Soil charcoal analysis: a reliable tool for spatially precise studies of past forest dynamics: a case study in the French southern Alps

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A HOLOCENE RESEARCH PAPER THEMATIC SET

Abstract: This paper presents and discusses the use of soil charcoal analysis (pedoanthracology) to reconstruct past forest dynamics in a larch forest of the upper Guil valley (French Alps, Queyras). We also discuss the role of anthropogenic fire in forest dynamics. The radiocarbon dates from this site demonstrate that arolla pine (*Pinus cembra*) and larch were present in the area since 7566–7673 cal. BP and 5934–6123 cal. BP, respectively. The identification of a piece of charcoal to fir (*Abies alba*) dated to 5734–5908 cal. BP suggests that this species was present at 1980 m a.s.l. since *c.* 6000 cal. BP and had a higher ecological tolerance than previously assumed. The cover of larch forests has increased since the second half of the Holocene because of anthropogenic practices (eg, clearing with fire, cattle grazing). However, today, owing to the abandonment of pastoral practices, the arolla pine has become dominant, which greatly modifies the forest structure and the landscape.

Key words: Charcoal analysis, Holocene, *Larix decidua*, *Pinus cembra*, French Alps, subalpine stage.

Introduction

There is increased interest in natural or semi-natural forests in Europe because of their high biodiversity. Moreover, the fact that these ecosystems are under threat and have largely been ignored by conservation policies until quite recently adds to the interest of past forest research. Finally, the fact that we do not fully understand all of the functions of these ecosystems is another rationale for this work at a time when high-altitude forests (subalpine level: 1600–2100 m a.s.l.) become a conservation priority.

During the last few decades, forest dynamics have changed because of the termination or decrease of certain practices, such as forest exploitation and grazing. These changes led to an increase in forest cover in the Alps. There is no doubt that ecological processes in these landscapes have been heavily influenced by centuries of human activity. These activities need to be understood if forest managers are to predict future changes within the forest system. Anticipated climate changes for the twenty-first century are expected to cause changes in species composition, as well as changes in disturbance regimes (Intergovernmental Panel on Climate Change, 2001). This makes it difficult to predict the long-term development of forest landscapes. Fire is likely to become almost as important for the development of these landscapes as the direct effects of climate change, even in areas where major wildfires do not occur under current climatic conditions (Schumacher and Bugmann, 2006).

In this context, palaeoecological research, with its emphasis on the study of past forest dynamics, can inform management practices where sustainability is an important aim (Ehrlich, 1996; Norton, 1996). Palaeoecological studies (pollen analyses, studies of plant macrofossils, carbonized wood and subfossil trunks) allow us to assess the evolution of vegetation and landscapes and consider how these transformations are influenced by climate change and anthropic disturbances (Tessier *et al*., 1993; Carcaillet and Brun, 2000; Edouard *et al*., 2002; Larocque *et al*., 2003). Palynological evidence elucidates regional patterns of vegetation change. For example, we can see how important changes took place with the advent of human activity during the Neolithic and Bronze Age (Fauquette and Talon, 1995; Walsh and Richer, 2006; Muller *et al*., 2006). However, palynological data do not allow

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us to identify local, or 'slope-scale' changes in the vegetation (Carcaillet *et al*., 1998; Tinner *et al*., 1998; Ali *et al*., 2003; Carnelli *et al*., 2004). In this context pedoanthracology can work locally on issues related both to the joint history of humans and their environment (Henry *et al*., 2010 (this issue)), than the upper limit of alpine forests (Talon, 2010 (this issue)). However, in the context of multiproxy analysis, the pedoanthracology, coupled with other archaeological and palaeoecological analysis, provides valuable information (Poschlod and Baumann, 2010 (this issue)), the results of which are presented in this Thematic Set on pedoanthracology, titled 'Pedoanthracology and the reconstruction of past vegetation dynamics'. This paper is the fourth of the Thematic Set and is in a context where the lack of wet sites with well-preserved pollen and plant macrofossils means that our regional vegetation histories are incomplete.

Recent archaeological research has demonstrated that people have been present in these high altitude (subalpine) zones from the Mesolithic onwards. However, this early human activity was undoubtedly seasonal, and comprised hunting activities, which may have included burning for the creation of forest openings in order to attract animals (Mason, 2000; Walsh *et al*., 2005; Walsh and Richer, 2006). The repeated and regular use of the subalpine zone actually started during the late third and second millennia BC (the late Neolithic and early Bronze Age) (Barge *et al*., 1998; Walsh *et al*., 2007). The use of fire in land management had a profound impact on the vegetation adjacent to human settlements, and produced large quantities of charcoal/carbonized wood (Clark *et al*., 1989; Barbero *et al*., 1990; Carcaillet, 1998; Carcaillet *et al*., 1998). Nevertheless, charcoal fragments are not only produced by anthropogenic disturbances. Wildfires caused by natural processes have occurred during the last few millennia in the Alps. These fires can be the result of the accumulation of deadwood, which can burn given certain climatic and topographic factors (Cyr *et al*., 2005; Tinner *et al*., 2005).

