1.1	1.1	–	–	+2	–	–
<i>Dianthus sylvestris</i> Wulfen	–	–	+	2.2	–	–	–
<i>Anthericum liliago</i> L.	–	–	+	+1	+1	–	–
<i>Hieracium pilosella</i> L.	–	+	–	+1	+1	–	–
<i>Thesium divaricatum</i> Ian ex Mert. & Koch	–	+	–	+1	+1	–	–
<i>Sedum dasyphyllum</i> L.	1.1	–	+	+1	–	–	–
<i>Stachys recta</i> L.	–	+	+	+1	–	–	–
<i>Festuca marginata</i> (hacket) K. Richter	–	–	–	2.2	2.2	–	–
<i>Sanguisorba minor</i> Scop	–	2	–	–	+1	–	–
<i>Coronilla minima</i> L.	–	–	–	1.1	1.2	–	–
<i>Festuca cinerea</i> Vill.	+	–	–	–	–	–	–
<i>Eryngium campestre</i> L.	1.1	1.1	–	–	–	–	–
<i>Helianthemum apenninum</i> (L.) Miller	1.1	1.1	–	–	–	–	–

+ : cover < 1% ; 1.1 : 1–5% ; 2.2 : 5–25% ; 3.3 : 25–50% ; 4.4 : 50–75% ; 5.5 : 75–100% ; – : absent

Relevé of Saint-Crépin	1	2	3	4	5	6	7
<i>Globularia cordifolia</i> L.				1.2			1.1
<i>Dictamnus albus</i> L.			1.2	+1			
<i>Galium cornudifolium</i> Vill.	1.1		1.1				
<i>Carlina vulgaris</i> L.		1.1			1.1		
<i>Astragalus vesicarius</i> L.		1.1			+1		
<i>Acinos arvensis</i> (Lam.) Dandy		+		+1			
<i>Echinops ritro</i> L.				1.1	+1		
<i>Globularia bisnagarica</i> L.		+		1.2			
<i>Aethionema saxatile</i> (L.) R. Br.			1.1	+1			
<i>Anthyllis vulneraria</i> L. subsp. <i>vulneraria</i>			+1	1.2			
<i>Astragalus monspessulanus</i> L.						1.1	+
<i>Artemisia alba</i> Turra	+	1.1					
<i>Potentilla neummanniana</i> Reichenb.		+		+1			
<i>Galium verum</i> L.		+			+1		
<i>Inula montana</i> L.		+	+				
<i>Sempervivum calcareum</i> Jordan	+		+				
<i>Asplenium ruta-muraria</i> L.			+				
<i>Poa pratensis</i> L.	3.3						
<i>Trifolium</i> sp	2.2						
<i>Achnatherum calamagrostis</i> (L.) P. Beauv.				2.2			
<i>Festuca laevigata</i> Gaudin	1.1	1.1					
<i>Geranium sanguineum</i> L.			1.2				
<i>Onobrychis saxatilis</i> (L.) Lam.					1.2	1.2	
<i>Galium mollugo</i> L. subsp. <i>Erectum</i> Syme					1.2		
<i>Helianthemum nummularium</i> (L.) Miller					1.2		
<i>Achillea millefolium</i> L.	1.1						
<i>Epipactis microphylla</i> (Eheth.) Zwarts					1.1		
<i>Seseli montanum</i> L.		1.1					
<i>Antirrhinum majus</i> L.			1.1				
<i>Arrhenatherum elatius</i> (L.) P. Beauv. Ex J. & C. Presl	1.1						
<i>Festuca valesiaca</i> Gaudin						1.1	
<i>Globularia repens</i> Lam.				1.1			
<i>Helianthemum hirtum</i> (L.) Miller				1.1			
<i>Helianthemum oelandicum</i> (L.) DC.		1.1					
<i>Laserpitium gallicum</i> L.					1.1		
<i>Dactylis glomerata</i> L. subsp. <i>glomerata</i>	1.1						1.1
<i>Crepis albida</i> Vill.							1.1
<i>Ononis rotundifolia</i> L.							1.1
<i>Helianthemum apenninum</i> (L.) Miller	1.1					+1	
<i>Euphorbia cyparissias</i> L.					+1		
<i>Hypericum perforatum</i> L.				+1			
<i>Ononis natrix</i> L.				+1			
<i>Antirrhinum latifolium</i> Miller				+1			
<i>Asplenium fontanum</i> (L.) Bernth.				+1			
<i>Astragalus depressus</i> L.				+1			
<i>Astragalus incanus</i> L.				+1			
<i>Brachypodium pinnatum</i> (L.) P. Beauv.		+1					
<i>Campanula spicata</i> L.				+1			
<i>Knautia tineroi</i> Jordan				+1			
<i>Leontodon hirtus</i> L.			+1				
<i>Paronychia capitata</i> (L.) Lam.		+1					
<i>Silene otites</i> (L.) Wibel				+1			
<i>Verbascum thapsus</i> L.				+1			
<i>Viola rupestris</i> F. W. Schmidt					+1		
<i>Salvia pratensis</i> L.				+1			
<i>Hypericum hyscopifolium</i> Chaix			+				
<i>Laserpitium siler</i> L.			+				
<i>Polygala vulgaris</i> L.		+					
<i>Arabidopsis thaliana</i> (L.) Heynh.			+				
<i>Arabis collina</i> Ten.			+				
<i>Artemisia campestris</i> L.		+					
<i>Asperula cynanchica</i> L.				+			
<i>Carex halleriana</i> Asso.				+			
<i>Helleborus foetidus</i> L.			+				
<i>Lactuca perennis</i> L.				+			
<i>Lathyrus pratensis</i> L.		+					
<i>Plantago alpina</i> L.			+				
<i>Ranunculus bulbosus</i> L.		+					
<i>Anthyllis vulneraria</i> L. subsp. <i>praeporeia</i> (A.Kerner) Borni	1.1		+				
<i>Sempervivum arachnoideum</i> L.	+	+					
<i>Silene saxifraga</i> L.			+				

