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Multidisciplinary approach to investigate human-forest relationships in southern French Alps: How to estimate the impact of populations on the local mountain wood stock?

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ABSTRACT

This study presents a multidisciplinary approach between palaeoecology and the analysis of historical archives to reconstruct forest history subjected to long-term human activities. We focus on a case study from the southern French Alps (the Bléone Valley), for which a rich historical corpus but little palaeoenvironmental data are available. We compared and contrasted (i) pedoanthracological data obtained along an altitudinal transect (ca 400 m), (ii) dendrochronological data from historical buildings and old living trees, and (iii) historical data from written sources on forest management and land-use change. The aim of this paper is to demonstrate that the comparison between different proxy data to understand the history of mountain forest ecosystems and human-forest interactions is very challenging. We show that the spatial distribution of forest and treeline position have been impacted by human activities, mainly due to agro-sylvo-pastoral practices through the use of fire and forest cutting to maintain open pasture lands and local building purposes. Despite centuries of local agro-sylvo-pastoral activities, the forest composition has remained relatively unchanged since the Middle Ages. Our comparison of historical documents with dendrochronological data on local buildings and soil charcoal data shows that the local demands of wood cannot explain the observed large-scale changes in forest spatial continuity. Curiously, the highest demand for wood by local residents did not occur in pace with modern demographic boom (17th century), as would be expected. Thus, we suggest that supra-regional external regulations and State's control played a more important role in forest management. Royal shipbuilding industry, more lucrative economic stakes, and expanded demand for timber for construction of buildings in urban areas of the lower valleys and plains are among the external factors which impacted forest exploitation during periods when logging was prohibited.

1. Introduction

1.1. Background and objectives

Humans are an integral part of the long-term evolution of vegetation, and have played an important role in the ecological history of forest ecosystems since the diffusion of Neolithic sedentary lifestyle in the French Southern Alps starting around 5000 BCE (De Beaulieu, 1977; De Beaulieu et al., 1993; Magny, 1997; Nakagawa, 1998; Dupouey et al., 2002; Segard et al., 2003; Briggs et al., 2006; Girel, 2006; Jackson, 2006; Desmet et al., 2008; Richer, 2009; Talon, 1997a, 2010; Brisset et al., 2012; Walsh et al., 2007, 2014). Numerous palaeoenvironmental studies

using different proxies have investigated the history of vegetation in relation with human occupation in the southern French Alps. However, it is still difficult to have a precise picture of human imprint on the vegetation based on individual proxy records (mainly pollen and soil charcoal). Furthermore, due to spatial variations in geological, geomorphological and climatic setting, the availability of suitable sedimentary archives (lakes, peat bogs) or archaeological and historical archives differ from area to area in the southern French Alps.

In this study, we focus on the Bléone valley (Alpes de Haute-Provence, France). With a rich human history particularly marked by agro-pastoral practices, forest exploitation, and timber trade, there is a large corpus of historical data tracing human settlement, notably

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through demographic and forestry records for this mountain region. As far as the forestry and pastoralism are concerned, a wealth of documentation is available including works on the history of Provence landscapes (De Ribbe, 1857; Nicod, 1952; Douguedroit, 1976; Boyer, 1990; Pichard, 1999), pastoralism-deforestation relationships (Sclafert, 1959), regional administration (Peyriat, 1951, 1965; Vivier, 1992), and the history of forestry (Chalvet, 2011). However, above all, we should mention M.-P. Baume's work, a local historian, on the Faillefeu Abbey (Prads-Haute-Bléone) and its wood exploitation (2011), and J. Cazerès' publication compiling modern notarial deeds on the study area (2013). This sector has also been the focus of a PhD thesis on dendroarchaeology (Shindo, 2016) and has recently been the subject of a systematic pediaanthracological study (Gamba et al., 2022).

However, many questions still persist as for instance, the specific influence of human interventions on some key forest species such as fir (*Abies alba*). So far, no long-term Holocene pollen record is available at the proximity of the area. The closest palynological record, Lakes Lignin, is 21 km further to the west (Nakagawa, 1998) making it difficult to generalise its local forest dynamics to our study area. Hence, the local history of the forest dynamics remains poorly known and it is difficult to distinguish the natural versus anthropogenic origin of dominant tree species in its present floristic composition. From a dendrochronological point of view, ancient forestry practices are still relatively unknown. Subfossil trees (mainly Scots pine type, *Pinus t. sylvestris*) have been radiocarbon dated to several thousand years old, and seem not to be linked to any human activity (e.g. Miramont et al., 2000; 2011). Dendro-archaeological studies in the Southern French Alps focus on dry wood preserved in hundreds of mediaeval and modern elevated buildings and mines, especially in the north of the area (Edouard, 2010a, 2010b; Guibal and Meyran, 2011; Labbas, 2016; Shindo, 2016; Shindo et al., 2018, 2022). In the Bléone area, in contrast, such studies are not

abundant and have just recently started even though they offer a strong potential to understand the history of wood exploitation (Shindo, 2022). Moreover, as this region is at the meeting zone of the mountain and Mediterranean influences (Blanchard, 1956) with very specific human practices (Barruol et al., 2005; Baume, 2011), it is interesting to study how human-forest relations have evolved over time.

The aim of this paper is to combine three disciplines having different degrees of precision but which are very complementary: dendrochronology, pediaanthracology and history. We will investigate how to confront their respective contributions in order to re-contextualize the human impact perceived by (i) mediaeval written sources and witnesses, (ii) dendrochronological data of local buildings, (iii) soil charcoal data along altitudinal gradient. Our objective is to give a more holistic and objective reconstruction of human impact on mountain forest ecosystems through the last millennia.

1.2. Geographical setting

The Bléone valley, in the French Pre-Alps, is a transitional zone between the inner Alps and the Mediterranean region. The geology of the area is dominated by limestones (Debelmas, 1987).

The Bléone river takes its sources from the foothills of two summits (ca 2400 m), the Tête de l'Estrop (2961 m) and the Trois-Evêchés (2819 m). It joins the Durance river (a tributary of the Rhône) 70 km downstream (Fig. 1).

The current forest vegetation of the catchment area is mainly composed of holm oaks (*Quercus ilex* L.), Scots pines (*Pinus sylvestris* L.), downy oaks (*Quercus pubescens* Willd.) and stands of Phoenician juniper (*Juniperus phoenicea* L.) at low altitudes (1000–1300 m) and of beech (*Fagus sylvatica* L.), fir (*Abies alba* Mill.), spruce (*Picea abies* L.) and larch (*Larix decidua* Mill.) on higher slopes (1200–1900 m). Following the

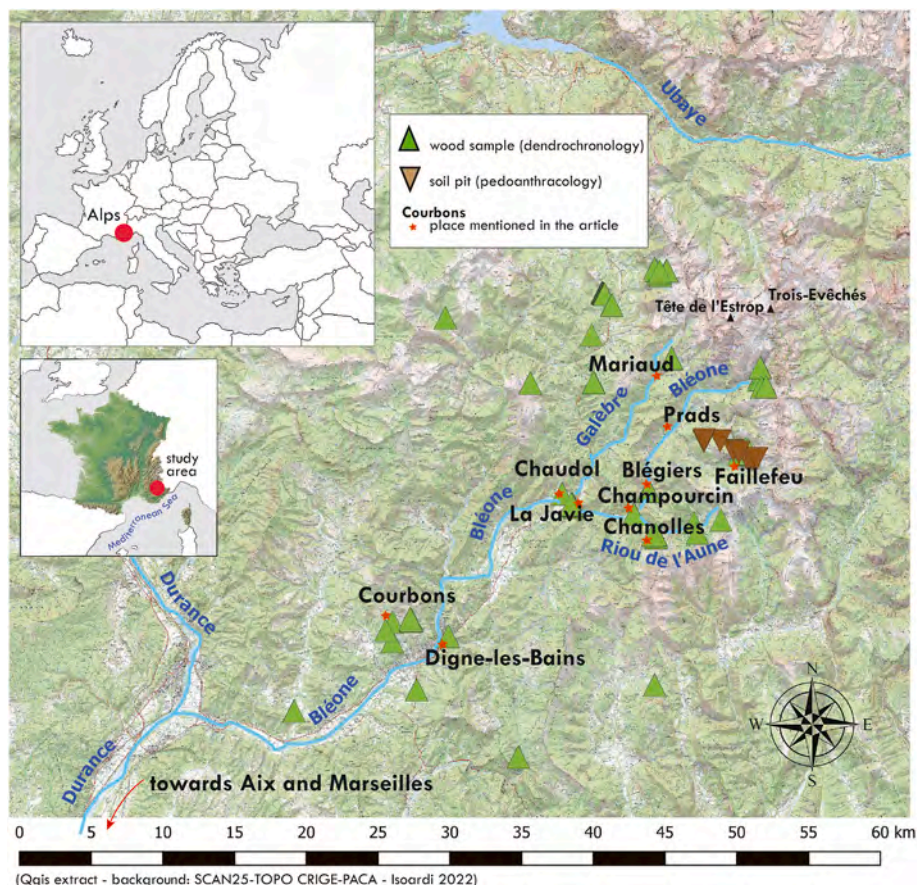


Fig. 1. Study area. Location of the buildings studied by dendrochronology, the pediaanthracological pits, and the toponyms mentioned in the article.

reforestation of the 19th century to the beginning of the 20th century, Austrian black pines (*Pinus nigra* Arnold), hooked pines (*Pinus uncinata* Ram. ex DC.) but also larches were planted on deforested slopes (Ozenda, 1970) through the reforestation program named “Restauration des Terrains de Montagne” (RTM), Mountain Land Restoration department. Some of the main associated planted species are sea buckthorn (*Hippophae rhamnoides* L.), common alder (*Alnus glutinosa* (L.) Gaertn.), black poplar (*Populus nigra* L.), willows (*Salix* sp.), golden chain tree (*Laburnum alpinum* (Mill.) Bercht & J. Presl), black locust (*Robinia pseudoacacia* L.) (Ministère de l’Agriculture, 1911).

In this study, the Chourges slopes (Fig. 1) were selected to perform pedoanthracological analysis. This site is located a few kilometers from the Faillefeu forest to the south and at the border between the montane and subalpine vegetation belts. In the lower elevations, the fir is found interspersed with larch and shrubby hardwoods (fir stand). *Laburnum alpinum* is also sporadically scattered within the dense stands of fir, on the forest edge. With increasing elevation, fir is gradually replaced with larch, which can form almost monospecific stands extending to the highest plateaus. This larch forest then gives way to a heathland dominated by common juniper (*Juniperus communis*). Larch trees have recolonised the slopes in recent times, as shown by a comparison of aerial photographs taken by the National Institute of Geographic and Forestry Information (IGN) between 1950 and today (Fig. 2). This recolonization phenomenon can be observed throughout the French Southern Alps (Choler et al., 2021). The *Larix* seeds may come from the plantations realized by “Eaux et Forêts” organisation (in turn part of the RTM program, see above) around 1880. These plantations were abundant in the area but the archives do not precise where, and what kind of species were specifically used on the Chourge slopes. As far as the French National Forest Office is concerned, very little silvicultural intervention was practised in the study area. Nonetheless, a few small plots were planted with larches in the 1980’s centered around the CHO4A pit (ONF personal communication). Consequently, the origin of the modern larch stands is from both natural and planted populations.