This paper presents the results of soil charcoal analysis (identification, quantification and dating) that allow us to define the nature of the ligneous vegetation in a larch forest, the species composition, and also consider the role of fire in the evolution of this forest during the last few millennia. In this paper we discuss (1) the probable composition of the forest prior to the anthropogenic modification of the landscape, and (2) the role of human activities.

Materials and methods

Study site

The Queyras comprises a massif centred on the Guil Valley in the southeast Briançonnais (Figure 1) within the southwestern sector of the Alpine arc. The geology of the area includes 'Queyras schistes lustrés', and compact limestone (Lemoine and Tricart, 1986). The climate has a mixed montane-mediterranean-continental character, with a minimum summer precipitation of 50 mm (July), and two periods with maximum precipitation (*c*. 100 mm) in late spring (June), and autumn (November). Climatic data obtained from the St-Véran weather station (2125 m a.s.l.) indicate a mean monthly precipitation of 75 ± 16 mm, whilst the mean annual temperature is 5.8 ± 5.5°C. Mean temperature for the coldest month (February) is −3°C, whereas the mean temperature for the warmest month (July) is 13°C. The woodland vegetation is comprised mainly of *Pinus cembra* L., *Larix decidua* Mill., *Pinus uncinata* Miller ex. Mirbel, *Pinus sylvestris* L., *Abies alba* Mill. and *Picea abies* (L.) Karst, situated at altitudes between 1700 and 2400 m a.s.l.

The Praroussin forest is located on the western slope of the Guil valley (44°45′N, 7°00′E). The particularity of this forest is that many of the larches and arolla pines are several hundred years old. In order to assess the heterogeneity of the forest communities in this area, two sites of 0.5 ha each at different elevations and exposures were selected. The first site, Praroussin I (PRA I), is located near the uppermost limit of the forest edge, and oriented NNW at 2080 m a.s.l. on a slope of *c*. 25–30°. *Larix decidua* (European larch) dominates this open forest, along with *Pinus cembra* (arolla pine). The understorey is dominated by *Rhododendron ferrugineum* L. (rhododendron), *Vaccinium myrtillus* L. (bilberry) and *Juniperus sibirica* Burgsd. (juniper). Dynamic regeneration of *Pinus cembra* and *Larix decidua* in recent times is apparent. The second site, Praroussin II (PRA II), is located at 1980 m a.s.l. The gradient here is around 30°, and marked by a dramatic break in slope. The understorey is mainly composed of herbaceous species with a few junipers and bilberries, as well as an extensive regeneration of arolla pine. This is occurring despite the intense grazing in the area.

Sampling strategy

Five evenly distributed pits 60 to 80 cm deep were dug across the study areas. Samples were taken at 10 cm intervals from all of the soil profiles. Charcoal was extracted employing protocols as described by Carcaillet and Thinon (1996). Only charcoal larger than 1.25 mm were sorted, weighed and identified.

Identifications were made using a reference collection of modern charred-wood species (IMEP CNRS/IRD) and wood anatomy atlases (Jacquiot, 1955; Jacquiot *et al*., 1973; Schweingruber, 1990). As wood of *Larix decidua* and *Picea abies* (Norway spruce) cannot be easily distinguished (Talon, 1997), they were recorded as *Larix/Picea*. However, larger charcoals (which are generally better preserved) were always identified as *Larix decidua*. Moreover, spruce is not present in the study area, which is why *Larix decidua* was incorporated with *Larix/Picea* in the results and interpretation. Charcoal fragments were weighed in order to calculate the 'specific anthracomass', which permits a quantitative expression of anthracological data (Carcaillet and Talon, 1996). Specific anthracomass can refer to profiles (P), levels (L) and taxa (T), and are presented as SAP (Specific Anthracomass per Profile), SAL (Specific Anthracomass per Level), and SAT (Specific Anthracomass per Taxon). Specific anthracomass expressed in mg/kg is calculated by dividing the charcoal mass (fraction > 1.25 mm, expressed in mg) by the soil mass (fraction lower than 5 mm, expressed in kg).

The entire anthracomass is then represented in an anthracological diagram. This permits the calculation of the variation of the SAT across the profile. The mean of the values from the five samples/pits at each site was calculated in order to produce a single anthracological diagram that represents the study zone as a whole. Twelve individual charcoal fragments were immersed for 24 h in a solution of sodium hexametaphosphate to disperse humic acids before being (AMS) radiocarbon dated at the Poznan Radiocarbon Laboratory (Poland). The selection of charcoal fragments for radiocarbon dating was based on dry weight of C, location in the pits and tree species. Six dates came from *Pinus cembra*, five from *Larix decidua* (unambiguous identification as *Larix decidua*) and one from fir (*Abies alba*). The dates were calibrated with the Calib Rev 5.1.0 program (Stuiver and Reimer, 1993).