Ras-Al-Maara vegetation Relevé	1	2
Slope (°)	20	15
Altitude (m)	2350	2200
Aspect	W	SW
Substrate	Calcareous	Calcareous

Low tree layer (2–5 m)		
Percentage cover (%)	0	20
<i>Juniperus excelsa</i> Bieb.	–	2.2
<i>Rosa canina</i> L.	–	1.2
<i>Prunus ursina</i> Ky.	–	+

Upper shrub layer (0.5–2 m)		
Percentage cover (%)	–	25
<i>Acer hermoneum</i> Bornm. et Schwerin.	–	1.1
<i>Juniperus excelsa</i> M. Bieb.	–	1.1
<i>Crataegus azarolus</i> L.	–	1.1
<i>Rosa canina</i> L.	–	2.2
<i>Cotoneaster nummulariifolia</i> Fisch. et Mey	–	1.3
<i>Sorbus torminalis</i> (L.) Crantz	–	1.2
<i>Rhamnus libanotica</i> Boiss.	–	1.2
<i>Berberis libanotica</i> Ehrenb.	–	2.2

Lower shrub layer (<0.5 m)		
Percentage cover (%)	35	25
<i>Noaea mucronata</i> (Forsk.) Moqu.	–	2.2
<i>Astragalus bethlehemiticus</i> Boiss.	3.2	2.1
<i>Achillea kotchyi</i> Boiss.	–	1.3
<i>Ribes orientale</i> Desf.	–	+
<i>Rhamnus libanotica</i> Boiss.	–	1.1
<i>Rhamnus punctata</i> Boiss.	–	+
<i>Centaurea dumulosa</i> Boiss.	–	+
<i>Astragalus colutooides</i> Willd.	2.2	2.1
<i>Ziziphora canescens</i> Benth.	–	1.1
<i>Onobrychis cornuta</i> (L.) Desf.	1.1	–
<i>Prunus prostrata</i> Labill.	2.2	2.2
<i>Cotoneaster nummulariifolia</i> Fisch. et Mey	1.1	1.1

Herbaceous layer		
Percentage cover (%)	10	10
<i>Asphodelus</i> sp	1.2	1.2
<i>Poa bulbosa</i> L.	–	1.1
<i>Dactylis glomerata</i> L.	–	1.1
<i>Carduus pycnocephalus</i> L.	2.2	1.1
<i>Centaurea iberica</i> Trev. ex Sprengel	2.1	–
<i>Stachys nivea</i> Labill.	–	1.1
<i>Cerastium cerastoides</i> (L.) Britton	–	1.1
<i>Scrophularia xanthoglossa</i> Boiss	–	+
<i>Scorzonera phaeopapa</i> Boiss.	+	+
<i>Euphorbia macroclada</i> Boiss.	2.1	1.1