2. Material and methods

2.1. Method concerning historical sources and possibility to cross pluridisciplinary data

This section is based on a comprehensive review of mediaeval to contemporary sources treating the exploitation of wood and pastures. After selecting the most relevant information, we transformed the historical punctual data into a more illustrative and semi-quantitative presentation, which better permits comparing them in a more

appropriate way, to quantitative data obtained through dendrochronology or pedoanthracology. Hence, based on the analysis of historical sources, we produced graphs (Fig. 11), expressing:

- local demographic pressure on the ecosystems in the form of a “faim de terre” sometimes at the expense of forests,
- pressure on forest resources, mainly for economic reasons (logging for wood export),
- pastoral pressure whose need for grazing leads to a reduction in wooded area, while keeping the environment open.

The timeline is the ideal tool, halfway between narrative and modelling, for integrating different types of data in a single figure and juxtaposing different timeframes. A visual language common to all the themes is used to construct the trajectory of phenomena and the dynamics of events, with their changes, breaks, thresholds and phases of equilibrium. It also models the quantitative aspect, in an empirical way (except for demography). The overall understanding is visual and immediate, offering a synoptic view of data on vegetation and landscape viewed by different disciplines.

To design this timeline, we first had to select the relevant elements in the corpus linked to the problem. Then, we produced a horizontal band for each theme on a large benchmark with centennial-scale x-axis.

The chronological range is shown by horizontal bands, marking the temporal limits of each major themes (a, d, or c). Dotted lines refer to the uncertainty of the phase. The stars represent individual short-term events;

The “qualification” of events, in terms of pressure on wood resources, is shown by the colour gradient with darker end of the spectrum indicating higher pressure on forest resources. For the stars, blue indicates action in favor of forest development, and red, the opposite. We have modelled the importance/weight of supra-regional restrictions on the harvesting of local wood on a band of red shading.

For demographic data, the quantification, which is very precise since the Middle Ages, is materialised by depicting vertical bands with their size proportional to the weight of the human communities (previously, simple + and - signs, and an arrow for a situation of growth). In the case of the Faillefeu forest (very close to Chourges), arrows indicate a dynamic of progression or decline of the forest.

In Fig. 11, the above historical data, translated into the timeline, are compared with the dendrochronological as well as pedoanthracological data and the historical climate phases. Concerning dendroarchaeology, each horizontal strip represents a cored beam the colour of which identifies the tree species, the sapwood, the last ring. The length of the strip depends on the number of measured rings: the longer the strip, the

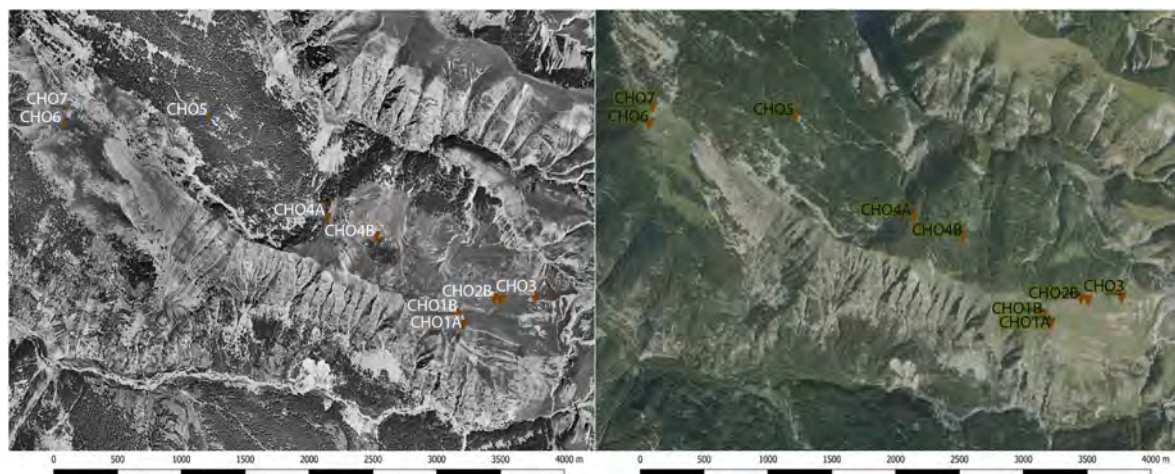


Fig. 2. Satellite image showing forest recolonization since the 1950s. Images are derived from the “Institut national de l’information géographique et forestière (IGN)”.

older the tree was when it was felled. Pedaanthracological results are presented on three graphs with altitude on the y-axis, time on the x-axis, distinguishing their origin according to current vegetation (forest *versus* pasture); one spot for each identified and dated charcoal. We've added here dendrochronological information from the cored living tree in Chourges. A few synthetic climatic indications (cold phase in white/warm phase in black), are shown based on historical climatological data from GREC-PACA, 2016).

2.2. Dendrochronology

Dendrochronology makes it possible to date and understand the relationships between the evolution of the forest landscape, ancient silvicultural practices and the uses of wood (Schweingruber, 1988). In the Bléone valley, since 2014, 43 historical buildings have been the subject of dendrochronological studies. These buildings were selected on the basis of their dendrochronological potential (undisturbed structures and accessible timber for sampling), but especially if the 'owners' permission was granted. Thus, 282 wood pieces were sampled. Most of them have been cored (Pressler manual increment borer (Haglöf company, Sweden) and Rinntech electric core drill (Rinntech company, Germany)). When timbers were removed from the structure, a section was cut with a chainsaw. In the laboratory, wood species were identified (Schweingruber, 1990) and ring-widths were measured using the incremental measuring table LINTAB and TSAP-Win software (Rinntech, 2014) with 0.01 mm accuracy. In each case, several rays per sample were measured and averaged in order to obtain a series suitable for dating. Then, with Dendron IV software (Lambert, 2006), tree-ring series were indexed using the "Corridor", a polynomial indexation which considers the amplitudes of the inter-annual variations while preserving the average frequency variations (Durost and Lambert, 2006; Lambert, 2006). Once indexed, the dendrochronological curves were cross-dated using the Student test (*t*).

In 2014, on the Chourges slopes, five large living larch trees with remarkable bearing were also cored with a Pressler manual increment borer. A countdown of the tree rings from the bark (ring of the year 2014) to the pith (ring close to the tree's birth year) made it possible to determine the age of the trees as an information to understand the landscape's history.

2.3. Pedaanthracology

'Pedaanthracology' also named 'soil charcoal analysis' is a palaeoecological tool to reconstruct the composition of the woody vegetation

in the past using the identification and dating of wood charcoals preserved in soils resulted from natural (lightning) or anthropogenic (forestry and pastoral management) fires (Thinon, 1992). Since its development in 1990's, it has incited a major advance in reconstructing the Holocene history of mountain forest ecosystems at small spatial scale. For instance, soil charcoal data have made it possible to (i) nuance the involvement of climate in the fluctuations of the upper treeline over time (Talon, 2010; Saulnier et al., 2015; Cunill et al., 2013), and (ii) highlight the determining role of anthropogenic activities and fire events in the structure and composition of vegetation (Ali et al., 2005; Dutoit et al., 2009; Talon, 2010; Bal et al., 2011; Robin et al., 2013; Lindskoug and Villafanez, 2020). The comparative approach of pedoanthracology and dendrochronology has recently proved its high potential to unravel the human footprint on the natural forest dynamics (Saulnier, 2012; Touflan, 2010; Touflan et al., 2010).

The objective of our pedoanthracological approach was to determine temporal changes in the structure of vegetation at a very local scale. Accordingly, ten soil pits were dug along an altitudinal transect crossing several vegetation belts from the bottom to the mountain top (Fig. 3). Pits CHO1, CHO2, CHO3, CHO6 and CHO7 were dug in a juniper heathland whereas pits CHO4 and CHO5 were dug under the forest canopy (fir forest for CHO5 and larch forest for CHO4) (supplementary material, Table. A). We classified the pits according to the degree of openness of the environment: open (CHO1, CHO2B, CHO6 and CHO7), semi-open (CHO2A and CHO3) and closed (CHO4A, CHO4B and CHO5). To better track the position of the boundaries between these open and closed forests and their variations over time, the pits dug at the edge of the present grassland (CHO1, CHO2 and CHO4) were duplicated 40 m apart, given the high spatial variation of soil charcoal records. In each of the pits, soil samples were taken from the bottom to the top of the profile every 10 cm (level 0–10 cm, 10–20, etc., down to 60–90 cm for the deepest one). Charcoals were extracted following Carcaillet and Thinon (1996) and Saulnier et al. (2015).

Charcoals >800 µm in size were identified and weighed to calculate the Specific Anthracomass (SA) (Thinon, 1992; Carcaillet and Thinon, 1996). The latter value can be expressed by taxon (SAT), by level (SAL) or by profile (SAP). It corresponds to the quantity of charcoals >800 µm (in mg) on the total mass of the dried sample collected (in kg). A minimum of 30 charcoals were randomly selected for identification. Charcoals were identified under an episcopic microscope (at ×200 and ×500 magnification) based on anatomical criteria described in wood or charred wood anatomy atlases and identification keys (Jacquiot, 1955; Schweingruber, 1990; Vernet and Ogereau, 2001). The reference collection of the Anthracology lab of Institut Méditerranéen de

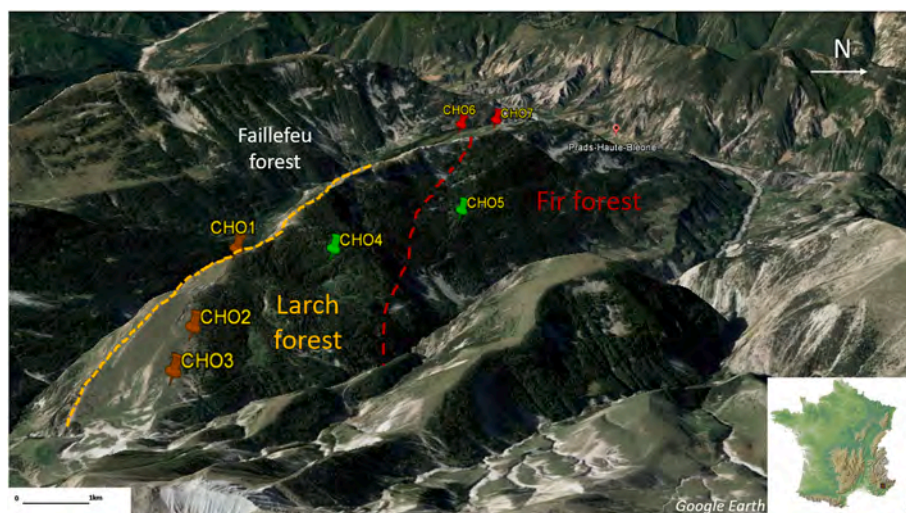


Fig. 3. Location of the pedoanthracological transect along Chourges slope (Alpes de Haute Provence, France).