Results

A total of 1506 fragments were identified: 745 for PRA I and 761 for PRA II. *Larix/Picea* (55%) and *Pinus cembra* (22%) represent the greatest proportions of identified species in the anthracological record. The other species identified are: silver fir, willow (*Salix* sp.), alpine bearberry (*Arctostaphylos uva-ursi* L.) and *Vaccinium* sp. (Appendices 1 and 2).

Pits 2, 3 and 5 in PRA I, have an SAP lower than 180 mg/kg, whereas the SAP of pit 4, from where the majority of the charcoal was extracted, reaches 3136 mg/kg (Table 1).

The mean SAP value of PRA II (1981 mg/kg) is twice that of PRA I (978 mg/kg). The same great inter-pit quantitative variation

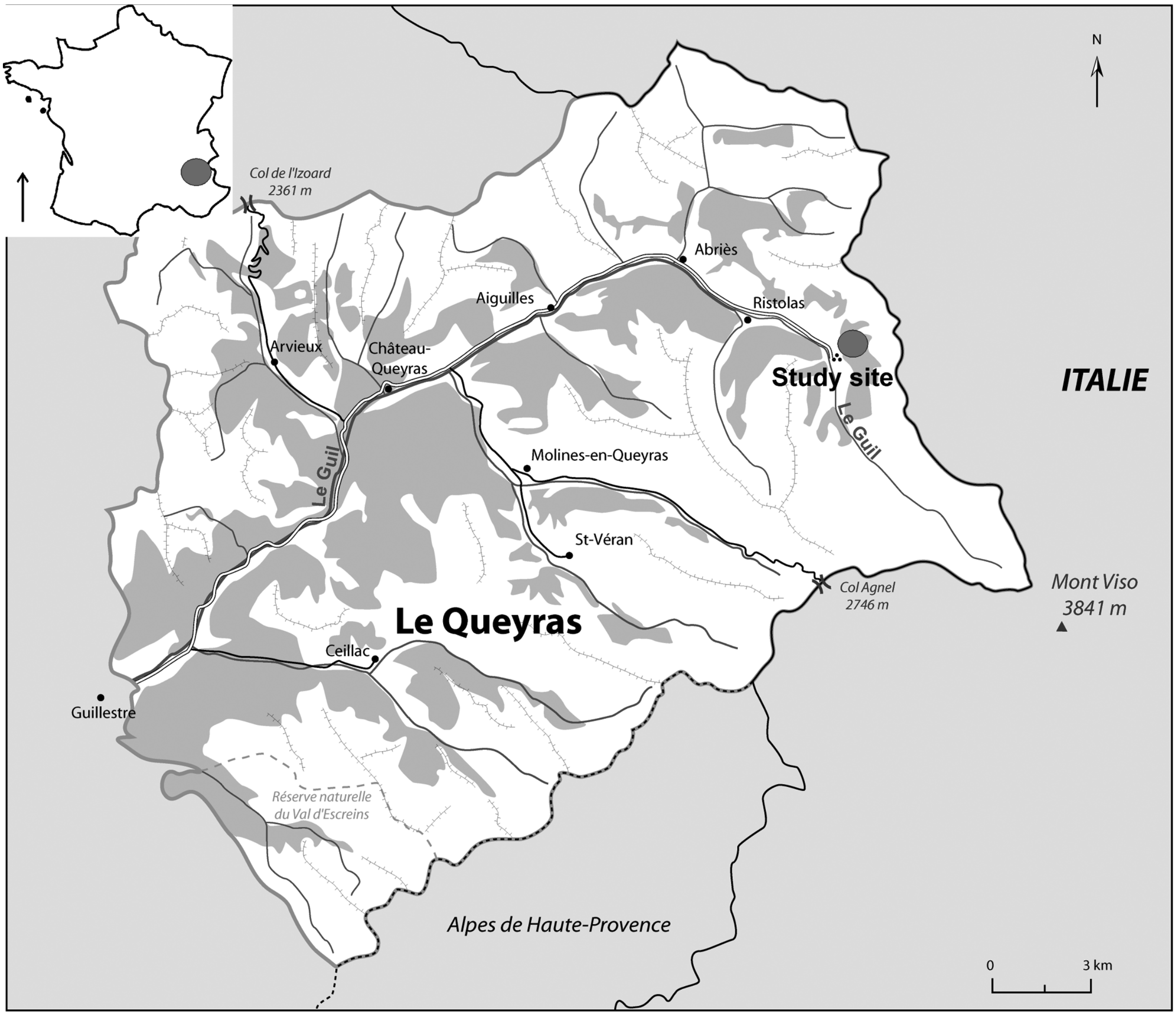

Figure 1 Location map of the Guil valley within the Queyras area. The study site is close to the hamlet of Echalp

as in PRA I, ranging from 3774 mg/kg (PRA I 4) and 340 mg/kg (PRA I 1) is observed.

Charcoal from understorey species (*Ericaceae*) are present in relatively small quantities compared with tree species. Moreover, they are absent from PRA I 1 and PRA I 4.

