

The age and history of the French Mediterranean steppe revisited by soil wood charcoal analysis

Frédéric Henry,¹ Brigitte Talon¹ and Thierry Dutoit^{2*}

(¹Aix-Marseille Université, Institut méditerranéen d'écologie et de paléoécologie, UMR-CNRS IRD, case 462, faculté Saint-Jérôme, F-13397 Marseille Cedex 20, France; ²Université d'Avignon, IUT, Institut méditerranéen d'écologie et de paléoécologie UMR CNRS IRD, Site Agroparc, BP 1207, F-84911 Cedex 9, France)

Abstract: In the Mediterranean basin, steppe vegetation is considered to be the result either of land clearing in the Neolithic or the result of harsh environmental conditions (shallow soils and/or Mediterranean drought). For the first time, a study was carried out in the French Mediterranean steppe area of the Crau in Southeastern France using soil wood charcoal analysis, a technique in which charcoals found in the soil are identified and dated. According to some authors, an original mixed oak and beech forest may have covered the plain and have been cleared in the Neolithic, or, in the view of other authors, the steppe vegetation may have existed in its present form since the Lateglacial period. A total of 14 soil samples and 23 C¹⁴ datings were performed. Our results show that no species of ancient forests dominated by *Quercus pubescens* and *Fagus sylvatica* or *Q. ilex* were present at the end of the Neolithic or during the Bronze Age. Only earlier successional species such as *Pinus pinea/halepensis*, *Phillyrea angustifolia* and *Prunus* sp. were burnt during these periods. The other charcoal identified from the Roman Empire, Middle Ages and Modern periods seem to be better correlated with pastoral settlements than natural secondary succession processes. These results obtained at a local scale confirm those already available from the western Mediterranean, which have shown that human impacts were the determining factors of the evolution of the Mediterranean vegetation during the Neolithic and Bronze age.

Key words: Paleocology, charcoal, soil, herbaceous plant communities, pastoral activities, Mediterranean steppe, Neolithic, Roman period, Medieval times, Modern period, Lower Provence, France.

Introduction

The origin of the western Mediterranean vegetation has been debated since the beginning of the twentieth century. This vegetation is generally considered to be the result of human impact occurring since the Neolithic (5000–1800 BC) (Kuhnholz-Lordat, 1938; Pons and Quezel, 1998) or the aridification of the western Mediterranean climate (5000 BC–AD 1000) which has occurred progressively from south to north (Jalut *et al.*, 1997). If recently climatic changes have been identified as the determining factor in the evolution of the Mediterranean basin (Jalut *et al.*, 2009); there is still a lack of data concerning semi-arid steppe areas which still cover 3 700 000 ha in the western Mediterranean ('*Dehesas*' in Spain; '*Montado*' in Portugal; '*Crau*' in France) and 63 000 000 ha in north Africa from the Red Sea to the Atlantic ocean (Le Houérou, 1995). These ecosystems are believed to have been

formed under both human and non-human associated processes (Le Houérou, 1969). Nevertheless the long-term history of steppe vegetation and the age of its formation are still debated, which may be attributable to the absence of pollen accumulation in dry soils and a lack of soil wood charcoal or phytolith analyses for this type of ecosystem (Vernet, 1997).

Recently, agricultural intensification and the decline of traditional land management have led to the loss and fragmentation of steppe ecosystems and to considerable floristic changes (Grove and Rackham, 2001). Nevertheless, these ecosystems support diverse and often specialized flora and fauna, including many rare and threatened species. For this reason, conservation and restoration of these vegetation types constitute one of the major keys to preservation of their biodiversity (Blondel and Aronson, 1999).

Using soil wood charcoal analysis (pedoanthracology), a technique in which charcoal pieces found in the soil are identified and radiocarbon dated (Thinon, 1992), we assessed data from a steppe vegetation area. Because soil charcoal analysis provides information

*Author for correspondence (e-mail: thierry.dutoit@univ-avignon.fr)

with great spatial precision (Touflan *et al.*, 2010, this issue), it is particularly well suited to the study and description of past forest plant communities growing in dry sites (Thinon, 1992; Carcaillet, 1998, 2001; Talon *et al.*, 1998; Carcaillet and Brun, 2000; Carnelli *et al.*, 2004; Talon, 2010, this issue). Studies on modern fires have shown that there is a good correlation between charcoal and vegetation in the absence of any transport (Scott *et al.*, 2000) and a relationship between the occurrence of local fires and peaks in macroscopic charcoal (Gardner and Whitlock, 2001). Although charcoal can easily be dispersed through surface run-off, large-scale aerial dispersal by wind and smoke is limited, particularly for fragments larger than 400 μm (Clark, 1998; Clark *et al.*, 1998; Blackford, 2000; Figueiral and Mosbrugger, 2000; Ohlson and Tryterud, 2000; Lynch *et al.*, 2004) which are the fragments that can be identified and dated.

By the use of the same methodology, previous research on the origin of dry grassland types such as: chalk grasslands in northwestern France (Dutoit *et al.*, 2009); dry calcareous grasslands of the Swabian Alps in southeastern Germany (Baumann, 2006; Poschlod *et al.*, 2008; Poschlod and Baumann, 2010, this issue); acidic uplands of the Vosges mountains in northeastern France (Schwartz *et al.*, 2005; Goepp, 2007) and pre-steppic ecosystems (called 'Causse') of the sub-Mediterranean mountains of France (Quilès *et al.*, 2002; Vernet, 2006), have already shown that the origin of present-day herbaceous vegetation seems to date back to the latest Neolithic to the Bronze Age for the Atlantic and continental sites (Gaillard *et al.*, 2009). Nevertheless, for the pre-steppic vegetation of the sub-Mediterranean mountains, fire events are also closely related with the existence of a dry climate that must be added to the anthropogenic impact. The latter result has confirmed those of pollen analyses (Jalut *et al.*, 1997, 2000) for the western Mediterranean. To validate definitively the hypothesis of the predominance of climatic changes over anthropogenic impact in the origin of Mediterranean steppe areas, we provide for the first time original data from a steppe area (La Crau) located in southeastern France (Lower Provence).