Biodiversité et d'Ecologie was also used to strengthen the identifications. Some taxa such as *Larix* and *Picea* are difficult to differentiate on the sole basis of wood anatomy. They are thus referred to as *Larix/Picea*. Similarly, fir and juniper which are sometimes difficult to differentiate are grouped into *Abies/Juniperus*. We kept the genera and higher taxonomic groups when the charcoals were too damaged to precise the identification (e.g. *Pinus* sp., no *Pinus*, shrubs, etc.).

Finally, a large part of the unidentifiable charcoals displayed a vitrified aspect (Mcparland et al., 2010; Marguerie et al., 2010) and were thus grouped under the term “vitrified”. Total specific anthracomass was represented for the whole transect to visualise the charcoal richness within each pit. The anthracomass of the most abundant taxa in the anthracological assemblages were represented for each pit and along the whole transect (Fig. 8).

2.4. Radiocarbon dating

Seven identified charcoals were selected for dating (Fig. 9). We selected these samples according to 1) the minimum weight needed for ^{14}C dating (>2 mg), 2) the optimal location within the transect to help to reconstruct the vertical fluctuations of the treeline, and 3) the taxonomic interest to evaluate the changes of forest composition (Gamba et al., 2022; Talon, 2010). Radiocarbon age determinations were performed at Poznan Radiocarbon Laboratory (Poland). The AMS radiocarbon dates were calibrated to the calendar timescale using the calibration program OxCal 4.4.2 with the updated InCal20 Northern Hemisphere radiocarbon age calibration curve (Reimer et al., 2020). Probability distribution curves of the seven radiocarbon dates were created in the R package “clam” (Blaauw, 2010; R Core Team, 2021).

3. Results

3.1. Historical review

3.1.1. Who owned the forests and pastures?

Under the Frankish kingdom, following Roman domination during which large farms are recorded in the valley floors (Berard, 1997), these territories were farmed by the Patrices, within the framework of large Merovingian and Carolingian *villae* following Roman tradition (Vaissière, 2016). At least one of these was given to the monks of Saint-Victor from Marseilles becoming the *Ager Galadius* which encompasses the study area (Guérard, 1857; Arbaud, 1903, 1903–1904, Bergh, 1941; Balon, 1971; Sauze, 1984; Thiéry, 2013; Vaissière, 2016). It is possible, however, that certain parts of the land belonged to free peasants, or to another master or religious order (Devroey, 2004).

Subsequently, after the Saracen invasion at the end of the 10th century, a network of estates was created by small or larger families who established in all the strategic points of these valleys (see details in Thiéry, 2010; Vaissière, 2016). At the same time, as part of the spiritual impetus typical of this period, a number of religious estates of the 9th-10th centuries, which had been taken over during the period of disorder, returned to the religious orders in the 11th-12th centuries: this was the case for the abbey of Saint-Victor, which demanded the return of the entire *Ager Galadius*, which had been progressively eroded by the “alleutiers” (peasants) after 814 CE. By the 11th century, this estate had been considerably contracted. The Middle Ages in the Haute Bléone were marked by a multitude of players, a fragmentation of the territory, overlaps between various owners, some secular, some religious, changes in the domination of these lands with a background of tension, and power transition between these protagonists (Guichard, 1846; Isnard, 1913; Poly, 1976; Thiéry, 2010, 2013; Cazères, 2013; Vaissière, 2016).

The Count of Provence also had rights in Haute Bléone. During the 15th century, the majority of pastures belonged to Lords, with their own flocks. However, by then, most of the pasturelands belonged to a few lords who rented pastures to external flocks from Low Provence (Coste, 1972; Coulet, 1978). As far as our spots are concerned, La Chau belonged

since the 12th Century to the Faillefeu Abbey (Sclafert, 1959; Baume, 2011). We can't be certain if it was the same for the entire Chourges-Vachière Massif; but the eastern end of the massif (Vachière) dominated by pastures may have belonged to Faillefeu since the Medieval times. Concerning forested areas, the Faillefeu Abbey was also the owner of the vast forest extending on each side of the Aune river (south of the studied area). Unfortunately, we have no precision for the Chourges massif.

In modern times, the Digne Cathedral Chapter still had some rights in the valley (Cazères, 2013) and Faillefeu fell into the hands of Saint-Martial College from Avignon (Baume, 2011). However, at that time, the land was mainly in the hands of various lords and co-lords (see details in Baratier, 1969; and especially Cazères, 2013). It should be added that following a major demographic crisis, the lords' land and wood were given as emphyteusis (long-term lease), with the aim of restoring land buried by scrub, bush and shrubs by new immigrants (Sclafert, 1959, 105). However, some lords faced with an impoverished population that had to be rebuilt, refused to give up their land and preferred to apply the rules governing access to forests and pastures. Consequently, conflicts were frequent.

In the 18th and 19th centuries, most of the grazing land was owned by the communes such as the Faillefeu territory after the Revolution, including La Chau, Chourges and Vachière. Some forested areas also became communal (Cazères, 2013), especially La Chau and Croix de Chourges studied here. The Faillefeu forest, by contrast, became a private property after 1789; Baume (2011). At the beginning of the 19th century, the Napoleonic cadastre confirms that Chourges/Vachière and La Chau (where were located pits CHO6, 7, and CHO1, 2, 3, 4) are communal pastures, and Chourges (with CHO5) was a communal wood.

However, it is very difficult to attribute the plots studied through peditanthracology or dendrochronology to a specific owner before the contemporary period, except in specific and exceptional cases (Faillefeu archives).

3.1.2. Forestry pressure

The written sources that have come down to us are for the most part dealing with the regulatory or contractual aspects. Once interpreting them we should consider the possible negative correlations between human activities and forest expansion or contraction. Indeed, from the Middle Ages onwards and from the end of the 16th century to the end of the 18th century (French “Ancien Régime”), access to the forest was clearly regulated and/or taxed. Referring to prohibited practices, the texts thus mirror current practices, indirectly informing us of people's habits (Peyriat, 1965; Bechmann, 1984). For example, one of the oldest texts concerning the Bléone valley dates to 1191. It allows the inhabitants of the city of Digne to take wood from the Courbons forest (Fig. 1) for their personal use (Sclafert, 1959; after Guichard, 1846), and not for extensive trade.

In the Bléone valley, the question of forest resource protection arose quite quickly, because from the middle of the 12th century, the abbey of Faillefeu is founded (Chalaisian Abbey resulting from Boscodon, which will become thereafter a Priory under the order of Cluny at the end of the 13th century). This abbey had water saws as early as 1304 and the exploitation of the local forest was from the beginning one of its important economic sources, alongside pastoralism (Baume, 2011; Vaissière, 2016).

However, Ecclesiastics are not the only ones to exploit forests. Indeed, the texts testify to the need to protect this resource; as in 1237, with the creation of a political institution (“consulat” in French) in Blégiers and Mariaud, dealing with the protection of the mountains, woods and local pastures (Sclafert, 1959). However, the protection measures were not always followed by positive effects, as show the reports of Faillefeu Abbots, from 1304 until the beginning of the 15th century (cutting wood without permission, too much fellings, bad management, poorly guarded forests, etc. Baume, 2011). In contrast to these measures, following the serious demographic crisis that the whole

of High Provence experienced around 1340 (Black Death, pillaging, wars, famines and other epidemics, [Baratier, 1961](#)), great tolerance is observed by the lords and communities. They let the populations to freely exploit the resources, among which the forests were the most attractive. This is the case of the former enclosure of Blégiers and Chanolles set up in the 14th century ([Sclafert, 1959, 94](#)). Moreover, a trial shows alluses of the Faillefeu forest since 1511 by local population ([Douguedroit, 1976](#)): animal grazing in the forest, taking dead wood for heating and forges, as well as for tools and houses. In exchange, precautions had to be taken against fire, control over the amount of wood cut and rafts made from this wood, preventing foreigners from introducing livestock in this forest (these practices may have prevailed from 1511 to 1865 and beyond).

With the demographic and economic revival, the mediaeval preoccupation concerning forests continues in modern Era. But let us not be mistaken: the main objective is not to protect a forest to allow it to regenerate and evolve freely, but rather to conserve a raw material with a market value ([Pichard, 1999](#)). In addition, new types of information reach us through notarized contracts of sale of wood or rent.

From the beginning of the 17th century, whether it was a question of prohibiting the introduction of small and large ruminants into the Faillefeu forest, cutting living trees, collecting wood to build or repair houses, or controlling the number of wood rafts for export ([Douguedroit, 1976](#); [Baume, 2011](#); [Cazères, 2013](#)), the regulations seem to grow, in fact at the same rate as the forest harvesting. Concerning Faillefeu, even under a new rule, the Priory still showed bad forest management (overexploitation). Indeed, in her study, M.-P. [Baume \(2011\)](#) inventoried 26 cutting contracts in the 16th century, 28 contracts in the 17th century and about ten for the 18th century for the Faillefeu forest alone, which was not the only forest exploited in the Haute Bléone: Chourges-Vachières was another. In Faillefeu (the best documented area), pine, fir, larch and spruce logs were pulled by oxen and then transported by floating (from 1585 at least) on the river Bléone to the river Durance to supply the construction sites of the lowland cities. The development of water saws in the 17th century along the river Bléone is another testimony to this sustained prehension ([Cazères, 2013](#)). At the same time, in the late 16th to the early 17th centuries, the European wars of religion ruined Faillefeu Abbey, and its abandoned buildings were left to be pillaged. This led to a lack of managed forestry. Indeed, in 1659, a commission informed the Royal Judge of the Faillefeu deforestation caused by lack of surveillance.

During the 17th century, protection measures accelerated when the States of Provence took over the protection of the forests (as well as the pastures; [Baume, 2011](#)). However, in the same time appears a major force of wood prehension: the Royal Navy, the most important timbers consumer under Louis XIV to Louis XVI. After the “Grande Ordonnance des Eaux et Forêts” of 1669 (a forestry code), the “Grande Ordonnance de la Marine” of 1681 illustrates the situation, by giving priority over all felling to the shipyards. The users of the Faillefeu forest, for example, paid the price in 1689 when they were forbidden by the Navy to collect the 100 pieces of wood to which they were previously entitled ([Baume, 2011](#)). At the same time, forest inventories were established in order to assess the state of the shipbuilding forests and therefore to prohibit felling: first with Habert de Montmort between 1683 and 1686; then in the years 1720–1730 (Inventory of useable woods by Chabert de L’Isle in 1723, and the goat survey of the Eaux et Forêts administration in 1730). Nowadays, these inventories are extremely useful for establishing the forest state in the 17th and 18th centuries ([Pichard, 1999](#)). As far as measures are concerned, the Parliament recommended, for example, to sow white oak acorns, to plant oaks and elms on cleared areas ([De Ribbe, 1857](#)), to prohibit goats, to make the extraction of pitch from white pine trees subject to permission, to limit the cuts of living trees and shrubs, or to prohibit the floating of log, with the obligation to decrease cuttings on Vachière (zone of Chourges) around the middle of the 18th century. But it is undoubtedly a continuous power relationship because, generally in the 18th century, the necessity (economic crisis, impoverishment,

demographic increase) pushes men to attack the forest resources. After the French Revolution in 1789, Faillefeu forest was sold to private individuals. Due to its geographical remoteness, abuses were frequent and as an example two illegal new water saws were built in 1820 ([Baume, 2011](#)).