The anthracological assemblages across PRA I are largely dominated by *Larix/Picea* and *Pinus cembra* (Figure 2). Together, these species represent at least 60% of the charcoal identified, whilst they constitute 85% for pits 1, 4 and 5. The mean SAT value for PRA I indicates a dominance of both *Larix/Picea* (51%) and *Pinus cembra* (30%). However, the opposite trend was apparent in PRA I 1, with only 10% of *Larix/Picea* against 76% for *Pinus cembra*.

Larix/Picea dominates the charcoal assemblages from PRA II. *Pinus cembra* is the second most important taxon, representing almost 15% of the anthracomass. The combined values of *Larix/Picea* and *Pinus cembra* are never more than 82% of the total anthracomass for all species (Table 1).

Unlike the PRA I results, we find larch in all of the sampling levels of PRA II. Arolla pine is the dominant species, although it is less significant than larch across other levels from these pits. This is certainly the case for pits 1, 3 and 5. In addition, other taxa, such as fir and willow, were present in PRA II. These taxa do not appear in PRA I. *Abies alba* is present in four of the five pits from PRA II, but always in small quantities. However, its anthracomass increases with depth (Figure 3). *Salix* is only present in PRA II 2. Shrubby species such as Ericaceae are poorly represented.

Table 1 Specific anthracomass by profile (SAP in mg/kg) from each site and relative quantity of the two most important species

Site	Pit	SAP	L/P (%)	P.c (%)	Others (%)
PRA I	1	1322	10	76	14
	2	126	35	38	27
	3	125	52	8	40
	4	3136	87	6	7
	5	180	72	21	7
	Average	978	51	30	19
PRA II	1	340	65	7	28
	2	1349	65	15	20
	3	1568	64	4	32
	4	3774	35	47	18
	5	2875	69	2	29
	Average	1981	60	15	25

L/P, *Larix/Picea*; P.c, *Pinus cembra*.

The radiocarbon dates indicate mid- to late-Holocene fire events (Table 2). The oldest date comes from *Pinus cembra* (7566–7673 cal. BP) in PRA I. *Larix decidua* dates range between 5934–6123 cal. BP and 742–911 cal. BP. The single date for fir (5734–5908 cal. BP) also corresponds to the oldest date for the PRA II site. The youngest dates come from the PRA II site, with four dates ranging from 742–911 cal. BP to 895–959 cal. BP.

Charcoal found in the soil layer trapped in the roots of an uprooted larch, 10 m away from PRA II 2, were identified and

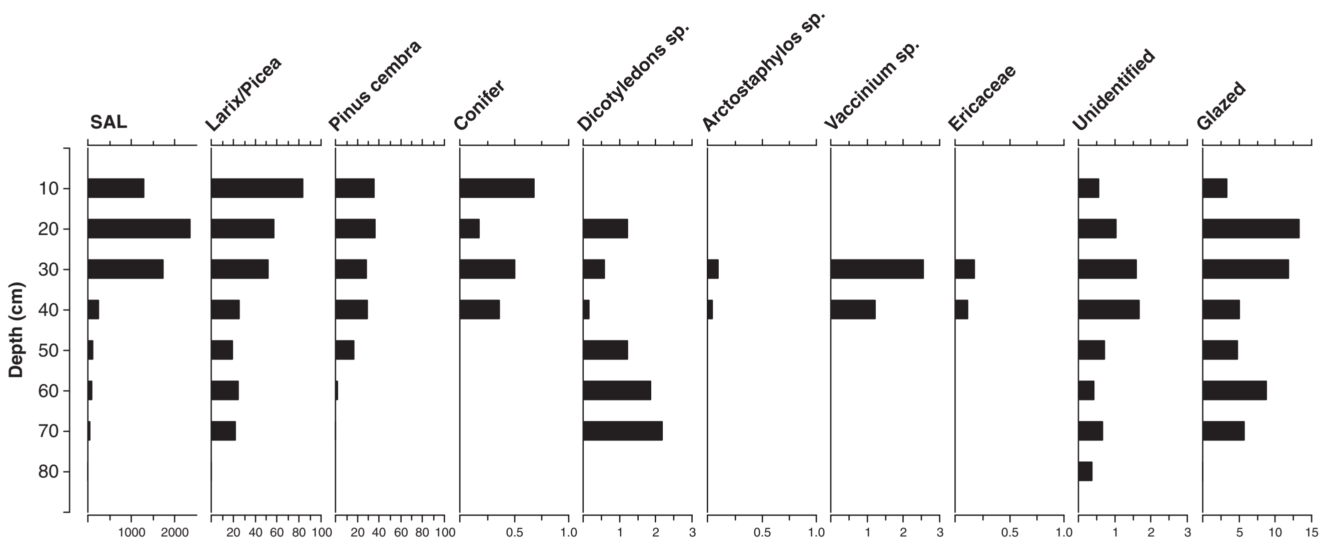

Figure 2 Anthracological mean diagram (mg/kg) for the five pits of PRA I at 2080 m a.s.l. The SAL is the totality of charcoal extracted from one depth level. Each taxa is represent by the weight of charcoal identified (mg/kg) for each depth level

dated. All of those fragments belong to arolla pine. The date (1408–1539 cal. BP) is almost the same as that obtained from a piece of larch charcoal from pit 4 (1409–1542 cal. BP).