As for other areas of steppe vegetation in Europe, the origin of the herbaceous plant community in the plain of the Crau is still debated (Molinier and Tallon, 1950; Devaux *et al.*, 1983). Two different hypotheses have been proposed. One, based on the observation of present plant communities, suggests that the present steppe vegetation originated from an ancient forest dominated by *Q. pubescens* and *F. sylvatica* (6000–2700 BC). Regional pollen analyses showed that this forest was dominated after by *Q. ilex* (2700–600 BC) (Molinier and Tallon, 1950; Dupias and Molinier, 1966; Triat-Laval, 1978) because of climate aridification which started around 5000 BC with the commencement of the sub-Mediterranean climate (Jalut *et al.*, 2009) and/or because of the first human clearings, which dated in this area from the late Neolithic to the Bronze Age (2500–1200 BC).

The second hypothesis, based on the study of plant community dynamics, considers the present steppe herbaceous community as a subclimax (Weaver and Clements, 1938) which has never reached its herbaceous climax equilibrium because of the maintenance in the last six millennia of high grazing pressure responsible for the maintenance of overgrazed herbaceous plant communities (Devaux *et al.*, 1983).

The main question in the present study will be: is the Mediterranean steppe vegetation of the Crau area the result of forest anthropogenic clearing or had the present-day steppe vegetation already occurred before anthropogenic impact? These results obtained at a local scale with soil wood charcoal analyses will then be discussed in order to validate or not the climate forcing identified by previous paleoecological investigations to explain the Holocene changes of the circum-Mediterranean vegetation.

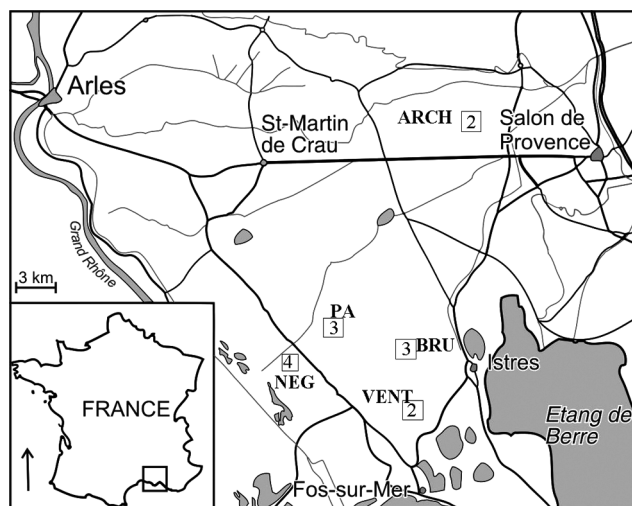


Figure 1 Location of the Crau plain in France and location of the five study sites in the study area (NEG, Nègreiron; ARCH, Archimbaud; PA, Petit Abondoux; BRU, Brune d'Arles; VENT, Ventillon). Squared values indicated the number of soil profiles realised in each site

Methods

Study area

The study was carried out in the Crau plain (55 000 ha), to the southeast of Arles, located about 50 km northwest of Marseille, France, between the Rhône Delta and the Berre lagoon (Figure 1). The plain is a fossilized river bed formed by the ancient deposits of the Durance River between 2 000 000 and 30 000 years ago that during the Pleistocene period flowed directly into the Mediterranean Sea.

The substrate of the plain was deposited during three distinct phases associated with three different geological units: (1) the Villafranchian Crau (2 000 000–800 000 BP) located in the north-western part of the Crau plain and characterized by the dominance of calcareous pebbles of 10–15 cm length; (2) the Rissian Crau (300 000–120 000 BP), deposited in the intermediate part of the plain and characterized by the presence of large crystalline pebbles measuring 15 cm length; and the Wurmian Crau (120 000–30 000 BP) located in the southeastern part of the plain and characterized by a small quantity of small pebbles (Colomb and Roux, 1978).

The entire Crau plain has an extremely flat topography with rounded siliceous stones covering 50% of the soil surface. The average soil depth is 40 cm overlying a 1 to 5 m thick layer of impermeable conglomerate, making the alluvial water-table inaccessible to the roots of plants (Colomb and Roux, 1978). The fersialithic soils of the Wurmian Crau are characterized by the presence of numerous pebbles (40–60%), by low nutrient content in potassium and phosphorous and the absence of calcium carbonates in the surface layers. The main differences between the fersialithic soil of the Wurmian Crau and that of the surroundings Villafranchian and Rissian Crau, is that its soil is deeper (around 60 cm) and richer in organic and nutrient content. All these soils have been considerably truncated by eolian erosion ('Paleo-Mistral') in the Lateglacial period (Bouteyre and Duclos, 1994).

The dryness of the ecosystem is induced by the Mediterranean climate (mean temperature 14.5°C, yearly precipitation of 500–600 mm; Cherel, 1988). While the steppe plant community of central Crau is determined by *Brachypodium retusum* (Poaceae), *Thymus vulgaris* (Lamiaceae) is the dominant plant species in the western areas (Loisel *et al.*, 1990).