Saint-Crépin 1

Depth layers	Total number of charcoal fragments	Total charcoal mass (mg)	Charcoal fragments observed		Charcoal fragments observed (%)	
			N	M	N	M
Level I						
> 1.25 mm	222	420.8	222	420.8	100	100
1.25 – 1 mm	91	66.3	91	66.3	100	100
1 – 0.8 mm	354	122.2	40	19.5	11.3	16.0
0.8 – 0.5 mm	526	94.1	40	16.4	7.6	17.4
Total	1193	703.4	393	523	32.94	74.4
Level II						
> 1.25 mm	255	689.8	255	689.8	100	100
1.25 – 1 mm	95	59	95	59	100	100
1 – 0.8 mm	459	160.1	40	20	8.7	12.5
0.8 – 0.5 mm	512	56.2	40	9.9	7.8	17.6
Total	1321	965.1	430	778.7	32.6	80.7
Level III						
> 1.25 mm	111	204.1	111	204.1	100	100
1.25 – 1 mm	55	31.2	55	31.2	100	100
1 – 0.8 mm	233	82.1	40	21.2	17.2	25.8
0.8 – 0.5 mm	450	76.4	40	8.4	8.9	11.0
Total	849	393.8	246	264.9	28.98	67.3
Level IV						
> 1.25 mm	131	238.2	131	238.2	100	100
1.25 – 1 mm	688	40.9	68	40.9	100	100
1 – 0.8 mm	275	99.1	40	16.9	14.5	17.1
0.8 – 0.5 mm	702	122	40	7.7	5.7	6.3
Total	1176	500.2	279	303.7	23.7	60.7

Saint-Crépin 2

Depth layers	Total number of charcoal fragments	Total charcoal mass (mg)	Charcoal fragments observed		Charcoal fragments observed (%)	
			N	M	N	M
Level I						
> 1.25 mm	67	103.8	67	103.8	100	100
1.25 – 1 mm	21	12.9	21	12.9	100	100
1 – 0.8 mm	124	43.9	40	16.9	32.3	38.5
0.8 – 0.5 mm	475	75.6	40	8	8.4	10.6
Total	687	236.52	168	141.6	24.5	59.9
Level II						
> 1.25 mm	122	221.3	122	221.3	100	100
1.25 – 1 mm	45	34.4	45	34.4	100	100
1 – 0.8 mm	321	110.2	40	15.4	12.5	14.0
0.8 – 0.5 mm	680	20.26	40	8.7	5.9	42.9
Total	1168	386.16	247	279.8	21.1	72.5
Level III						
> 1.25 mm	26	71.8	26	71.8	100	100
1.25 – 1 mm	9	5.1	9	5.1	100	100
1 – 0.8 mm	27	8.4	27	8.4	100	100
0.8 – 0.5 mm	140	19.3	40	6.3	28.6	32.6
Total	202	104.6	102	91.6	50.5	87.6

Table IV. Number and anthracomass of charcoal fragments studied in the different soil layers.

N: Number of fragments | M: Mass of fragments (mg)

Abstract

Juniperus thurifera from the western Mediterranean Basin and *Juniperus excelsa* from the eastern Basin are considered geographical vicariant junipers. Their ecological status remains poorly defined, and the literature contains contradictory interpretations regarding the ecology and dynamics of *J. thurifera* populations.

The largest French population of *J. thurifera*, located at Saint-Crépin, was investigated using a pedoanthracological approach in order to reconstruct past woody vegetation from charcoal remains preserved in the soil. The results indicate that the current *J. thurifera* stand represents a degraded stage of a former deciduous oak forest.

A similar study was conducted on *Juniperus excelsa* at Ras-Al-Maara in the Anti-Lebanon range. However, the strongly eroded soils yielded only a limited number of charcoal fragments, preventing a reliable comparison with the *J. thurifera* stands of Saint-Crépin.

Keywords : *Juniperus thurifera* L.; *Juniperus excelsa* Bieb.; pedoanthracology; charcoal analysis; Southern Alps; Anti-Lebanon.

Résumé

Juniperus thurifera du bassin occidental de la Méditerranée et *Juniperus excelsa* du bassin oriental sont deux genévriers géovicariants. Leur statut écologique reste encore mal défini et la littérature présente de nombreuses interprétations contradictoires concernant l'écologie et la dynamique des peuplements de *J. thurifera*.

La plus importante station française de *J. thurifera*, située à Saint-Crépin, a été étudiée à l'aide d'une approche pédoanthracologique afin de reconstituer la végétation ligneuse passée à partir des charbons de bois conservés dans le sol. Les résultats montrent que le peuplement actuel de *J. thurifera* correspond à un stade de dégradation d'une ancienne chênaie caducifoliée.

Une étude similaire a été réalisée sur *Juniperus excelsa* dans la station syrienne de Ras-Al-Maara. Toutefois, les sols fortement érodés n'ont livré qu'un faible nombre de charbons, ne permettant pas une comparaison fiable avec les peuplements de *J. thurifera* de Saint-Crépin.

Mots-clés : *Juniperus thurifera* L. ; *Juniperus excelsa* Bieb. ; pédoanthracologie ; charbon de bois ; Alpes du Sud ; Anti-Liban.