It was not until 1827 that a new forestry code was promulgated, and that the deforestation trend was reversed. It subjected all communal forests to the forestry regime and reduced the rights of use to a maximum ([Vivier, 1992](#)). The application of this regime was supervised by a forestry guard and fellings were subject to authorization. For example, in 18 February, 1838, “a request for the issuance of a cut of 100 trees to be taken in the Chourges wood” by the commune of Prads was rejected by the administration (written source 7M 235, AD04). A series of laws on deforestation in the mountains between 1860 and 1884, linked to a national reforestation policy (“Restauration des Terrains de Montagne” or RTM), led to the purchase of high altitude land by the state in order to replant trees (between 1882 and 1942, mainly on the upper Bléone). These laws obliged municipalities to reforest their lands or face expropriation ([Ministère de l’Agriculture, 1911](#); [De Réparaz, 2000](#); [Bee, 2004/2005](#); [Chalvet, 2011](#)). In the southern Alps, the forester Prosper Demontzey has successfully carried out several reforestation projects in the Bléone valley ([Pardé, 1998](#)). The Faillefeu Forest and Croix de Chourges were affected by this reforestation between 1900 and 1940. Nowadays, The National Office of Forest is managing these areas but in fact, very few plantations have been done since the mid-20th century, and none in the place of the pedoanthracological pits. Finally, by a law of 1922, the Faillefeu forest is now subject to restrictive regulations in order to make it a protected forest. Indeed, the “old” trees give it a heritage value ([Bee, 2004/2005](#)).

In this region, a lot of the modern forested area come from the man-made or natural reforestation. These reforestations were carried out in the face of opposition from the mountain people, as reforestation implied the removal of much of the pastoral land. The relationship with the forest resources has thus always been complex, between sparingness (whose motive is often economic) and excessive or even uncontrolled prehension.

3.1.3. Pastoral pressure

Sheep breeding, in particular through transhumance, is an activity that also affects the forest, via the creation of pastures at high altitude. Since the Neolithic, this activity is responsible for the lowering of the upper limit of forests of about 400m ([Talon, 2010](#)). The sheep farming history also impacts the forest history.

Historical archives concerning pastoralism are older than those concerning forests, and date to as early as 814, the Wadalde polyptych, an accounting document, tells us about a sheepfold within the *Ager Galadius*, a large area under the management of the monks of Saint-Victor of Marseilles in Haute Bléone. Unfortunately, we cannot locate exactly these pastures, but they were close to Blégiers, Prads, and Chanolles ([Sauze, 1984](#); [Thiéry, 2013](#); [Vaissière, 2016](#), and see [Fig. 1](#)).

From the Middle Ages, thanks to the monks of Saint-Victor and those of Faillefeu, the sheep pastoralism developed well, first for the wool trade at the beginning of the 11th century; with the first fuller at Chaudol, a mill used to degrease and soften wool ([Baume, 2011](#); [Vaissière, 2016](#); [Cazères, 2013](#)), second, from the 12th century, with the setting up of transhumance from the lowlands (with summer transhumance added to winter transhumance). Thus, herds came from the Haut Var, the Aix and Crau Basins, more than 100 km away, for which the grazing areas are fairly well-known (these flocks added to those of the Lords and local inhabitants; which caused some tensions). A flock pathway was to run along the bottom of the valley. As written before, in order to protect local resources (wood as well as pastures), consuls of Blégiers and Mariaud were created during the 13th century (with restrictions against foreign flocks – [Sclafert, 1959, 58](#)). However, just before the middle of the 14th century, there was a break in the balance between the pastoral area and the needs of the herds ([Coste, 1972](#))

resulted in overgrazing and a torrent erosion crisis in the 15th century (Douguedroit, 1976, 416). Measures were then taken against deforestation and invasions by foreign herds, but it was the demographic decline linked to the troubles of the 14th - 15th centuries (including wars, famines, and epidemics) (Sclafert, 1959) that may have reduced the pressure on mountain land. However, flocks never really stopped browsing in the Bléone mountains.

From the 15th century onwards, the exploitation of pastures remained a good way to become rich (Coulet, 1978) and the authorities removed the severe regulations linked to access to pastures due to the need for population to recover and to recolonize lands after the demographic crisis. The pressure of people and sheep increased again, slowly at first but gradually more and more strongly. The overgrazing of the previous centuries, linked to the arrival of foreign herds, was forgotten, and at the same time sheep farming became a preoccupation of all social classes. However, cattle numbers increased rapidly and the available lands became scarce from the 17th century onwards. At the same time, the “nourriguiers” of Provence (herd managers) were merciless concerning the number of herds brought, and the consequent impact on grass resources. In the 17th and 18th centuries, many cattle from Low Provence and Arles passed through every year in summer, as it was really at this time that summer transhumance well established. Pastures belonging to Faillefeu (as Vachière, eastern part) and to the communes (Chourges, La Chau, La Baisse, etc) were still rented to external flocks –bigger and bigger, but usually pay attention to abuses. Furthermore, it should be remembered that between the 11th and 18th centuries, the processing of wool for textile manufacture never ceased in haute Bléone (Cazères, 2013). A second peak in pastoral pressure was then reached and continued until 1830–1860, which marked the demographic decline of the mountain areas. Mountains witnessed a rural exodus while the switch to sheep breeding for meat has been reducing pastoral life (De Réparaz, 2000).

3.1.4. Trends from historical sources

It emerges from the historical data analysis, two key moments of anthropogenic pressure on the wood resources in Haute Bléone mainly related to economic reasons mentioned before but also to demographic fluctuations (Fig. 11). The first event dates to the 13-14th centuries, to the beginning of the 15th century and the second one dates to the end of the 16th century to the beginning of the 19th century.

However, as far as the exploitation of wood is concerned, there is a lack of written sources for the 15th and early 16th centuries. The slackening of pastoralism during this period needs to be put into perspective: even during the mid-14th century demographic crisis, the herds never stopped grazing the pastures.

3.2. Dendrochronology

3.2.1. Species used in buildings

Among the 282 sampled wood pieces, 109 are larch (*Larix sp.*), 62 are Scots pine or mountain pine (*Pinus sylvestris* or *Pinus uncinata*), 61 are deciduous oak (*Quercus sp.*), and 29 are fir (*Abies alba*). Then there are 9 pieces of elm (*Ulmus sp.*), 5 of willow or poplar (*Salix/Populus*), the anatomical distinction between these two species is not easy, see Schweingruber, 1990), 2 of ash (*Fraxinus sp.*), 2 of walnut (*Juglans sp.*), 2 of fruit tree (*Rosoideae maloideae*) and the last one is a beech (*Fagus sp.*) (Fig. 4). It is very common to find the softwood species fir, larch and Scots pine in French Alpine constructions (Shindo, 2016). Oak has been frequently less identified until now because it grows at lower altitudes, up to about 1300 m. The upper Bléone valley includes a large part of the oak area, which may explain its use in buildings. Minority species may reflect opportunistic harvesting of available trees in the vicinity of buildings.

Anatomically, larch and spruce are very similar. The only indisputable criterion for distinguishing these two species is the appearance of the areolated punctuations of the radial tracheids (Anagnost et al., 1994;

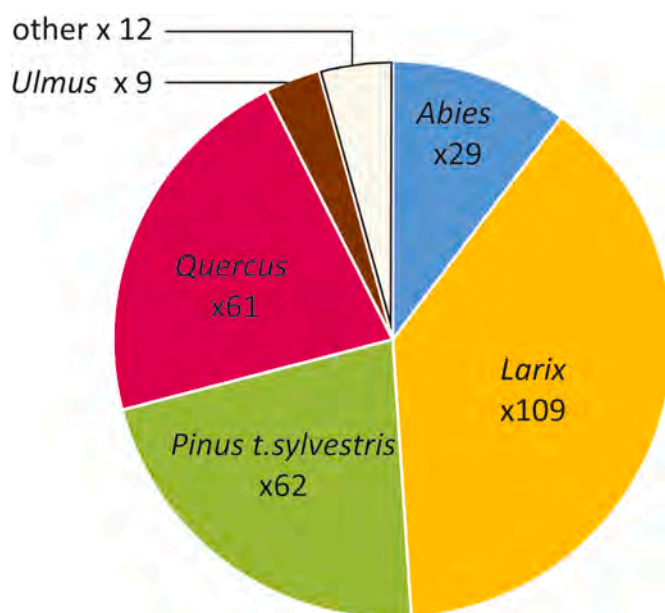


Fig. 4. Distribution of the species of the 282 studied samples (others: *Salix/Populus, Fraxinus, Juglans, Rosoideae maloideae, Fagus*).

Talon, 1997b), which are difficult to observe. Another criterion for differentiating these two species is the presence, in larch, of sapwood rings that are lighter than those of heartwood, whereas the sapwood of spruce is not distinct (Schweingruber, 1990). However, in the absence of bark, which is the case for the majority of samples, if a wood has a single colour, it cannot be established whether it is spruce with no distinct sapwood, or larch whose sapwood has disappeared. Here, among the dendrochronological samples, 60 of the 109 wood pieces identified as “larch” are dated on the larch dendrochronological references, which confirms this identification. On the other hand, uncertainty remains for the 49 undated samples. Precise anatomical identifications should be carried out again on these samples in the future to try to safely determine their species, larch or spruce. This would confirm or not the presence of spruce in the past. Indeed, in contrast to the northern Alps, there is less spruce in the southern Alps (Ozenda, 1985). However, ongoing research into written sources has shown the presence of spruce some fifteen km south of the Bléone, throughout the 17th century (B. Renoux, independent researcher). Caution must be taken, however, as it is referred to as “serente” in these ancient texts, a term that may also have been used to refer to larch. Moreover, spruce pollen is heavy and rarely traveling beyond 500 m (Jackson, 1990), so in order to verify the presence of this species in the Bléone valley, a very local palynological analysis is needed. Finally, living spruce stands have recently been identified at Faillefeu, on the other slope of Chourges (by E. Gamba and B. Talon), which reinforces the possibility of having spruce in the frameworks.

3.2.2. Construction phases in the Bléone valley

Eighty-nine larch, oak and fir series are dendrochronologically dated over the period 948–1970 (Table 1). These trees were felled between the 14th and the 20th century. Due to a lack of dendrochronological references, Scots pine t. series are not dated. As for the hardwood series, they are too short to correlate with security at a single location in the reference system.

The earliest identified felling in the Bléone valley dates to the first half of the 14th century (the first sample in Fig. 5 appears to be older but many rings are missing from its periphery and it is therefore not possible to estimate its exact felling date). Then, there are no felling events in the second half of the 14th century. During the 15th and early 16th centuries, many trees (mostly oaks) were felled, which corresponds to the

Table 1

Dendrochronological dating results: oak, larch and fir mean chronologies synchronized with reference chronologies. Only the results in first rank are presented. The number of replications for oak is low because the reference chronologies for this species are under construction (Shindo, 2020).