Discussion

The data from PRA I demonstrate that arolla pine was present in this area from *c.* 7600 cal. BP to 1500 cal. BP (Table 2). Therefore, as it is still present today on site, it has been continually present on these slopes for more than 7600 years. Previous soil charcoal analyses carried out in neighbouring valleys confirm these results (Talon, 1997; Talon *et al*., 1998; Ali *et al*., 2005). Our results suggest the establishment of larch from *c.* 6000 cal. BP, whereas other studies have indicated an earlier arrival, dating back to 8000 cal. BP in the southernmost Alps (Ortu *et al*., 2005). The soil charcoal records from PRA I (Figure 2) present evidence for the prevalence of larch over arolla pine; a situation demonstrated by several palaeoecological studies (eg, Edouard *et al*., 2002; Ortu *et al*., 2005; Muller *et al*., 2006).

The relatively few available dates prevents us from proposing a hypothesis on fire frequencies at the location of PRA I. Nevertheless, it is clear that more than one fire did occur between 7566–7673 cal. BP and 1510–1627 cal. BP. Neither does this study allow us to identify with certainty a natural or an anthropogenic cause for these events. However, recent archaeological research in the southern French Alps (The Ecrins National Park, the Ubaye Valley, including the northern edge of the Mercantour National Park) has demonstrated that people frequented the subalpine and alpine zones from the Mesolithic onwards, and that during the late third and second millennia BC, the use of forest resources for human activities was common (Walsh *et al*., 2005).

The archaeological research thus supports the assumption of an early date for the first human incursions into the Alps at high altitudes. The archaeological studies suggest that at the end of the Würm glaciation prehistoric foragers intruded the Alps from the south following the retreating glaciers (Walsh *et al*., 2005; Walsh and Richer, 2006). Nevertheless, this early evidence for human activity only reflects the sporadic presence of hunter-gatherer groups, and not a permanent occupation, or repeated seasonal use of the subalpine and alpine altitudes. Several studies show that the exploitation of alpine valleys was common in all the alpine arc, from French Alps to Austria (Schmidl *et al*., 2005). We also assume that there was minimal human pressure on these landscapes

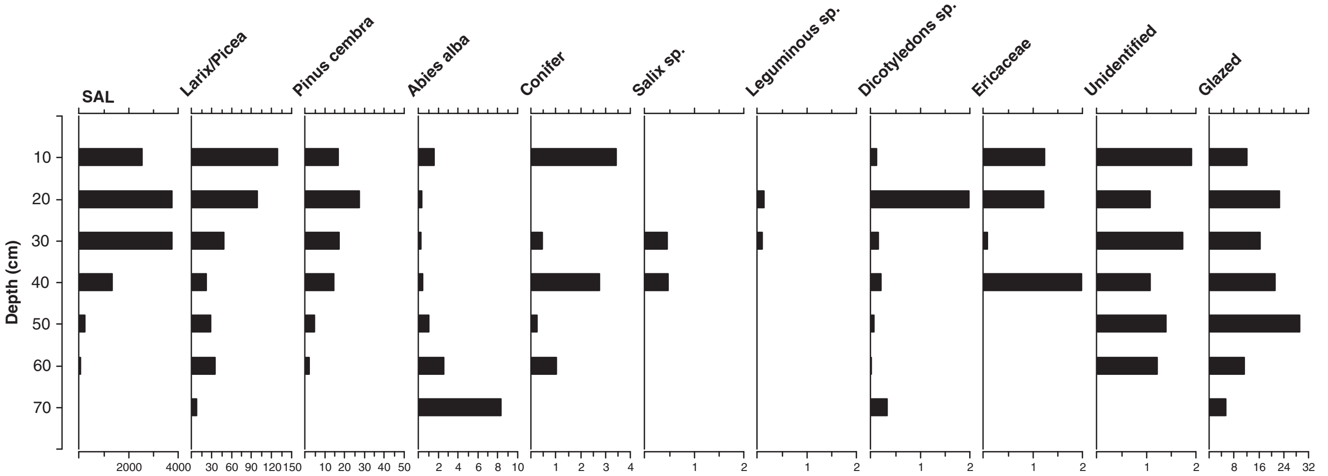

Figure 3 Anthracological mean diagram (mg/kg) for the five pits of PRA II at 1980 m a.s.l. The SAL is the totality of charcoal extracted from one depth level. Each taxa is represent by the weight of charcoal identified (mg/kg) for each depth level