Since antiquity, this pebbly plain has been a rich livestock grazing area by virtue of its rich herbage. The unique environment and

economy of the plain was described by both Strabo and Pliny the Elder (Leveau, 2004). Sheep grazing was the traditional land use for several centuries and is the only form of vegetation management advocated to ensure the durability of the steppe (Fabre, 1997). In the sixteenth century, canals were built to irrigate 15 000 ha of steppe with the rich and silty water of the Durance river. Today, human activities, such as melon cultivation and orchards, irrigated hay fields and industries have reduced the dry grassland surface from 55 000 ha to 11 500 ha (Buisson and Dutoit, 2004, 2006; Römermann *et al.*, 2005; Buisson *et al.*, 2006).

Sampling and taxonomic identification

Charcoal pieces were sampled from soil extracted from layers of soil profiles (Thinon, 1992) in the remnant patches of undisturbed Mediterranean steppe vegetation. In these areas, Roman sheepfolds, huts and inns were identified by archaeologists in the 1990s (Hitchner, 1994; Badan *et al.*, 1995, 1997). The pastoral structures were visible in the landscape as very low stony mounds containing remnants of walls in the foundations and small amounts of pottery, amphora, and tiles. In general, this type of structure measures around 10–50 m by 5–8 m. The walls were constructed of clay-packed stone. The cob walls were built with small stones blended with earth, laid on rows of pebbles placed as headers used as foundations. After their abandonment, walls have fallen down and the ground has been eroded (by wind, sheep trampling), which flattened the relief. Two thousand years later, where the surface has never been removed (cultivation, orchards, etc.), these foundations are still visible in the absence of soil sedimentation in this area.

In 2006, 14 profiles were dug in the remnant pieces of steppe vegetation (Figure 1). Of them, 50% were dug under these foundations, with the aim of improving the probability of finding old charcoal in these soils protected by the pebbles from the strong wind and sheep trampling erosion which has occurred in the plain over at least the two last millennia. The time of occupancy of each Roman sheepfold or inn has been estimated on the basis of coins and ceramics (Table 1). Each profile dug under a foundation was also coupled with a soil profile taken in the soil of the steppe vegetation several hundred meters from the archeological traces as a control to counterbalance the maximum of impacts on vegetation expected in archeological sites and to identify charcoal from pieces of wood which could have been used for the construction and heating of these former Roman settlements. Nevertheless, there is no basis for certainty that these areas of steppe vegetation were never impacted by temporary human settlements in the Middle Ages or during the Neolithic because of the difficulty of recognizing the archeological traces of these settlements on the soil surface.

After removing the rows of pebbles from the Roman foundations, soil samples were taken using a standard method (Carcaillet and Thinon, 1996), namely soil profiles were dug to bedrock and 15 l of soil were sampled every 10 cm between the soil surface and the impermeable conglomerate, starting from the deepest layer to prevent contamination from upper layers (Table 2). Samples of 15

kg of dry soil were taken at each layer through a sieve of 2 cm mesh to exclude stones and gravel. Two profiles were taken under the Roman inn of Brune d'Arles (BRU a and b) because of the large size of its foundation in comparison with the sheepfolds, two subsites in the site of Négreiron (NEG 1 and 2), because part of this site, which is on the border with the Camargue wetlands, was already colonized by scrub vegetation (NEG 2) and two profiles were taken in the steppe soils of Petit Abondoux (PA), because the first had been taken at random in a former Neolithic site PA (N) (Badan and Conges, personal communication, 2006).

Samples were dried and the dry material was then carefully wet-sieved with a defloculant ($\text{Na}_4\text{P}_2\text{O}_7$) through four sieves of 5 mm, 2 mm, 800 μm and 400 μm mesh (400 μm corresponds to the minimum size for handling and anatomical identification). Charcoal was extracted from the mineral fraction (sand) by flotation in a column with an ascending water current (further details in Carcaillet and Thinon, 1996), and from the organic fraction (roots and other plant remains) by hand sorting under a low-power binocular microscope. Larger charcoal pieces were cleaned by an ultrasonic wave generator, and more fragile charcoal pieces were treated with HF (70%) and HCl (35%) to destroy clays. Charcoals were observed with an incident light microscope (episcopic microscope equipped with differential interference contrast) under magnifications of 200 $\times$, 500 $\times$, and 1000 $\times$. Identification of charcoal fragments was achieved on the basis of wood anatomical criteria. It was performed using the charred wood reference collection from the Mediterranean Institute of Ecology and Palaeoecology (Marseille, France) as well as atlases of wood anatomy (Jacquot, 1955; Greguss, 1959; Jacquot *et al.*, 1973; Schweingruber, 1990).

In order to test if, under the sheepfold foundations, the conservation of wood charcoals are better than in the steppe, we compared samples between archeological sites and steppe soils. The charcoal richness of each sample was calculated and this index was compared between sites and treatments (Roman foundation – steppe soils) after log-transformation using univariate ANOVA tests.

A total of 20 tree charcoal fragments of masses between 1 and 10.1 mg were radiocarbon dated at the Poznan Radiocarbon Laboratory (Poland) using Accelerator Mass Spectrometry (AMS). The ^{14}C dates were calibrated as AD/BC using IntCal 04 calibration, CALIB 5.0 software (Stuiver *et al.*, 2006).

Results

In this study, few charcoal samples were found in comparison with other soil wood charcoal analyses already carried out in ancient forests (Vernet *et al.*, 2005; Vernet, 2006) but our results could be compared with those obtained from sampling performed above the upper treeline in alpine grasslands (Talon *et al.*, 1998), and in calcareous grasslands in northwestern (Dutoit *et al.*, 2009) or central Europe (Baumann, 2006; Goepp, 2007).