Specie (and number of individual series)	Dates of the first and last rings	Student t. max.	r, correlation coefficient, max.	Number of replications on the reference chronologies
Oak (×18)	1261–1570	7.6	0.4	2
Larch (×60)	948–1970	15.4	0.68	54
Fir (×11)	1352–1902	11.7	0.5	23

first major building phase identified by dendrochronology. During the second half of the 16th century and the 17th century, there was a clear slowdown in the felling. If this is not a sampling bias, it may correspond to a slowdown in building activities, and/or the reuse of older timbers. Then there is a continuous felling from the 18th to the 20th century.

Oak is only used up to the 16th century; we have not dated any oak from the 17th century onwards (and it was not identified in any of the soil-anthracological pits). Since it is present in small quantities in the landscape today, its absence from local buildings can be explained rather by a change of use from the 17th century. Indeed, it may have been reserved for naval construction and exported to Mediterranean shipyards (Shindo, 2022). This rarefaction may also be due to climate change caused by the Little Ice Age in 1560–1850 (Edouard et al., 2009, see Fig. 11), although it is not yet possible to prove this hypothesis because of the limited oak data available.

Finally, it is also worth pointing out that the major felling construction phases coincide with periods of weak forest regulation (15th - early 16th, late 18th - 20th centuries, cf. part 3.1.2.). In the case of this territory, low legislative pressure leads to more felling for local construction, without it being possible to draw any conclusions on the impact on forest stands.

3.2.3. Old trees as evidence of forest protection

Due to their large diameter (>1 m), we did not reach the pith of the old living larches at Chourges. At least 10 cm are missing each time to reach the pith and their birth dates are therefore unknown. However, the oldest measured ring dates from 1669, which means that some of these larches were already present eleven years before in 1658, when the “Vachière” area was protected (see part 3.3.4. and Fig. 6). The precise location of this Vachière protected area is unknown but it is very close to Chourges and these larches must certainly have benefited from this

protection. Moreover, their remarkable silhouettes make them striking elements, serving as landmarks and protection against the sun, which may partly explain why they are still present today.

3.3. Pedaanthracology

3.3.1. General results

We found charcoal in all the pits (Fig. 7) and overall, we observe a decrease in anthracomass from top to bottom in all the profiles (supplementary material, Tabl. B). We note a heterogeneity of anthracomass between pits. The richest profiles are CHO5 and CHO2B and the poorest are CHO1B, CHO1A and CHO3.

A total of 1243 charcoal fragments were identified for 315 kg of sieved soil and 15 taxa were identified (Table 2), some down to family (Fabaceae), some to genus (*Acer* sp., *Juniperus* sp., *Laburnum* sp., *Pinus* sp.), others down to the species (*Abies alba*, *Arctostaphylos uva-ursi*, *Pinus cembra*) as well as intermediate taxa (*Larix/Picea*, *Abies/Juniperus*, *Pinus sylvestris/uncinata*, conifer no pinus, conifer indeterminable and shrubs indeterminable), with a large predominance of conifers over shrubs with 172.5 mg/kg against 30.5 mg/kg. Two taxa are predominant among the identifications: *Larix/Picea* (104,7 mg/kg) and *Abies alba* (22,9 mg/kg).

In this study, we were able to identify fir to the species level because it is the only species present of its genus in the southern French Alps. We encountered great difficulty in differentiating many fragments between fir and juniper, which we noted as *Abies/Juniperus*. The taxa belonging to the “shrubs” present structures of small woody plants resembling small shrubs (“micro-chamaephytes”, Raunkiær, 1934), even those for which we could not pursue the identification. We did not find any large deciduous trees of the Beech type except *Laburnum* in the pits dug in the pastures (Tabl. 2). The presence of charcoals proves that the Chourges slopes have experienced fire episodes, and we can attest to their locality through the presence of vitrified charcoals (Talon, 2010). These results can probably be linked here with the historical references to pastoral activities outlined above (Baume, 2011; Cazères, 2013; Sclafert, 1959). The same forest species that colonize the slope today are found in charcoals, which attests to a certain forest continuity in time without being able to infer the proportions of each species present in the past. Thus, past human activities do not seem to have profoundly changed the forest composition.

Nonetheless, if the taxonomic composition does not seem to have been disturbed over time, this is not the case for the forest structure. We observe a heterogeneous distribution of each SAT among different pits.

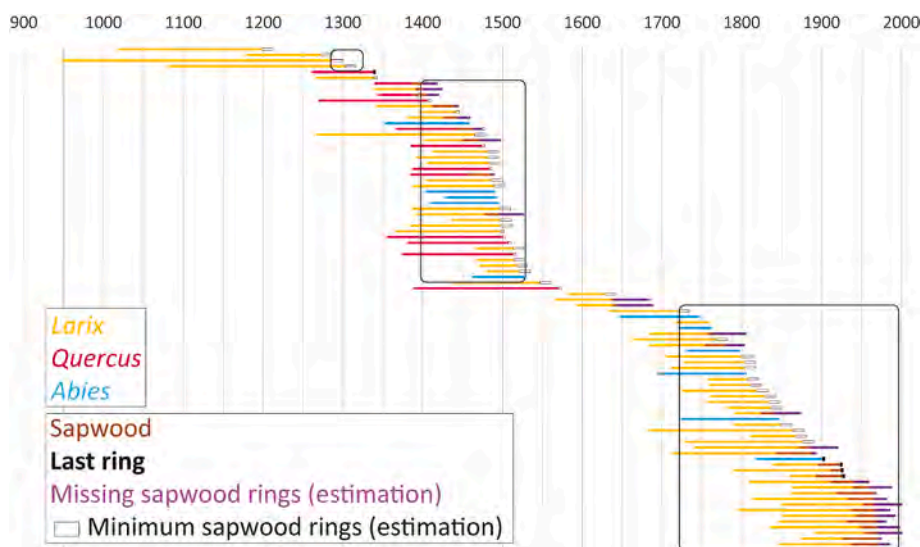


Fig. 5. Bar diagram of the 89 dated series. Each horizontal line represents a piece of wood. Larches are in yellow, oaks are in pink and firs are in blue. Larch sapwood rings estimation: 32 ± 18 (2σ) (Shindo, 2016) oak sapwood rings estimation: 19 ± 15 (2σ) (Durost and Lambert, 2006). When sapwood (brown) is preserved but not the last ring, the maximum number of missing sapwood rings was estimated (purple, 50 rings for larch, 34 rings for oak). When no sapwood rings are preserved, the minimum number of missing sapwood rings was added (white rectangles, 14 rings for larches, 4 rings for oaks).

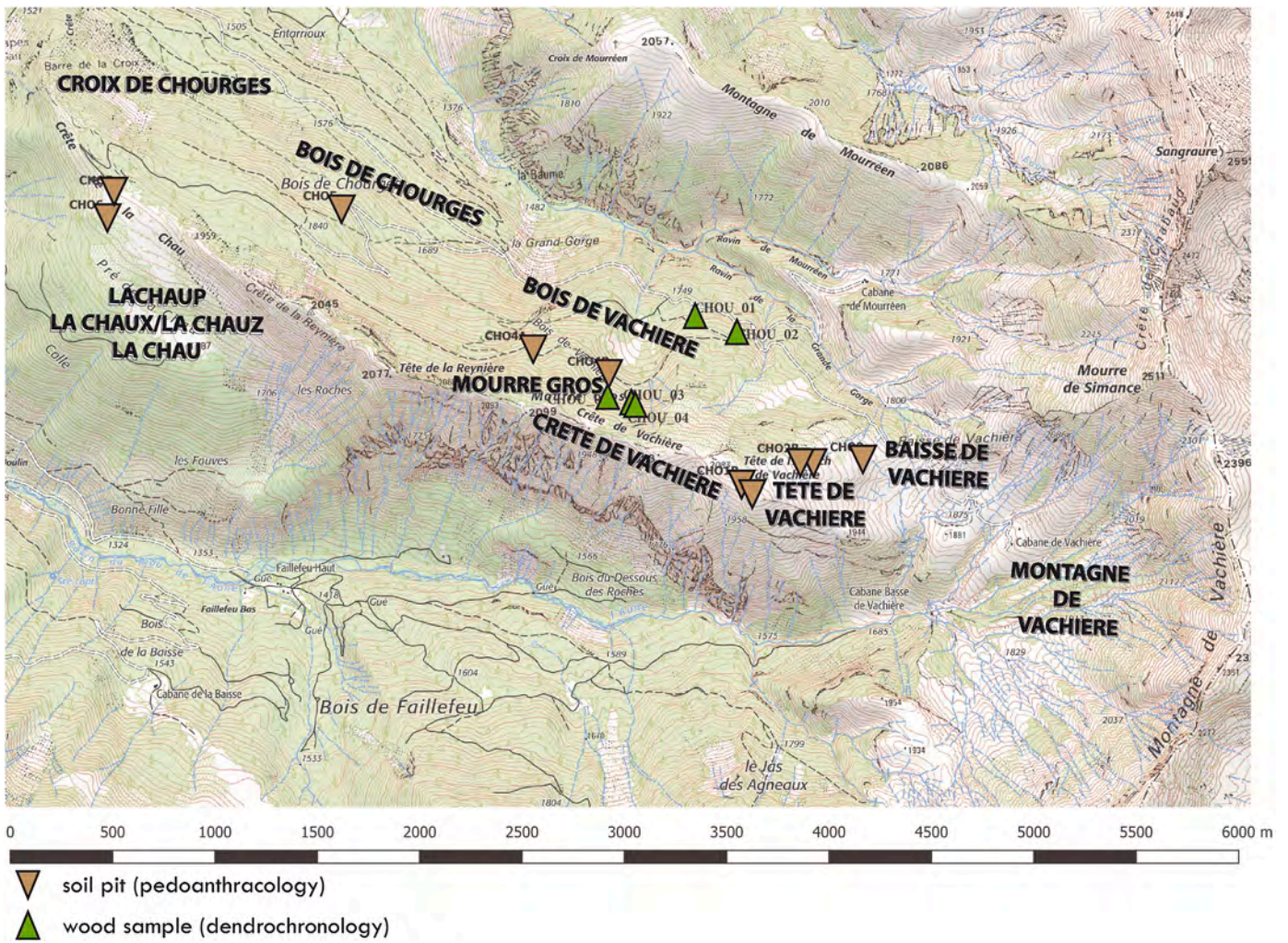


Fig. 6. Location of the pedoanthracological and dendrochronological sites; attempt to locate the Chourges and Vachières toponyms.

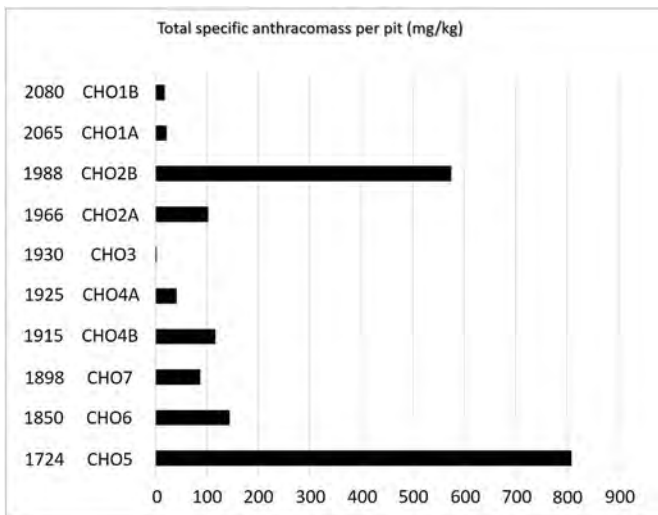


Fig. 7. Specific anthracomass per pit (identified and unidentified charcoals).