Table 2 List of radiocarbon dates

Site	Pit	Material	Dating	Depth (cm)	Species	Age BP	Age cal. BP (2 σ)	Reference
PRA I	1	charcoal	AMS	60	*Pinus cembra*	1655 ± 30	1510–1627	Poz-16000
	1	charcoal	AMS	30	*Pinus cembra*	2930 ± 30	2973–3167	Poz-16001
	2	charcoal	AMS	30	*Pinus cembra*	6750 ± 40	7566–7673	Poz-16003
	2	charcoal	AMS	50	*Larix decidua*	2595 ± 30	2705–2771	Poz-16002
	3	charcoal	AMS	50	*Larix decidua*	5265 ± 35	5934–6123	Poz-16004
PRA II	4	charcoal	AMS	20	*Pinus cembra*	915 ± 30	764–919	Poz-16008
	4	charcoal	AMS	20	*Pinus cembra*	985 ± 30	895–959	Poz-16010
	OS[a]	charcoal	AMS	OS	*Pinus cembra*	1590 ± 30	1408–1539	Poz-18171
	2	charcoal	AMS	30	*Larix decidua*	905 ± 30	742–911	Poz-16007
	2	charcoal	AMS	10	*Larix decidua*	965 ± 30	795–888	Poz-16006
	4	charcoal	AMS	40	*Larix decidua*	1595 ± 30	1409–1542	Poz-16076
	2	charcoal	AMS	30	*Abies alba*	5065 ± 35	5734–5908	Poz-18170

[a]OS, off site, uprooted tree.

prior to the Neolithic. Therefore the first fires (7566–7673 cal. BP and 5934–6123 cal. BP) were probably caused by lightning. The three later fires (2973–3167 cal. BP, 2705–2771 cal. BP and 1510–1627 cal. BP) may well have been caused by people; the earliest of these three fires dates to the mid–late Bronze Age. The archaeological evidence from the southern French Alps leaves little doubt that activity at altitudes between 1800 m and 2500 m became relatively intense during the late Neolithic and the Bronze Age. The latter period is characterized by the first evidence of permanent (annual) occupation in the subalpine zone, and a consequent increase in forest exploitation resulting from pastoralism and metallurgy (Barge *et al*., 1998; Walsh *et al*., 2005). People may well have undertaken the opening of the forest, with fire used for clearing some areas. Such an event has been clearly identified in the Champsaur on the Jujal III archaeological site (Court-Picon *et al*., 2007) and it is quite probable that the area around the complex of late third and second millennia BC sites at Serre de l'Homme were cleared through the use of fire. People engaging in the use of slash-and-burn is also a possibility. Of course, many of these openings could have been the product of lightning fires that took place during a period of drought, or even caused by wind throws.

The quantities of charcoal extracted from PRA II were greater than PRA I (Tables 1 and 2). Consequently, it seems that fires have been more frequent here, based on the assumption that the higher the biomass burning, the higher the charcoal accumulation (Carcaillet *et al*., 2006) or the vegetation and understorey comprised more combustible material than in the PRA I area.

The dates obtained for PRA II are very close to one another (742–911 cal. BP to 1409–1542 cal. BP), although one dated fragment came from a unit 20 to 40 cm deep (Table 2).

The similarity of these dates could be the result of micro relief heterogeneity, but also due to soil disturbance caused by snowfall, avalanches, tree throws, landslides and bioturbation by activity of earthworms, marmots, snow vole (Brown, 1977; Schaetzl *et al*., 1989; Norman *et al*., 1995; Nachtergale *et al*., 2002; Talon *et al*., 2005). In turn, these processes could be a consequence of deforestation (Eugenio and Lloret, 2004). This hypothesis is supported by radiocarbon dates that coincide with the demographic peak of the Middle Ages. Historical documents (Falque-Vert, 1997; Audisio, 1998) and archaeological evidence (Walsh, 2005) confirm a significant increase in settlements at all altitudes across the southern French Alps. Therefore, with the available dates (742–911 cal. BP to 1409–1542 cal. BP), it seems very likely that the great accumulation of charcoal in the PRA II area represents the use of fire as a part of forest exploitation during the Mediaeval period. Thus, the disturbance of the soil profile might be the results of this forest exploitation.

The charcoal assemblages also indicate that historically there has been greater species diversity in this area. For example, fir and willow (Figure 3), both absent today, were once present. The presence of fir at *c*. 5900 cal. BP, at 1980 m a.s.l. on a western-facing slope, confirms that its ecological requirements were less restricted than commonly believed (Ozenda, 1985). Furthermore, the reappearance of firs has been observed on sites that have been considered unsuitable (eg, too dry, or beyond the altitudinal limit of the species) and the upper Guil valley is a part of these sites. There is no doubt that fir had a mid-Holocene distribution that was wider than we had once assumed (Carcaillet and Muller, 2005).

The preponderance of larch is not confirmed by this study, but according to the species (taxa) recorded in the charcoal spectra it is suggest that the larch forest was mixed comprising larch, arolla pines and isolated firs. Moreover, the occurrence of willow, and small leafy trees, indicates that this mixed forest was open enough to allow the expansion of a shrubby understorey.