A total of 597 wood charcoals have been extracted from 700 kg of dried soil (Table 3). The charcoals were very fragmented because of the impact of sheep trampling on these very shallow soils and most of the pieces were vitrified, bore a scoria-like appearance and could not be identified. No charcoal greater than 2 mm in height was found. Most of the charcoal ranging from 1.25 mm to 2 mm was extracted from the site at NEG 2 in the south of the study area. ANOVA test showed no significant difference ($F = 3.93$; $p = 0.052$) between charcoals extracted from steppe samples ($N = 109$) and under Roman foundations ($N = 488$). Nevertheless, a strong site effect was detected ($F = 188.29$; $p = 0.0000$) because one site (NEG 2) accounts for around 50% ($N = 340$) of the total amount of charcoal found for the whole study area.

Table 1 Chronological occupation of the Roman sheepfolds and the Roman inn sampled in the Crau area (from Badan *et al.*, 1995, 1997)

Place name	Code	First archeological traces	Last archeological traces	Estimated time of occupation (years)
Archimbaud	ARCH	80 BC	AD 250	330
Brune-d'Arles	BRU	140 BC	50 BC	90
Négreiron (1)	NEG 1	AD 75	AD 150	75
Négreiron (2)	NEG 2	AD 40	AD 160	120
Petit Abondoux	PA	AD 55	AD 325	270
Ventillon	VENT	AD 220	AD 430	210

Table 2 Characteristics of the 14 soil profiles sampled for charcoals on the Crau area

Profile number and code	Elevation (m)	Location	Former land use	Total soil depth (cm)	Number of charcoal dated	Number of sampled layers	Sample layer codes	Depth of each sampled layer (cm)
Archimbaud ARCH	54	43°65 04°95	Sheepfold foundation	62	0	6	A	0–10
							B	10–20
							C	20–30
							D	30–40
							E	40–50
							F	50–62
Archimbaud ARCH s	55	43°65 04°94	Steppe	60	2	5	A	5–15
							B	15–25
							C	25–35
							D	35–45
							E	45–55
La Brune d'Arles (a) BRU a	15	43°53 04°90	Inn foundation	40	3	4	0	0–5
							A	5–15
							B	15–25
							C	25–40
La Brune d'Arles (b) BRU b	15	43°53 04°90	Inn foundation	50	2	5	A	0–10
							B	10–20
							C	20–30
							D	30–40
							E	40–50
La Brune d'Arles BRU s	15	43°53 04°90	Steppe	50	0	4	A	5–15
							B	15–25
							C	25–35
							D	35–50
Négreiron 1 NEG 1	15	43°52 04°89	Sheepfold foundation	38	0	4	A	0–10
							B	10–20
							C	20–30
							D	30–38
Négreiron 1 NEG 1s	5	43°53 04°82	Steppe	45	0	4	A	5–15
							B	15–25
							C	25–35
							D	35–45
Négreiron 2 NEG 2	5	43°53 04°81	Sheepfold foundation	45	1	4	A	0–10
							B	10–20
							C	20–30
							D	30–45
Négreiron 2 NEG 2s	5	43°53 04°81	Matorral	48	1	5	A	0–10
							B	10–20
							C	20–30
							D	30–40
							E	40–48
Petit Abondoux PA (N)	15	43°54 04°87	Steppe/ Neolithic site	38	10	4	A	0–10
							B	10–20
							C	20–30
							D	30–38
Petit Abondoux PA	15	43°54 04°86	Sheepfold foundation	43	0	4	A	0–10
							B	10–20
							C	20–30
							D	30–40
Petit Abondoux PA s	15	43°53 04°86	Steppe	35	0	3	A	0–10
							B	10–20
							C	20–35
Ventillon VENT	15	43°49 04°92	Sheepfold foundation	40	1	4	A	0–10
							B	10–20
							C	20–30
							D	30–40
Ventillon VENT s	15	43°49 04°93	Steppe	36	3	3	A	5–15
							B	15–25
							C	25–36

Dating confirmed that soil layers had been disturbed and that charcoal of various ages was mixed in the soils (Talon *et al.*, 1998). Eleven taxa have been determined. All these taxa are at present found in and/or around the borders of the steppe vegetation area (Devaux *et al.*, 1983) except *Taxus baccata* (Figure 2). These taxa are common species of the present-day herbaceous steppe plant communities that dominate in the

Crau plain including *Thymus* sp., *Lavandula* sp. and other Lamiaceae, early successional species (*Phillyrea angustifolia*, *P. pinea* and/or *halepensis*, *Prunus* sp., *Juniperus* sp.) and one species introduced during Roman times (*Cupressus sempervirens*). No evidence of the presence of charcoals that indicated the former presence of late-successional species (*Q. pubescens*, *F. sylvatica*) was identified. Nevertheless, it is

Table 3 Charcoal richness of the 14 soil profiles realised in the Crau plain under the Roman foundations or in the steppe soils

Site	Roman foundations	Steppe soils
ARCH	11	10
BRU a	60	
BRU b	38	8
NEG 1	5	14
NEG 2	286	54
PA (N)	70	
PA	9	12
VENT	9	11
Total	488	109

still not possible to date to identify anatomical differences between *Q. coccifera* from *Q. ilex*.

Greater numbers of charcoals were found for *Prunus* sp. (6) and *P. pinea/halepensis* (6). *Prunus* sp. is a shrub genus with high light requirements regardless of which species is in this area (*P. spinosa* or *P. dulcis*), confirming the presence of frequent openings within the habitat. *Prunus* sp. were found in two soil profiles separated by 7 km (PA and VENT.s), indicating that these taxa could have been a frequent species in this area if the radiocarbon datings are close together. *P. pinea/halepensis* is a wind-dispersed early successional species which is able to colonise steppe vegetation in the absence of grazing. These last

taxa have been also found at two sites more than 14 km apart (ARCH and BRU).