3.3.2. Pits dug under modern forest cover: CHO4 and CHO5

These pits were dug under the actual forest cover and we proved that there were also trees and maybe a forest in the past. CHO4 and CHO5 are the richest pits for *Abies alba* (Fig. 8 C) and they are less rich in *Larix/*

Picea (Fig. 8 B). These results corroborate historical archives that mentioned a forest cover since at least the Middle Ages (see below, part. 3.3.4.).

However, high value of *Abies alba* anthracomass and low *Larix/Picea* anthracomass are found in CHO4A and CHO4B. These pits are currently in a well-established, nearly monospecific larch stand, slightly higher in elevation than CHO5, which is currently in a fir stand. We suppose that the fir stand presently lower in elevation (CHO5) may have reached, by the past, this area (1900 m, position of CHO4) and gradually gave way to the present-day larch stand. The results of radiocarbon dating (Fig. 9) reveal the presence of fir since the Early Bronze Age (1641-1498 BCE), which corroborates the hypothesis that this environment could have been colonized by fir for a long time, certainly in mixture with larch, and would have progressively disappeared in favor of the latter. We assume that this area was once a closed environment rich in fir and later became a pastoral area of pre-larch woodland type (the larch is a pioneer species that colonizes abandoned pastures; Rameau et al., 1993). We assume that this pre-woodland formation dates back to at least the 17th century based on the results of old larch trees coring, the oldest of which could date back to before 1658.

3.3.3. Pits dug in the modern *Juniperus* heathland CHO1, CHO2, CHO3, CHO6 and CHO7

The pastures occupied today by common juniper were certainly forested in the past and subject to repeated fires over time to prepare the land for grazing. The written archives mention grazing areas on the

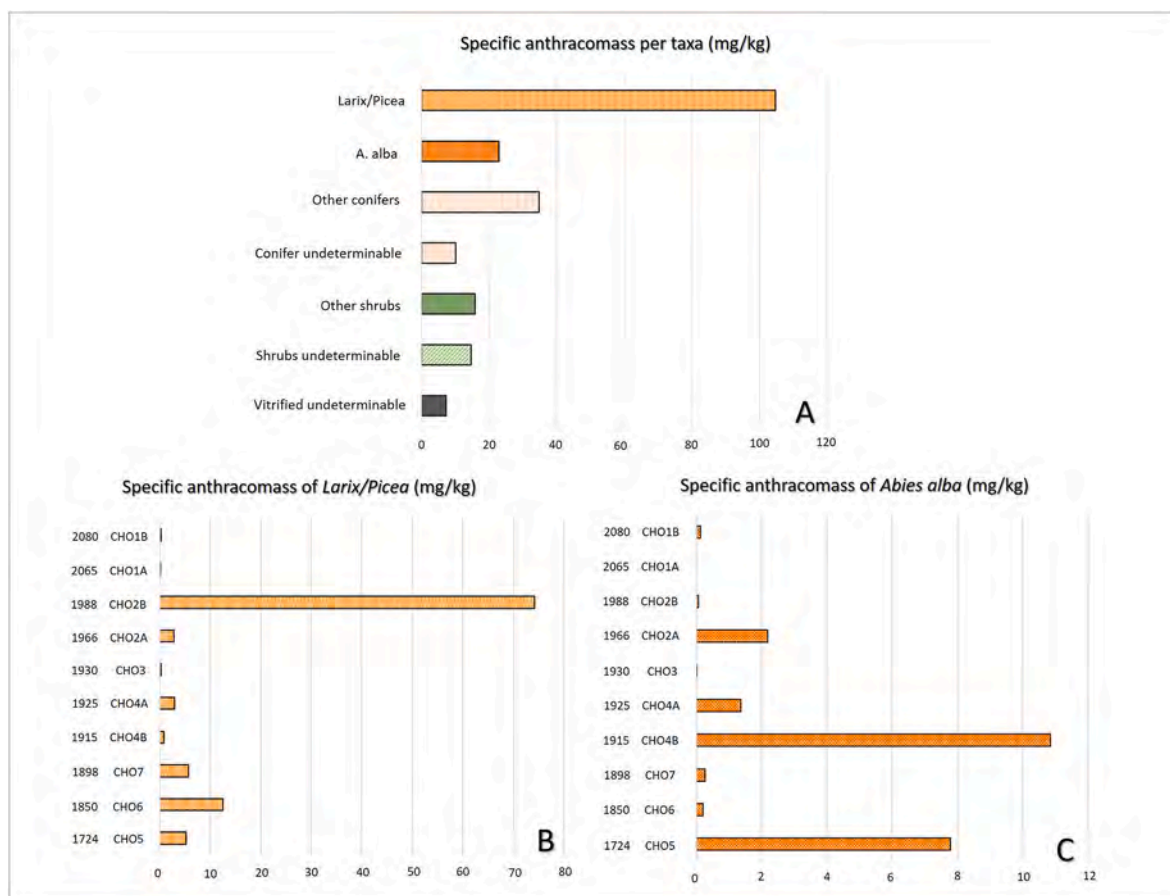


Fig. 8. Specific anthracomass A) per taxa for the whole transect, B) for *Larix/Picea*, C) for *Abies alba*. Minority taxa have been grouped under two categories: “Other shrubs” for *Laburnum* sp., *Acer* sp., *Arctostaphylos uva-ursi* and *Fabaceae*; “Other conifers” for *Pinus* sp., *Pinus cembra*, *Pinus sylvestris/uncinata*, *No pinus*, *Juniperus* sp. and *Juniperus/Abies*.

Chourges slopes since at least the 16th century, but without precising the locations (see below, part. 3.3.4.). Here, we can attest that the pastures extended up to the summit ridge because we find there the vestiges of a pastoral past. First of all, we note the presence of the fir tree (Fig. 10), whereas nowadays it is only present in lower altitudes. This testifies the forestry potential of these environments today: the fir was present up to high altitude (about 2000 m) but has gradually disappeared to make way for larch and pasture. Its presence was either in the form of true forest cover or a regenerating open stand. It has most certainly been removed by human activity in order to settle his herd. This is also the case for *Larix/Picea* which is found in quantity and whose radiocarbon dating attests to its presence since at least the Middle Ages (Fig. 9). The highest pit in altitude is the poorest in *Larix/Picea* and *Abies alba* but the richest in shrubs (Fig. 10). These are associated with recolonization of vegetation after pastoral abandonment and little grazing (Trabaud, 1987). The altitudinal limit of the trees was thus much higher than today. We assume that these spaces were disturbed and subjected to episodes of fire spread over time, due to the presence of vitrified charcoals found in all the pits. Although their condition does not allow for further identification, they resemble charcoal of small woody plants such as *Ericaceae*, *Lamiaceae*, *Rosaceae* or *Fabaceae*. This vegetation tends to be established during phases of pastoral abandonment (Trabaud, 1987; Métaillé and Faerber, 2003). As they are not grazed, it is necessary to burn these species in order to settle the livestock afterwards. This attests to the anthropogenic origin of these past fire episodes.

All these results support the hypothesis of a gradient of closure of the environment from the lowest altitudes (CHO5) to the summit ridge (CHO1). The higher the elevation, the more the conifers regress to the

benefit of shrubs, without disappearing (as attested by the presence of fir charcoal in CHO1). The upper slopes have been subjected to pastoral activities that have contributed to opening up the environment. The presence of these taxa up to the summit ridge is indicative of the reforestation potential of the Chourges slopes, which could close if the current grazing is abandoned, and we can assume that the larch present on a good part of the slopes will colonize them up to the ridge. In the longer term, the fir tree could also return to colonize the higher altitudes since it was present in the past, and perhaps eventually replace the larch.

3.3.4. More precise historical information on the Chourges-Vachières and La Chau massif

We will add some precise historical information concerning the Chourges slopes, in order to position the pedoanthracological pits in relation to the human context documented by the texts. The toponym ‘Chourges’, in the past, was probably not limited to the area defined on the current map. Furthermore, the present area of Chourges could have been called “Vachière” or “Mouregros” in the past, which requires extra care when gathering information from historical sources (Fig. 6).

There is no mention of “Chourges” or the “Vachière mountain” in texts prior to the 16th century. The “high mountain of Vachière” is not referred to as a pasture until 1568 (it is mentioned again in 1624 and 1658), but it is difficult to say whether this area of pasture extended to pedoanthracological pits CHO1 to CHO4.

In 1658 the enclosure of Vachière appears in texts, partially or totally deforested areas, where it is advisable to sow cereals: this could be the sampled pits CHO1 to CHO4. These protected areas are then mentioned in 1692, without specifying the species found in them.

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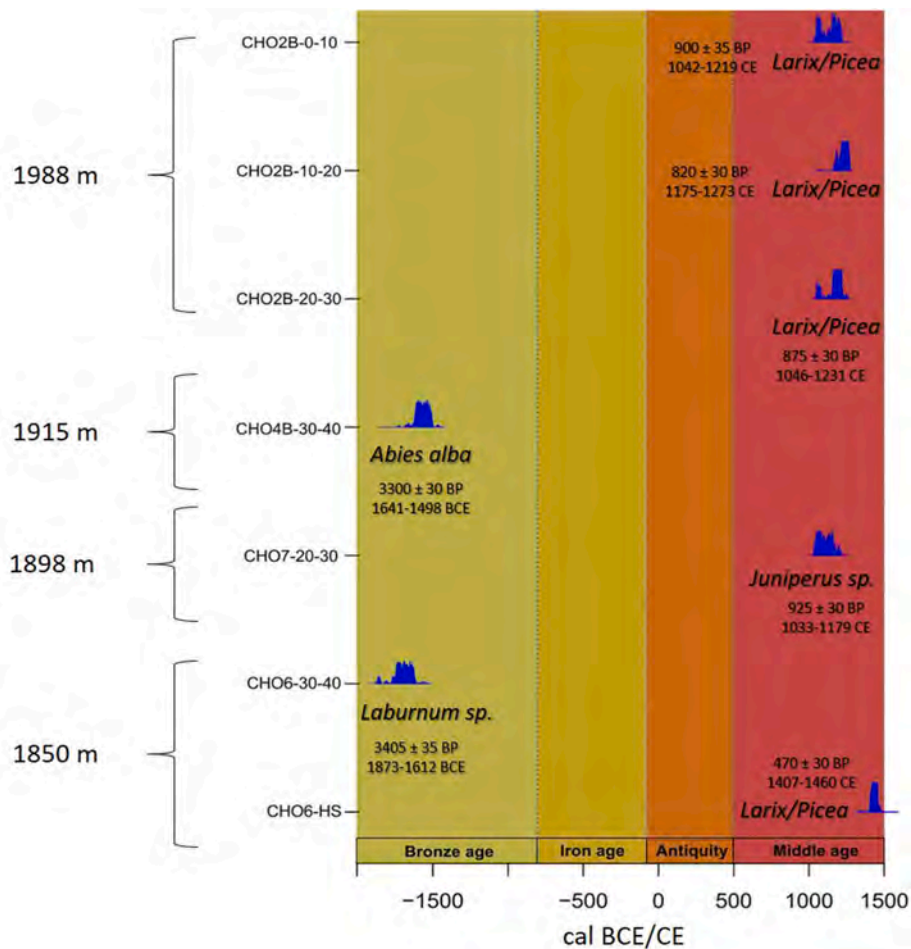


Fig. 9. Probability distribution curves for seven radiocarbon dates obtained from four pits positioned against the archaeological timescale.

