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Latest developments of dendro-archaeology in the French Alps: Assessing changes in mountain forests exploitation over the last millennium

Vincent Labbas [a,b,*], Melaine Le Roy [c,d], Lisa Shindo [e]

[a] Faculté de Philosophie et lettres, Département des sciences historiques, Université de Liège, 4000 Liège, Belgium
[b] Royal Institute for Cultural Heritage KIK-IRPA, 1000 Bruxelles, Belgium
[c] University of Geneva, Institute for Environmental Sciences, Climate Change Impacts and Risks in the Anthropocene (C-CIA), CH-1205 Geneva, Switzerland
[d] Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS, EDYTEM, 73376 Le Bourget du Lac, France
[e] Cluster of Excellence ROOTS, Christian-Albrechts-Universität zu Kiel, 24118 Kiel, Germany

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ABSTRACT

Dendrochronological studies are carried out on rural buildings in the French Alps for twenty years. In this contribution, we examine an extensive dataset of larch timbers ($n = 1294$) that were dendrochronologicaly dated at 139 buildings. This material yielded felling dates spanning the 11th century to the 20th century and contributed to improve our knowledge of human occupation and exploitation of mountain forests during the second millennium CE. From the 11th to the 14th century, rural populations increasingly exploited older forests. The crises of the 14th century led to a significant decrease in construction and by extension in tree cutting. The beginning of the 15th century marks a resumption of construction and felling which is continuous until the beginning of the 20th century. There is a relationship between the age of harvested trees, the number of dates and population fluctuations, which corroborates findings at the European scale. Regional trade probably influenced the stem diameters used in constructions in the immediate vicinity of the forests. Logging regulations can be perceived through variations in the age of harvested trees. The 14th century gap in felling dates would also mark a transition period in the exploitation of mountain forests and by extension a transformation of the economy.

1. Introduction

In the French Alps, tree ring research was initiated in the late 1970s, initially focusing on climate-growth relationships (Serre, 1978; Tessier, 1986). With the development of long master chronologies for main subalpine species, the dating range was extended to most of the last millennium (Edouard, 1994, 2010a; Edouard and Thomas, 2008). This dense network of reference chronologies has later been used for first long-term climate reconstruction in the western Alps (Corona et al., 2010). Backed by these chronological progresses, dendro-archaeological studies arisen in the second half of the 2000 s, targeting building heritage (rural buildings, churches, mining structures etc.) and aiming at better understanding human–environment interactions at high elevation since medieval times (Edouard, 2008, 2010b; Py et al., 2014). This research effort paralleled other studies conducted on mountain buildings in Switzerland, Italy, and Austria since the 1990s (Remacle, 2007, 2014; Büntgen et al., 2006b; Klein and Grabner, 2015). They are also the continuation of studies undertaken at the beginning of the previous century. Indeed, the importance of mountain territories for the understanding of socio-economic and environmental changes was highlighted by geographers in the first half of the 20th century, including the Alpine regions (Krebs, 1928; Früh, 1930; Blanchard, 1949).

Mountain forests appear in the literature under the angle of an almost constant anthropogenic pressure from the Middle Ages. Since the 11th-12th century CE, forests have been managed mainly by rural communities (Boyer, 1990; Falque-Vert, 1997; Lassalle, 2008; Mouthon, 2015). Moreover, the rural world is significantly representative of pre-industrial societies (Kowaleski, 2014) hence the importance of studying it in order to better understand human-nature relationships. Sclafert was one of the first to use medieval texts to understand the impacts of societies on mountain territories in the French Alps (Sclafert, 1959). From the 1990 s, research in history has led to a profound renewal of knowledge about the structures of societies in the French Alps during the Medieval (11th-13th centuries CE) and Modern (15th-20th

* Corresponding author at: Faculté de Philosophie et lettres, Département des sciences historiques, Université de Liège, 4000 Liège, Belgium.
E-mail addresses: vincent.labbas@kikirpa.be (V. Labbas), Melaine.LeRoy@unige.ch (M.L. Roy), lshindo@roots.uni-kiel.de (L. Shindo).

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centuries CE) Periods (Falque-Vert, 1997; Boyer, 1990; Palmero, 2005; Lassalle, 2008; Carrier and Mouthon, 2010; Mouthon, 2011), especially regarding the regulation of the ownership and use of pastoral lands and forests. For mountain societies, the economic importance of animal husbandry (local or transhumant pastoral practices), the exploitation of wood for commercial purposes and the resulting exchanges between communities but also with coastal towns since the 12th century, have been highlighted. In the 2010 s, dendro-archaeological studies were conducted on high altitude buildings in the Vanoise National Park, the Briançonnais and Dignes pre-Alps and the Mercantour National Park (Labbas, 2016; Shindo, 2016; Le Roy, 2017). Their aim was to address, with an annual resolution, the issues of (i) high elevation building dating and the evolution of construction dynamics and (ii) the use of wood and its impact on mountain environments, especially the forest. Timbers come from constructions located in the immediate vicinity of the forests, reflecting local origin, and allowing high spatial resolution studies (Boyer, 1990). These investigations allow a better understanding of the built structures mentioned in the historical literature.