The 23 dates obtained range from the late Neolithic to the present day (Table 4). The ^{14}C dates are significantly clustered in three periods (Figure 3). The first group (ten dates) correspond to the late Neolithic (two dates) (3700–2500 BC) and Bronze Age (eight dates) (2500–1200 BC), the second group (seven dates) corresponds to the Roman period (200 BC–AD 475) and the third group (six dates) to the Middle Ages (two dates) (AD 475–1500) and Modern period (four dates) (AD 1500–present). *Prunus* sp. clearly dominated the charcoal assemblage during the Bronze Age with the presence of *P. angustifolia*, *Lavandula* sp. and *P. halepensis/pinea*. The Roman period is clearly dominated by *P. halepensis/pinea*. Nevertheless, these charcoals were sampled under the foundations of the Roman inn (BRU) or the steppe near the Roman sheepfold of ARCH and they correspond to the period when these sites were occupied (Table 1). The Middle Ages and the Modern period are characterized by *Thymus* sp. a Rosaceae (probably *Rosa* sp.), a Monocot (most probable species: *Asparagus acutifolius* or *Smilax aspera*) and a sclerophyllous *Quercus*: *Q. coccifera* or *Q. ilex*.

Discussion

The dominance of charcoals from early successional species provides support for the hypothesis that the Crau plain was dominated by pioneer phases of forest dynamics during the Neolithic period. These

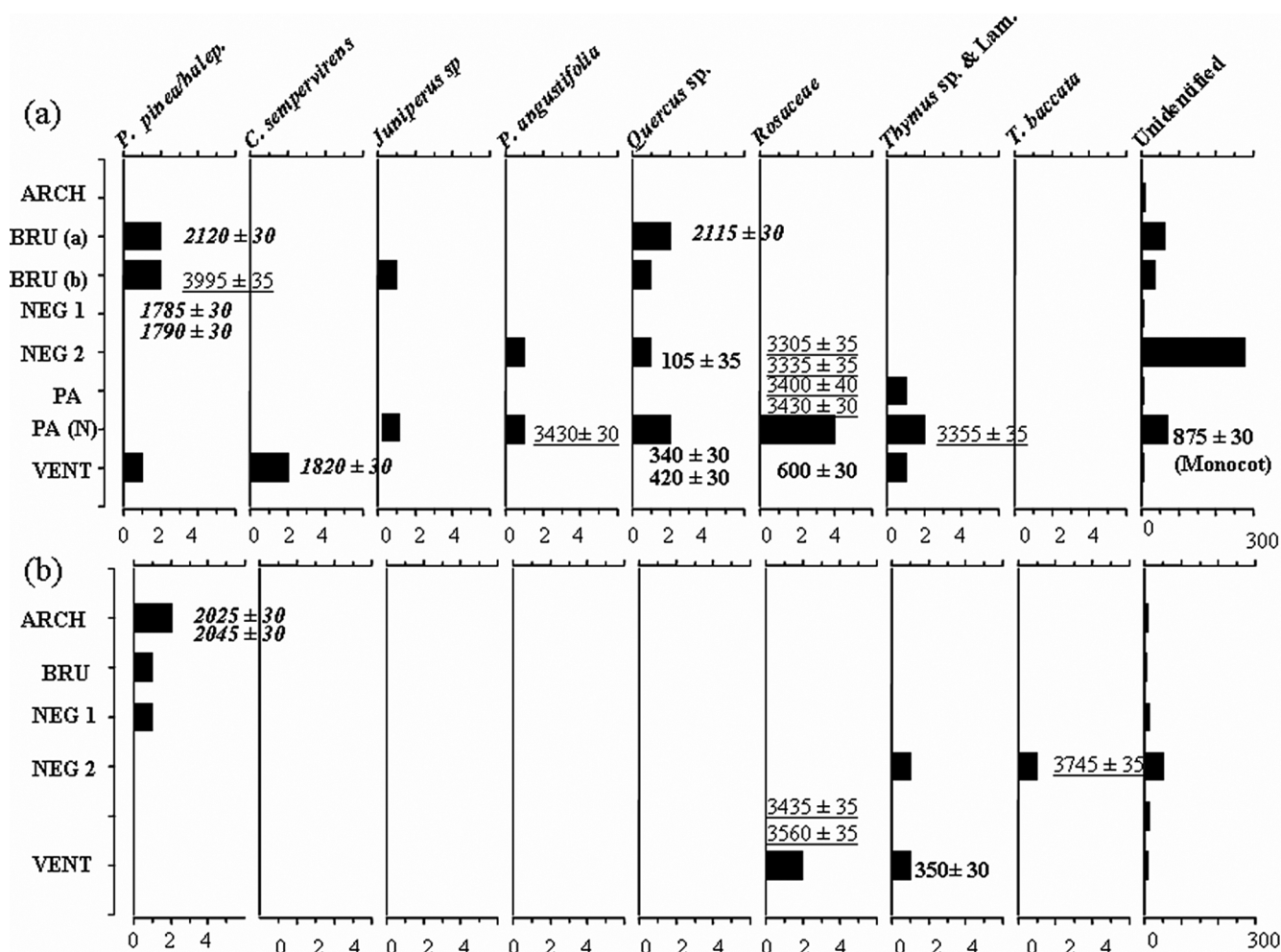


Figure 2 Pedoanthracological diagram of the 14 soil profiles realised in the Crau area. (a) Samplings realised under Roman foundations, (b) samplings realised under undisturbed steppe soils. Charcoals dated from the Middle Ages and Modern period are in bold, charcoals dated from the Roman period are in italic and charcoals dated from the late Neolithic and Bronze Age are underlined. The length of the black bars represents the number charcoals per taxon. See Tables 1 and 2 for the codes of sites

Table 4 Radiocarbon dates of the charcoals sampled in the soil profiles on the Crau area