PRA II is located between the hamlet of Echalp and subalpine meadows, this area having been used for spring and autumn pasture. Grass naturally grows under larch forests because of the neutral to slightly acid soils (rendisol) and well-decomposed litter. Moreover, high levels of solar energy can reach the ground, owing to the sparse, soft light foliage of larch and deciduous canopy. That is why larch and open larch forests (20–40% of tree cover) were favoured for human activities such as cattle grazing and summer farming, as opposed to arolla pine forest.

Human activity has profoundly altered the landscape we observe today. The abandonment of traditional practices has led to a change in modern forest dynamics, and we see a progressive closing of these areas because of natural reforestation in the subalpine levels (Motta and Nola, 2001; Ali *et al*., 2004). Ongoing dendroecological work (Talon *et al*., 2006) demonstrates that the current vegetation dynamics favour the development of arolla pine, thus modifying the forest structure. Over time, larch forests will be replaced by larch and arolla pine mixed forests, in which arolla pine and fir will play an increasingly important role, thus reproducing the situation that existed some 5000 years ago.

Conclusion

The Praroussin forest has been more open in previous times and underwent significant changes during the last 7600 years. According to the species (taxa) recorded in the charcoal spectra it is suggest that the larch forest was mixed comprising larch and arolla pines for much of the Holocene (from 6000 cal. BP). Arolla pine was present on this slope for more than 7600 years, and larch has been there for at least 6000 years. The forest also comprised willow, Ericaceae and especially fir, whose existence at 1980 m a.s.l. around 5900 cal. BP is typical of a species that demonstrates ecological adaptability. The forest dynamics of the lower part of the slope (PRA II) have been more influenced by anthropogenic activities and were driven much more strongly during the demographic peak of the 'Mediaeval Warm Period'. Human activities (fires and pasture) progressively damaged the organic layers, thus favouring larch regeneration. Consequently, the levels of arolla pine were greatly reduced. However, recent changes in land use, combined with the effects of global warming, have resulted in changes in modern forest dynamics and structure, leading to a recovery of arolla pine on the slopes. The choice of forest management is dictated by the goal for landscape management. We have to choose between maintaining larch-dominated human induced forests and restoring natural mixed arolla pine-larch forests. If the second seems to be the easier way for forest managers, maintaining the larch dominance in this forest requires keeping pastoralism activity.

Whereas fires were probably set deliberately in the subalpine zone during certain periods in the past, this is not normally true today. If we are to contribute to the development of conservation policies we must attempt an understanding of the probability and potential frequency of naturally caused fires in the future. We will improve the spatial resolution of our soil charcoal analyses with the help of a statistical analysis of the anthracological records (Touflan and Talon, 2009), together with dendroecological results. However, this work will also benefit from the longer-term integration of anthracological research with archaeological and palynological results from the same area. This is perhaps the only effective way to understand what differentiates an anthropogenic signal from a natural one. In order to separate anthropogenic from natural signals, one needs reliable, independent climate reconstructions that can be compared with fire history.

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Appendix 1

Distribution of the specific anthracomass (mg/kg) with depth for the five pits from PRA I

Pit	Depth (cm)	SAL	L/P	P.c	C	Dicot	Arcto	Vacci	Erica	Und	G
PRA I 1	10	2960	72.2	203.17	–	–	–	–	–	–	12.44
	20	2926	40.41	198.07	–	–	–	–	–	5.99	43.86
	30	1848	12.45	151.75	2.04	–	–	–	–	6.03	47.37
	40	412	2.91	148.83	2.35	–	–	–	–	0.34	11.84
	50	136	–	88.85	–	–	–	–	–	0.2	–
	60	3	–	3.1	–	–	–	–	–	0.34	–
	70	–	–	–	–	–	–	–	–	–	–
	80	–	–	–	–	–	–	–	–	–	–
PRA I 2	10	382	36.35	40.95	–	–	–	–	–	–	3.17
	20	116	3.55	3.42	0.55	–	–	–	–	–	20.49
	30	98	8.1	3.16	–	–	–	–	0.55	–	7.83
	40	26	1.44	12.39	–	–	–	–	0.54	0.9	2.33
	50	4	2.78	–	–	–	–	–	–	0.77	0.31
	60	–	–	–	–	–	–	–	–	–	–
	70	–	–	–	–	–	–	–	–	–	–
	80	–	–	–	–	–	–	–	–	–	–
PRA I 3	10	438	6.76	12.61	–	–	–	–	–	–	3.47
	20	298	41.31	3.52	–	4.87	–	–	–	–	7.15
	30	126	21.24	0.24	0.32	2.04	0.53	12.58	0.32	1.9	10.24
	40	70	10.66	1.06	0.13	0.31	0.22	5.19	0.13	4.65	3.95
	50	34	7.33	0.74	–	4.77	–	–	–	1.46	1.74
	60	11	4.07	0.22	–	2.9	–	–	–	0.26	0.89
	70	2	0.94	–	–	–	–	–	–	0.7	0.18
	80	1	–	–	–	–	–	–	–	0.81	0.27
PRA I 4	10	2272	155.18	–	1.61	–	–	–	–	–	–
	20	7830	168.59	–	0.29	–	–	–	–	–	–
	30	6234	173.17	14.73	0.28	–	–	–	–	–	–
	40	743	86.04	20.06	–	–	–	–	–	–	1.82
	50	564	93.59	14.29	–	–	–	–	–	–	22.6
	60	585	123.76	8.99	–	5.77	–	–	–	0.54	45.5
	70	323	115.07	1.1	–	11.78	–	–	–	1.1	29.04
	80	–	–	–	–	–	–	–	–	–	–
PRA I 5	10	357	154.24	–	–	–	–	–	–	–	–
	20	886	26.67	22.52	–	–	–	–	–	–	–
	30	170	26.5	0.49	0.33	–	–	–	–	–	–
	40	13	2.28	0.16	–	–	–	0.49	–	0.49	6.18
	50	1	0.32	0.63	–	–	–	–	–	–	0.47
	60	0.1	–	–	–	–	–	–	–	–	0.13
	70	1.2	0.24	–	–	–	–	–	–	–	0.97
	80	0.5	0.28	–	–	–	–	–	–	0.28	–