Table 2

Presence (in grey) and absence (in white) of taxa found in the different pits of the pedoanthracological transect of Chourges.

	CHO1A	CHO1B	CHO2A	CHO2B	CHO3	CHO4A	CHO4B	CHO5	CHO6	CHO7
<i>Larix/Picea</i>										
<i>Abies alba</i>										
Conifer										
<i>Abies/Juniperus</i>										
<i>Pinus cembra</i>										
<i>Pinus sylvestris/uncinata</i>										
<i>Juniperus sp.</i>										
No Pinus										
<i>Pinus sp.</i>										
Shrubs										
<i>Laburnum sp.</i>										
<i>Arctostaphylos uva-ursi</i>										
<i>Acer sp.</i>										
Fabaceae										
Vitrified										

de Montmort (1682–1686, [Pichard, 1999](#)) that the tree species are mentioned. There is a mention of 45 fir trees “of no value” in the “Quartier de Gougues de Mouregros”, which could correspond to CHO4. The area of CHO5 may have been referred to as “Quartier de Chourges” and has 160 spruces “of no value”. As mentioned in 3.2.1., spruce was indeed present in this valley in the past. However, the trees described in this inventory do not appear to be suitable for producing good quality timber.

In the 18th century, the Chourges and “Mouregros” pastures are

mentioned again (which ones would tend to be located not far from the pits CHO1, CHO2, CHO3 or CHO4).

In 1724, there is no mention of Chourges in the Royal Survey ([Pichard, 1999](#)). This implies, at best, that the forests are not dense enough; or at worst, that there are only scattered trees, too difficult to exploit. But throughout the 18th century, there is regular mention of logging on the Vachière mountain, with larch, pine, broom and osier - even though it is stated that these forests are degraded.

Also in the 18th century, a military map (Tardy, 1778 in [Pichard,](#)

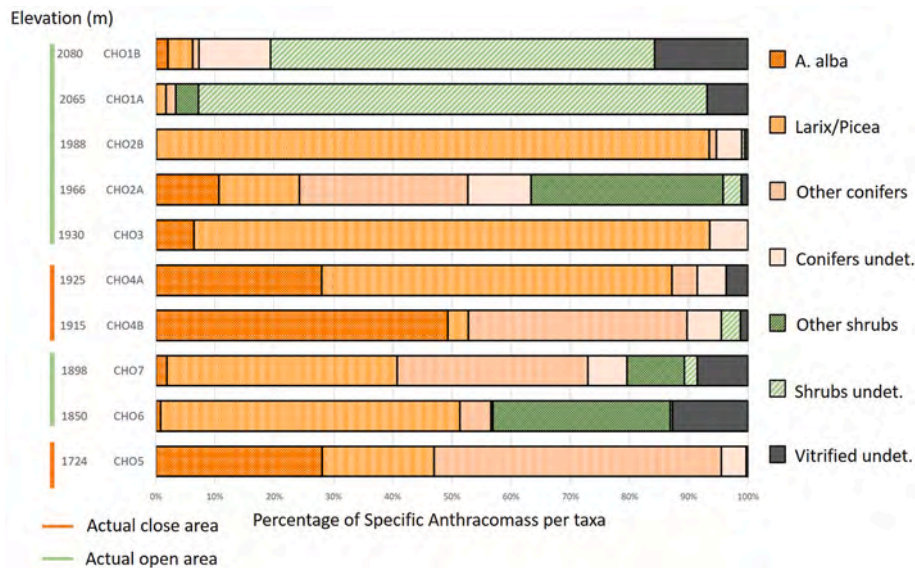


Fig. 10. Percentage of Specific Anthracomass per taxa and per pit. Minority taxa have been grouped under two categories: “Other shrubs” for *Laburnum* sp., *Acer* sp., *Arctostaphylos uva-ursi* and Fabaceae; “Other conifers” for *Pinus* sp., *Pinus cembra*, *Pinus sylvestris/uncinata*, No pinus, *Juniperus* sp. and *Juniperus/Abies*.

1999) shows a forest cover on a slope of the Chourges mountain. The Cassini map in 1782, although not very accurate and difficult to geo-reference, would also show a forested area on CHO5 while CHO1 to CHO4 are in open area (pasture). CHO4 appears to be the boundary between these two areas, a difference that can also be seen on later maps (1829 and 1860s) with a forest to the west, on CHO5, and a pastoral area from CHO1 to CHO4 (CHO4A being at the limit).

In the 19th century leases, the Vachière mountain was always designated as pastureland between 1807 and 1836.

It thus appears, by regression from more recent cartographic data, that the pastoral zone could be located on CHO1 to CHO3 and the forest zone on CHO5. For CHO4, the question is not clear-cut: it can be assumed that the forest area has been gradually transformed into pasture. However, in terms of use, it is possible that the grazed area was sporadically dotted with large larch trees (some of which can be dated to the 17th century by dendrochronology, see above, part. 3.2.3.) to provide shade for herds (only larch allows grass to grow at its foot). It is also possible that these trees, left in place over generations, were used to mark boundaries. Are these old larch trees in the CHO4 area the remains of an old forest?

CHO4A was still on the edge of the forest in 1948, but currently, the forest progression is extending on CHO4A and B (only CHO1 to CHO3 are still in open areas). None of these areas were reforested by man-made plantations at the end of the 19th and 20th centuries. Only larch trees were planted in 1989 in CHO4A.

On the contrary, it's much easier to locate the place called “La Chau”; where are situated CHO6 and CHO7 pits: this small plateau at the western end of the Chourges massif has not changed its name through time (only its spelling, between Lachaup, Chauz, La Chauz, and finally La Chau), and has been a pasture since at least the 11-12th centuries. During the 14th century, high altitude hay was cultivated here (Sclafert, 1959, 18; Baume, 2011; Cazères, 2013).

4. Interdisciplinary discussion

4.1. The evidence of a sylvo-pastoral management

Our results show that the forest structure in Chourges slopes has permanently fluctuated between open pastures and more or less closed forest since at least the Middle Ages. The landscape has frequently undergone fire episodes that have disrupted the forest trajectories. These

disturbance phases were followed by recolonization with post-fire pioneering taxa, occasionally punctuated with development of pasture and then land abandonment, especially deduced from charcoals assemblages for the highest pits (CHO1, CHO2, CHO6 and CHO7). However, the degree of openness of the landscape is not easy to establish due to the punctual nature of pedoanthracological data. We hypothesise that these openings/closures and disturbances are due to variations in the intensity of pastoral activities. The historical archives corroborate our hypothesis (see 3.3.4.) also supported by the presence of vitrified charcoals in the pits. The latter attest to a local origin of fires because they are not or only slightly reworked in time (Ohlson and Tryterud, 2000; Talon, 2010). We thus propose the following hypothesis: their presence would be due to the repetition of sylvo-pastoral management fires. Since at least the Neolithic, humans have used fire to maintain the open pastures for livestock grazing at the expense of forest (Dussol et al., 2021; Tomson et al., 2021). Taxa indicative of pastoral abandonment such as juniper dating from the Middle Ages (1033–1179 CE) (Schwartz et al., 2005) or laburnum (dating to the Early Bronze Age (1873-1612 BCE) and bearberry (*Arctostaphylos uva-ursi*) are found in the charcoal from juniper grassland pits. They attest to an at least temporary abandonment of pastoral activities and corroborate the hypothesis of an alternation of open and closed environments over time, and this maybe since the Bronze Age (cf. radiocarbon dating, Fig. 9).

A further information deduced from charcoal assemblages is that the vertical distribution of some taxa has significantly changed. For example, the fir which was once present up to the crest mixed with larch, is nowadays restricted to lower elevations (Fig. 3). We assume that the dominance of larch to the detriment of the fir is linked to the long-term sheep farming that requires dense herbaceous cover (Oudin and Fourchy, 1952).

4.2. Comparison of tree species in forests and buildings (in the Middle Ages and modern period)

In our study area, no ancient text mentions the tree species living in the forests before the 17th century (Pichard, 1999). The plant names appearing in the texts are not very precise and they can be attributed to several species. For the Middle Ages, the palaeobotanical data can thus help to identify the botanical origin of the species.

The identified charcoals dated to the Middle Ages (larch/spruce and juniper, Fig. 9) do not all belong to the same woody taxa identified in the