¹⁴ C age years BP	Calibrated age (years BC/AD) and civilisations	Charcoal species	Approximate weight (mg)	Profiles and depth (cm)
<i>Modern</i>				
105 ± 35	AD 1810–1880	<i>Sclerophilous Quercus</i>	4.5	NEG 2 (10–20)
340 ± 30	AD 1460–1640	<i>Sclerophilous Quercus</i>	1.03	PA (N) (10–20)
350 ± 30	AD 1480–1530	<i>Thymus vulgaris</i>	1.47	VENT s (15–25)
420 ± 30	AD 1435–1520	<i>Sclerophilous Quercus</i>	2.1	PA (N) (0–10)
<i>Middle Ages</i>				
600 ± 30	AD 1290–1410	Rosaceae	2.55	PA (N) (0–10)
875 ± 30	AD 1040–1230	Monocot	1.4	PA (N) (10–20)
<i>Roman Empire</i>				
1785 ± 30	AD 130–340	<i>Pinus halepensis/pinea</i>	1	BRU b (10–20)
1790 ± 30	AD 130–260	<i>Pinus halepensis/pinea</i>	1.21	BRU b (20–30)
1820 ± 30	AD 135–200	<i>Cupressus sempervirens</i>	3.3	VENT (20–30)
2025 ± 30	55 BC–AD 25	<i>Pinus halepensis/pinea</i>	3.9	ARCH s (35–45)
2045 ± 30	170 BC–AD 30	<i>Pinus halepensis/pinea</i>	4	ARCH s (35–45)
2115 ± 30	195–95 BC	<i>Quercus</i> sp.	1	BRU b (5–15)
2120 ± 30	350–40 BC	<i>Pinus halepensis/pinea</i>	1	BRU b (0–5)
<i>Bronze Age</i>				
3305 ± 35	1620–1525 BC	<i>Prunus</i> sp.	2.9	PA (N) (10–20)
3335 ± 35	1700–1520 BC	<i>Prunus</i> sp.	2.38	PA (N) (10–20)
3355 ± 35	1740–1530 BC	<i>Lavandula</i> sp.	2.07	PA (N) (10–20)
3400 ± 40	1840–1600 BC	<i>Prunus</i> sp.	1.16	PA (N) (20–30)
3430 ± 30	1880–1630 BC	<i>Phillyrea angustifolia</i>	1	PA (N) (10–20)
3430 ± 30	1880–1630 BC	<i>Prunus</i> sp.	10.01	PA (N) (10–20)
3435 ± 35	1880–1640 BC	<i>Prunus</i> sp.	6.14	VENT s (0–10)
3560 ± 35	1960–1870 BC	<i>Prunus</i> sp.	6.6	VENT s (5–15)
<i>Late Neolithic</i>				
3745 ± 35	2280–2030 BC	<i>Taxus baccata</i>	1.17	NEG 2 (10–20)
3995 ± 35	2620–2450 BC	<i>Pinus halepensis/pinea</i>	2.92	BRU b (5–15)

See Table 1 for codes; s, steppe.

plant species were burned, probably attesting episodes of vegetation clearance by fire of Matorral and Pine forest vegetation types.

Late Neolithic and Bronze Age

Among the charcoal pieces dating from the late Neolithic and Bronze Age, only species from Matorral and early successional forests were found except *T. baccata*, a tolerant species able to colonize dry grasslands even when grazed because it is toxic, and which can also be established in the shade of mature species, such as *F. sylvatica* or *Q. pubescens*. *T. baccata* had never been found previously in the regional palynological records in this area (Triat-Laval, 1982; Andrieu-Ponel *et al.*, 2000). *T. baccata* charcoal probably originated from a utilitarian object such as a sheepfold stick.

Our results from ¹⁴C dating of charcoal fragments showed that fires appeared in the late Neolithic and their frequency increased during the Bronze Age. This result is consistent with the general transformation of the landscape induced by agro-pastoral practices detected during the late Neolithic and Bronze Age in Lower Provence (Triat-Laval, 1978). More than 100 Neolithic campsites or settlements have been already found in this area (Hitchner, 1994; Badan, personal communication, 2006). Fires during these periods can be explained by the need for pasture for goats and sheep whose domestication occurred penecontemporaneously in Lower Provence (Columeau, 2003). For archeozoologists, it is clear that pastoral practices may have existed for a long time in the Crau area, as evidenced by the presence of scarce animal bones relics originating from animals (sheep, goats, cattle) which were present in the plain (Leguilloux, 2003).

Moreover, because no charcoal of *Quercus* sp. was found during the late Neolithic and Bronze Age, it would appear that during these periods the landscape was covered by matorral vegetation and *P.*

pinea/halepensis forests but not by forests dominated by *Q. ilex*, as observed in former palynological studies realised at a regional scale (Triat-Laval, 1978, 1982). This result is consistent with the existence during these periods of a sub-Mediterranean climate since 5000 BC, as already evidenced by comparison of paleoenvironmental data in the western Mediterranean (Jalut *et al.*, 2000).

Nevertheless, this result must be also interpreted with circumspection because most of the dated charcoals of *Prunus* sp. (six dates) were identified from a single site (PA N, five dates) and thus, because the dates are relatively close together (1830–1525 BC), these charcoals could have their origin in the same piece of wood, stem or root. Moreover, this profile taken earlier in a soil identified as supporting undisturbed steppe vegetation has been recognized as a Neolithic settlement (Badan and Congès, personal communication, 2006).

No charcoal was dated from the Iron Age (1200–200 BC and no fire signal was detected throughout the plain over 1200 years. This could be explained by an increase in grazing pressure and a specialisation in unimproved monocultural sheep breeding in relation with the commencement of full Mediterranean conditions (500 BC–0). This could explain the maintenance of steppe vegetation dominated by herbaceous species and also the absence of pastoral structures during this period because the use of unimproved races of sheep did not necessitate the construction of pastoral huts (Columeau, 2003).