The SAL is the totality of charcoal extracted from one level. L/P, *Larix/Picea;* P.c, *Pinus cembra;* C, conifer; Dicot, dicotyledons; Arcto, *Arctostaphylos;* Vacci, *Vaccinium;* Erica, *Ericaceae;* Und, unidentified; G, Grazed.

Appendix 2

Distribution of the specific anthracomass (mg/kg) with depth for the five pits from PRA II

PIT	Depth (cm)	SAL	L/P	P.c	A.a	C	Sal	Leg	Dicot	Erica	Und	G
PRA II 1	10	1536	83.27	–	–	–	–	–	–	–	0.94	22.74
	20	223	45.68	10.15	–	–	–	–	7.89	–	0.94	20.68
	30	6	4.02	0.97	–	0.55	–	–	–	–	0.14	0.14
	40	2	0.71	–	–	1.59	–	–	–	–	0.18	–
	50	8	1.18	3.07	–	0.24	–	–	–	–	1.42	2.36
	60	–	–	–	–	–	–	–	–	–	–	–
	70	–	–	–	–	–	–	–	–	–	–	–
PRA II 2	10	5744	177.34	25.88	–	–	–	–	–	5.44	5.92	15.57
	20	2479	28.71	23.25	1.9	–	–	0.63	–	4.99	1.63	6.82
	30	47	15.12	0.75	1.75	1.67	2.34	0.58	0.17	0.5	2.51	4.18
	40	19	6.31	0.55	–	1.58	2.21	–	0.47	0.32	1.03	0.95
	50	3	1.25	0.5	–	0.25	–	–	0.33	–	0.25	0.25
	60	4	2.13	0.78	–	0.58	–	–	–	–	0.39	–
	70	–	–	–	–	–	–	–	–	–	–	–
PRA II 3	10	1759	95.68	1.24	–	–	–	–	–	–	–	8.76
	20	4389	222.6	3.11	–	–	–	–	–	–	–	19.49
	30	2415	109.16	7.17	–	–	–	–	–	–	1.59	9.16
	40	863	24.91	11.05	1.5	1.5	–	–	–	–	–	43.26
	50	207	27.94	–	5.24	–	–	–	–	–	0.63	64.76
	60	–	–	–	–	–	–	–	–	–	–	–
	70	–	–	–	–	–	–	–	–	–	–	–
PRA II 4	10	2390	75.39	37.01	6.2	–	–	–	–	–	–	3.18
	20	7788	68.84	80.45	–	–	–	–	–	–	1.22	13.24
	30	7460	29.1	79.95	–	–	–	–	–	–	3.4	12.53
	40	3189	16.84	50.7	–	1.03	–	–	–	–	3.93	27.6
	50	263	11.53	22.98	–	1.02	–	–	–	–	2.6	25.95
	60	47	11.07	9.44	–	–	–	–	–	–	2.18	5.63
	70	–	–	–	–	–	–	–	–	–	–	–
PRA II 5	10	367	241.51	–	–	23.27	–	–	–	–	–	4.4
	20	5240	216.58	3.83	–	–	–	–	–	–	–	59.95
	30	10 934	118.04	0.98	–	–	–	–	–	–	–	62.55
	40	3388	69.08	14.69	1.53	8.78	–	–	–	30.15	–	35.5
	50	977	95.35	1.28	–	–	–	–	–	–	–	42.15
	60	173	59.5	–	4.83	1.71	–	–	–	–	–	17.76
	70	29	7.17	–	8.42	–	–	–	–	–	–	4.3

The SAL is the totality of charcoal extracted from one level. L/P, *Larix/Picea;* P.c, *Pinus cembra;* A.a, *Abies alba;* C, conifer; Sal, *Salix* sp.; Leg, leguminuous; Dicot, dicotyledons; Erica, *Ericaceae;* Und, unidentified; G, grazed.

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