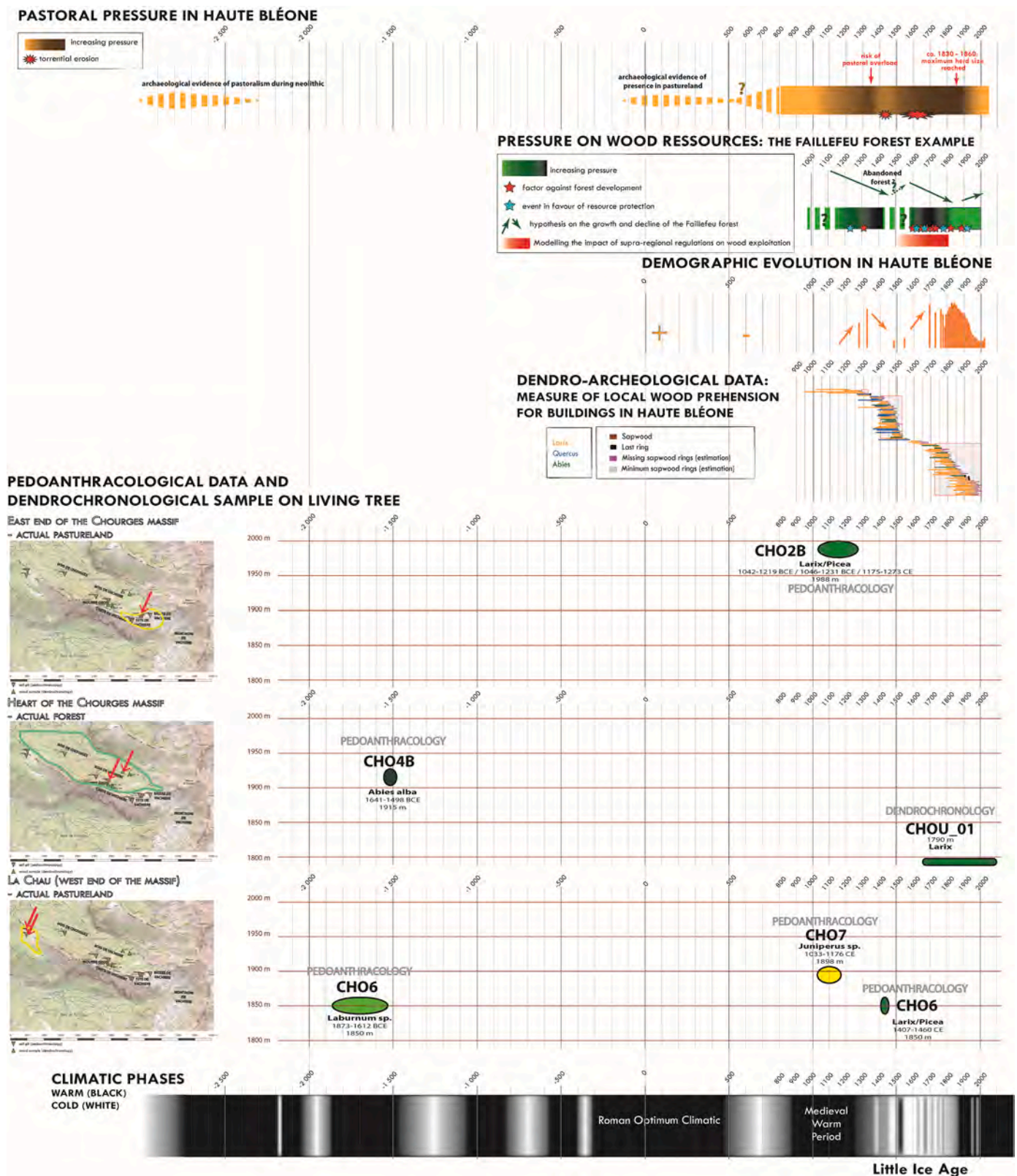


Fig. 11. Synthetic timeline. Synoptic view of historical, demographic, dendrochronological and pedoanthracological data, and overview of climatic phases.

local buildings (larch/spruce, oak, fir and scots pine or mountain pine, see Fig. 5). Concerning juniper, this species is very rarely used in the buildings of the Southern Alps (see for example Labbas, 2016; Shindo, 2016), which is not surprising. As for the oak timbers identified in the building, they cannot come from trees that grew at the high altitudes

corresponding to the highest pedoanthracological pits. In fact, the oak grows mainly in the lower foothills, although it is not uncommon to find a few individuals in the montane zone, up to about 1500m (Rameau et al., 1993). Its absence in the pedoanthracological spectrum is thus logical. Scots pine/mountain pine was mainly identified in the buildings

but only in one pedoanthracological pit (CHO6). Although not dendrochronologically dated, stratigraphic observations in buildings would link the use of Scots pine/mountain pine to relatively recent periods, certainly after the use of larch and fir beams. If this is not a pedoanthracological sampling bias, one explanation could be that it did not grow in the past in the Chourges area. Moreover, very few local place names bear any trace of pine: none on the mountain of Chourges; only one mention of "pinée" (*Pinus*) 5 km away on another hill further north. Larch/spruce is the only species identified in both the pedoanthracological pits and in the buildings, which supports the possibility of one local supply in the Middle Ages, and also in archives (see the Habert de Montmort's forest inventory, for the 17th century). As for the fir tree, it was present in the forests of Haute Bléone during the Bronze Age (pit CHO4B-35, see Fig. 9), but we have no data on the anthropogenic use of pine wood at that time. Later, in the Middle Ages, fir was used in buildings in lesser quantities than larch/spruce. However, we have no fir charcoal dates for this period. Nonetheless, pedoanthracological results show a change in the establishment of the fir tree. Given that fir trees are well used in local buildings and that importation from distant areas is difficult to envisage for these non-prestigious buildings, it can be concluded that fir trees did grow in the Middle Ages in Haute Bléone but their precise location remains unknown. The time of its disappearance from high altitudes remains to be determined e.g. using further radiocarbon dates.

4.3. Information on the landscape management methods

Pedoanthracological and historical data corroborate each other in revealing the deliberate opening of landscape to facilitate livestock grazing. The timing of the transformation of forest areas to pastures documented in the textual sources coincides with the presence of charcoal of small woody plants including the junipers, which currently grows in open and deforested landscapes. We can find written evidence of periods of opening followed by gradual closure, and again the re-opening of the landscape by deliberate burning of woodlands. We showed that pedoanthracology can provide information on the spatio-temporal pattern of the establishment and disappearance of pastures (e.g. for the Bronze Age and Middle Ages, see radiocarbon dates in Fig. 9). By contrast, in the textual sources, although the exact locations of landscape openings and closures cannot be specified, their precise dating may be possible. We can therefore tentatively consider the simultaneities between the text-based dates with the carbonization dates of taxa inferred from soil charcoal analysis and dating. More radiocarbon ages are available, more precisely the spatio-temporal distribution of tree species can be reconstructed. Finally, pedoanthracology may provide information on the methods of creating pastures; the use of repeated fires can be deduced from the vitrification of charcoal due to anthropogenic burning whereas generally it cannot be deduced from textual archives.

4.4. Forest composition and structure through time

The combination of these three disciplines also gives information on the temporal occupation and taxonomic characteristics of the landscape.

Pedoanthracology provides data whose temporal resolution is multi-millennial. Conversely, dendrochronology and history provide results on a multi-centennial to annual scale. The combination of these three disciplines therefore allows a complete temporal vision. It also makes it possible to tell whether the forest structure has changed over time: the anthracological pits dug in actual open pastures contain charcoal. This means that the layout of the forest has not always been the same, the treeline reached a higher altitude than today and was disturbed at some point.

Concerning the taxonomic richness of the landscape, pedoanthracology and dendrochronology support the maintenance of an overall taxonomic continuity over time but with a spatial distribution of certain

species that has changed: fir has disappeared from high altitude forests but may have been maintained at lower altitudes to be used in construction.

The disturbance of this landscape is certainly due to the local population's activity: wood exploitation for building (cf. dendrochronology), firewood or wood for exportation (cf. historical archives) and silvo-pastoral activities (cf. pedoanthracology).

4.5. Historical and pedoanthracological data: two converging evidences of pastoral abandonment

Our data suggest a possible resumption of pastoral activity in the environment after a phase of abandonment dated - at least temporarily - to the 11-12th century. This is evidenced by the presence of juniper charcoal in CHO7 (see 3.3.3.). Indeed, mountain communities experienced a period of socio-economic disruption in the 10th - beginning of the 11th centuries until the 11-12th century when the monastic foundations, the arrival of religious orders to mountains and the establishment of feudalism created a new mode of population control (Carriér and Mouthon, 2010; Vaissière, 2016). Indeed, it was in the 12th century that the abbey of Faillefeu was founded whose economy was based on forestry and sheep farming (Baume, 2011). Our environmental data confirm an intensification of human impact on the landscape at this time.

4.6. Filling the gaps in historical sources with palaeoenvironmental data

Dendrochronological data suggest two major local construction phases which needed a high demand for timbers between the 15th - early 16th and between the late 18th - 20th centuries. These phases are correlated with periods of less pressure on mountain wood resources as suggested by textual sources. These sources also suggest that in between these periods, a strong regulation on wood exploitation was imposed by the state (in red on the final synthetic Fig. 11) to feed the ship construction industry which also needs a lot of wood.

As far as the older construction phase is concerned (15th-early 16th centuries), it is interesting to compare this phase with the notion of "recovery" after the demographic crisis, a period when, as we saw above, legislation was very flexible (see part 3.1.2).

In this case, how did local people manage their needs during these population growth peaks? This question invites us to re-examine the practices of recycling and reuse of old wood material. Indeed, recycling was practised not for concern for the environment, but out of necessity and convenience (see for example Bernard et al., 2012; Labbas, 2019; Sands, 2022).

As far as the second phase is concerned (late 18th - 20th centuries), it can be hypothesised that during the phases of high State control of wood in the Southern Alps, the local populations could not use it as they needed for everyday purposes, especially for construction. The wood exploitation in these regions was then exported elsewhere, especially to provide timber for buildings in the lowland urban areas (Marseilles, Aix) and the Navy (Terrer, 1978; Bouticourt, 2016; Shindo and Claude, 2019). It is only in periods of less economic activity (and therefore less regulation of the forests) that Alpine populations were able to use local wood for themselves. This observation shows their subordination to higher injunctions. Hence, the second dendrochronological phase may also be explained by the recycling hypothesis.

5. Conclusion

Combining the results of historical review, dendrochronology and pedoanthracology provides a powerful tool to estimate the long-term impact of human activities on forest dynamics. We showed that the three disciplines are mutually illuminating on both temporal and spatial scales. There is a real interest in working together, especially for areas that lack adequate palaeoenvironmental or historical and archaeological

data. Each discipline can fill in the gaps of the other and contribute to the missing knowledge on forest history which has been subjected to millennia of human activities. In our case, we demonstrated that the forest layout has been disturbed most probably due to local human activities (silvo-pastoralism, local building construction, wood exportation) since at least the high mediaeval time. However, local communities certainly did not have free hand on their own timber resources. It seems necessary to put their role in deforestation into perspective. It is not only because of their use that the forest has been devastated since the mediaeval times, but also because of other activities and external factors such as grazing by herds from lowlands and excessive cutting of wood for cities on the plains and shipyards. More research is needed, as many other factors must have been involved. For example, we have not yet identified any charcoal kilns or mines both needing a lot of wood in other mountain regions like in the Ecrins mountains (Hautes-Alpes, see Py et al., 2014).

In our study, we focused on the human dimension of the environmental changes with less attention given to climate change impacts. To our knowledge, there is so far no local palaeoclimatic data available for our study area which makes it difficult to disentangle the relative impact of climate versus human activities on forest dynamics. Nevertheless, it is well established that the high-frequency climatic changes have significantly modulated the socio-environmental interactions e.g. during the Little Ice Age (Pfister and Wanner, 2021) which could also have affected our study area. For example, the opening up of the forests at the end of the Neolithic and the beginning of the Bronze Age evidenced by high-elevation archaeological excavations, took place during a warmer climatic phase which could have facilitated forest exploitation. Similarly, the Roman Climatic Optimum could have influenced human activities during Protohistory and Antiquity. In the same way, the reforestation during the 11th-12th centuries is coincident with a significant socio-political instability possibly linked to the Mediaeval Warm Period. The same applies to The Little Ice Age: even though the economy was prosperous, with pastoralism once again flourishing and forests being exploited on a massive scale, climatic conditions were more severe.

Finally, this study is part of a larger collaborative effort, to which will soon be added the results of another pedoanthracological transect carried out in the Faillefeu forest (on the north side of the neighbouring mountain, to the south of Chourges) and beyond in other Alpine valleys, in order to provide more elements to a comparative study. The latter transects are even richer in historical and archaeological information and will enable us to refine the preliminary results of this study in terms of dynamic response of forest to human activities.

Author contributions

E. Gamba and B. Talon acquired and analysed the pedo-anthracological data. D. Isoardi collected and analysed historical and textual archives. L. Shindo acquired and analysed the dendrochronological data. All authors contributed equally in the writing of the article.

Data availability

The data will be available on request from the authors.

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Declaration of competing interest

The authors have no competing interests to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.quaint.2023.07.011>.

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