Roman period

The importance of pastoralism in the ancient economy of the Crau is well recognized (Leveau, 2004). In the Roman, Medieval, early Modern periods and today, the Crau plain has always been a major center of pastoralism (Fabre, 1997). Although it has long been suspected, on the basis of statements in Strabo and Pliny (Leveau,

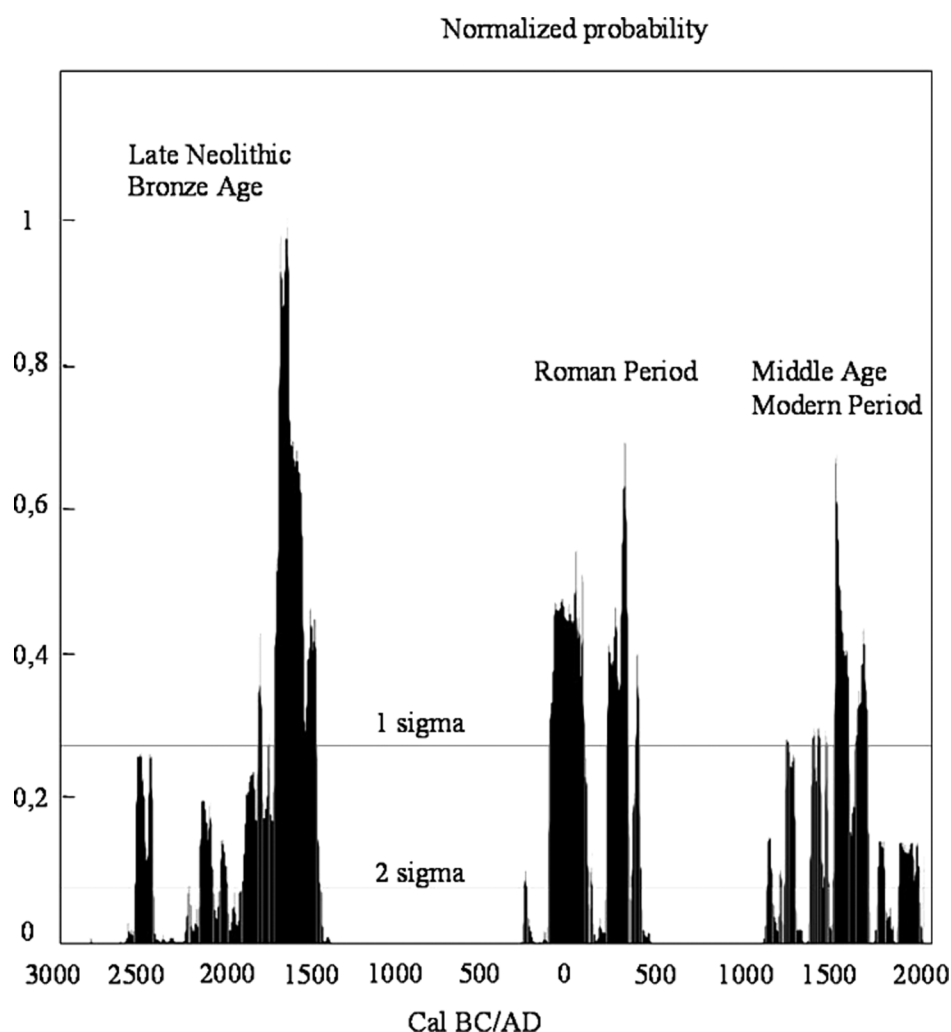


Figure 3 Temporal distribution of the 23 dated charcoals in the Crau plain

2004), that the Crau supported a significant pastoral economy in the Roman period, the discovery of several dozen Roman sheepfolds (more than 150 in 2009; Badan, personal communication, 2009) and artifactual evidence have confirmed the existence of a strong pastoral community in the Crau (Badan *et al.*, 1995). Analysis of the pastoral sites themselves offers some insight into the pastoral economy described by Strabo and Pliny. Specifically, the monocultural function of these sites in the steppe is indicative of intensive stock-raising in the Crau from at least the first century BC, if not earlier (Columbeau, 2003; Leguilloux, 2003).

Our results show that the charcoals sampled are mostly correlated with the working periods of the Roman sheepfolds and that *P. halepensis/pinea* and *Quercus* sp. were probably used as firewood or timber wood during those periods (Badan *et al.*, 1995). Recent identification of charcoal found in baker's ovens and from ridge pieces or roof trees in the Brune d'Arles site can confirm the use of these taxons by the Romans (Gastaud, 2009). The presence of *Cupressus sempervirens*, a species introduced into France by the Romans, confirms that some species could have been planted to protect the sheepfold from the strong winds (Mistral) and that the shepherds were able to bring wood from the surrounding areas of the steppe at the edge with the Alpilles mountains, the Berre lagoon or the Camargue wetlands (Badan *et al.*, 1995)

Middle Ages

The very small number of charcoals, the absence of charcoal from tree or scrub species and the lack of datings at least between AD 340

and AD 1040 confirms the results already obtained by archaeologists (Hitchner, 1994) for the Middle Ages. The virtual absence of archeological evidence for pastoral activity in the Crau area in the Middle Ages is as striking as for events prior to the tenth century. It is clear that a sort of break in the pattern of pastoral activity in the Crau occurred between the Roman period and Middle Ages. This change is most likely to have taken place between the seventh and tenth centuries when this part of Provence was a military frontier in the struggle against the Saracens. During this anarchic period, the specialized pastoral activity practiced earlier was perhaps eroded and replaced by a mixed household economy set within towns protected by walls (eg, Arles) in which pastoral activity was indistinguishable from cultivation. Purely pastoral sites – indeed for that matter any forms of isolated settlement – would thus arguably be an improbable feature of the Crau landscape in the period. As a consequence, no timber wood was brought into the Crau plain because no new sheepfolds or pastoral huts were built during that period. The suggested absence of large-scale specialized pastoral activity prior to the late Middle Ages would have the advantage of accounting for the emergence of the new type of wind-break pastoral site (Stouff, 1986). The study of this type of site by archeologists suggests that animals were grazed in small flocks or herds. These sites are distinctively different in design from those of the Roman period. All are defined chiefly by a long (50–80 m) low (2 m maximum) cobblestone wall (60–90 m wide), curved at both ends and aligned generally east–west, designed to act as a windbreak against the mistral. These sites were also distinguished by isolated square or rounded

stone structures, measuring no more than 3 m to a side, and set 20–30 m behind the windbreak wall. These were in some instances no more than small windbreaks, but in most cases they were reasonably well-constructed dwellings with an entrance at the south or west side. Another characteristic feature of most of these structures was partial or complete stone open-air enclosures attached to the south side and/or west end of the windbreak walls. These enclosures were relatively stone free areas and frequently contained scattered fragments of sheep bones. This arrangement may reflect the late-Medieval practice in which proprietors contracted the grazing of small flocks to individual shepherds confirming that no sheepfold or other permanent settlements were built during that period. The absence of pastoral structures during the Iron Age and the Middle Ages is also explained by zooarcheologists by the use during those periods of unimproved races of sheep, which did not require the construction of sheepfolds or pastoral huts (Columeau, 2003).

Modern period

Stouff (1986) suggests that the total number of sheep in the region of Arles in the fourteenth and fifteenth centuries did not exceed 100 000 and was probably closer to 70 000. This is less than the 150 000 of the Roman period (Badan *et al.*, 1995) and the 200 000–300 000 of the nineteenth century. The flocks came together in large numbers around water sources scattered throughout the Crau, to judge from the concentration of these structures near well sites. The intensity and long-term survival of this pastoral system is implied in the relatively large number of sites and in the many accretions and reconstructions made to them up to the present day.

The existence of the steppe landscape for this period is already attested by numerous historical studies based on the existence of archives and maps (Fabre, 1997). Our results clearly confirm these data and show the presence of only steppe species such as *Thymus* sp., a Rosaceae (probably *Rosa* sp.) and some sclerophyllous *Quercus* (*Q. coccifera* or *Q. ilex*).

The highest number of wood charcoals found in the NEG 2 site in the south of our study area on the edge with the Camargue wetlands (Figure 1) could be linked with the colonisation of this area by scrubs at the beginning of the nineteenth century because of a decrease of sheep pressure in this area following the installation of some cultivated fields. This phenomenon is clearly confirmed by the maps available from that period (Cassini's map, 1750; Staff map, 1856), which show the existence of cultivated fields and forests in this area around 1856 but not around 1750. The dating of a sclerophyllous *Quercus* from that period (AD 1810–1880) at this site clearly confirms the spatiotemporal precision of our soil charcoal analysis.

Because archives and maps available for the Crau plain for this period only mention the colonisation by forest species of the south-eastern border with the Camargue wetlands between 1750 and 1856, sclerophyllous *Quercus* found at other sites than NEG in the centre of the Crau (PA, VENT) had certainly been brought in from that area and used as firewood or timber wood for the construction of sheepfolds or pastoral huts. Unfortunately, it was not possible to distinguish *Q. ilex* from *Q. coccifera*. The first is a species which nowadays dominates young Mediterranean forests in the surrounding areas of the Crau (Molinier and Tallon, 1950). The second has been cultivated since the Middle Ages in the northwestern part of the plain to feed a cochineal that caused galls on leaves which were used to produce a red dye (Villeneuve, 1822). Nowadays, this species is totally absent from the steppe vegetation and very rare in the surrounding forest dominated by *Q. ilex*.

Conclusion

Our results show that the steppe of the Crau and its present herbaceous flora could be considered as a very old plant community

originating at least from the Bronze Age, but which has certainly been associated in its herbaceous structure and composition with centuries of pastoral activities. On the basis of our results, we might propose a third and intermediary hypothesis regarding its origin. The steppe vegetation did not originate from an old forest (Molinier and Tallon, 1950) and did not exist as an herbaceous stage during the Neolithic (Devaux *et al.*, 1983). The herbaceous plant community would appear to have its origins in an increase in the fire regimes which degraded existing Matorral vegetation and Pine forests. These vegetation types were present during the Neolithic because of the preliminary existence of very shallow, dry and nutrient-poor fersialithic soils truncated by eolian erosion in the Lateglacial period and the aridification of the climate which started in 5000 BC.

In this area, recent ecological studies have already highlighted the slowness of the plant secondary succession without grazing management (Devaux *et al.*, 1983; Borck, 1998). For example Henry (2005) has shown that no shrub of forest species is able to colonize the steppe vegetation even after 25 years of grazing exclusion. Of course, it cannot be assumed that the present ecological processes can be applied to those of the late Neolithic period; nevertheless, it seems that the harsh environmental conditions (soil, climate) and an increase in anthropogenic fires and grazing pressure could have been at the origin of the steppe vegetation.

To complete these first investigations, future research must include a regional multisite approach. Complementary soil wood charcoal sampling must be undertaken in the older surrounding Rissian Crau and Villafranchian Crau in order to confirm definitively the long-term existence of the only French Mediterranean steppe vegetation. In addition, multiproxy investigations (phytoliths, pollens, snails, bones, etc.) must be envisaged in order to relate our results with other paleoecological bioindicators.

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