In the Alps, larch (*Larix decidua* Mill.) is the most common species used for construction in the montane and subalpine zone, followed by fir (*Abies alba* Mill.), spruce (*Picea abies* L.) and Scots pine (*Pinus sylvestris* L.). It grows up to 2200–2400 m a.s.l., thus marking the upper limit of the forest (Edouard et al., 1991). The critical size reached by the larch dendrochronological data acquired in the French Alps makes it now possible to question the exploitation of mountain forests during the second millennium CE. With regard to silvicultural practices, the written records indicate that mountain forests (larch in particular) are not suitable for coppicing on the stump according to forest engineers in the mid-18th century (Ortolani, 2006). This is an important difference from the practices observed over the long term at low elevation areas, like in central Europe with oak trees (*Quercus* sp.) or occasionally at large medieval sites in northern France (Epaud, 2019; Muigg et al., 2020). The study of larch exploitation in the French Alps must therefore be seen through other parameters. Several recent studies have demonstrated the suitability of dendrochronological data to illustrate historical facts on a large scale or to highlight practices unknown in historical sources (Ljungqvist et al., 2018, 2022, 2021; Tegel et al., 2022). In this work we use felling dates, diameters, and age of the harvested trees with the aim of assessing the relevance of larch used in rural construction to explain past socio-economic trajectories.

2. Material and methods

2.1. Study area and sites (Fig. 1)

The 139 selected buildings are located in the Vanoise massif, the Durance area and the Mercantour massif (Fig. 1). Vanoise massif is a part of Savoie which was part of the County of Savoy from the 12th century, which became the Duchy of Savoie from the 15th century. In the south, the county of Nice, which was the eastern part of the county of Provence, was annexed by Savoie at the end of the 14th century. The Durance area, included in Dauphiné and Provence, became part of the Kingdom of France during the 14th and 15th centuries. Before the middle of the 15th century, the upper Durance Valley was part of the Dauphiné . From the middle of the 15th century this territory came under the control of the Kingdom of France. The middle Durance Valley, which was part of the County of Provence, became part of the Kingdom of France at the end of the 15th century. The political history of this region is complex, but it must be considered to explain past socio-economic patterns. The 15th century is a period of major political transitions in these territories. In Europe, the 15th century is normally still regarded to be part of the Medieval Period and particularly the Late Middle Ages (Ferguson, 1962). The profound socio-economic and cultural changes that occurred from the 14th century onwards have led several authors to describe this period, which differs from the previous one by its globalised character, as 'early modern' (De Vries, 2010).

The studied buildings are located between 770 and 2356 m a.s.l. The majority of the corpus consists of barns with an agropastoral function (storage of hay and livestock). These buildings are mostly erected on slopes and are therefore semi-buried, most often for the first level. Mountain societies have taken advantage of the slope, which contributes to the thermal insulation of their dwellings and protects them from the winter cold (Blanchard, 1949). It is also an advantage from a structural point of view, the slope ensuring rigidity of the semi-buried walls as well as a saving in materials (Pallanca, 2002; Labbas, 2016; Shindo and Giraud, 2021). In the Mercantour National Park and the upper Durance Valley, log construction is widely and predominantly used in the upper floors. In the Vanoise National Park, barn walls as well as roofs are mainly built of stone (Iancovescu, 2013; Le Roy et al., 2017). Several dwellings were also studied, most of which located in the Durance Valley. These buildings host a domestic function on the second level and generally a stable on the first level, in addition to agropastoral characteristics.

2.2. Existing database

The corpus used here is based on dendro-archaeological works conducted in the French Alps since the end of the 2000 s (Table 1). We focused on larch, which is the most representative species used in the Alps and accounts for 1294 timbers. Other species such as fir, Scots pine, spruce, cembran pine (*Pinus cembra*) and oak (*Quercus* sp.) are also used in mountain rural construction since the Middle Ages. These species represent 213 timbers in the French Alps rural buildings (14 %) and were not included in this study, as it is a marginal dataset compared to larch (Labbas, 2016; Shindo, 2016; Le Roy et al., 2017).

The studied buildings provide comparable dendro-archaeological larch data (Fig. 2). The felling dates positioned in each block-diagram have highlighted rural buildings that are understood over the long term, several centuries and sometimes almost on the scale of the last millennium. These constructions are characterized by the replacement of timber from previous building sites, frequent repairs or maintenance.

2.3. Sampling design

The strategy of site selection was similar for the three study areas. The aim was to select buildings that can be qualified as vernacular, being a material translation of pre-industrial and essentially agro-pastoral economic activities. The criteria of age and relative preservation with regard to recent transformations are thus shared for the three zones. However, the selection was also adapted to local specificities. In the Vanoise National Park, the selection was conducted with the aim of disclosing a representative sample of the Park's subalpine buildings (mountain pasture chalet, construction techniques, summer pasture architecture). Therefore, the choice was based on a pre-existing inventory and in consultation with Park agents and building owners (Iancovescu, 2013). In the upper and middle Durance Valley, the specificity of the selection lied in the documentation since the buildings were studied thanks to the previous work of the French Inventory and the Historic Monuments services. In the Mercantour massif, research was conducted in the protected area of the National Park on the basis of existing inventories (Rosa, 2005; Leyoudec, 2006). The selection also took into account the 19th century cadastre and oral surveys of local populations.

2.4. Tree ring dating

After wood species identification (Schweingruber, 1988), ring-widths were measured using the incremental measuring table LINTAB with 0.01 mm accuracy and TSAP-Win software (Rinntech, 2014). Tree-ring series were then indexed with different softwares and cross-dated using the Student test (t) with TSAP-Win (Rinntech) and Dendron IV (Lambert, 2006). Tree-rings widths are detrended using the Corridor method (Durost, 2005; Lambert et al., 2010; Lambert, 2011;

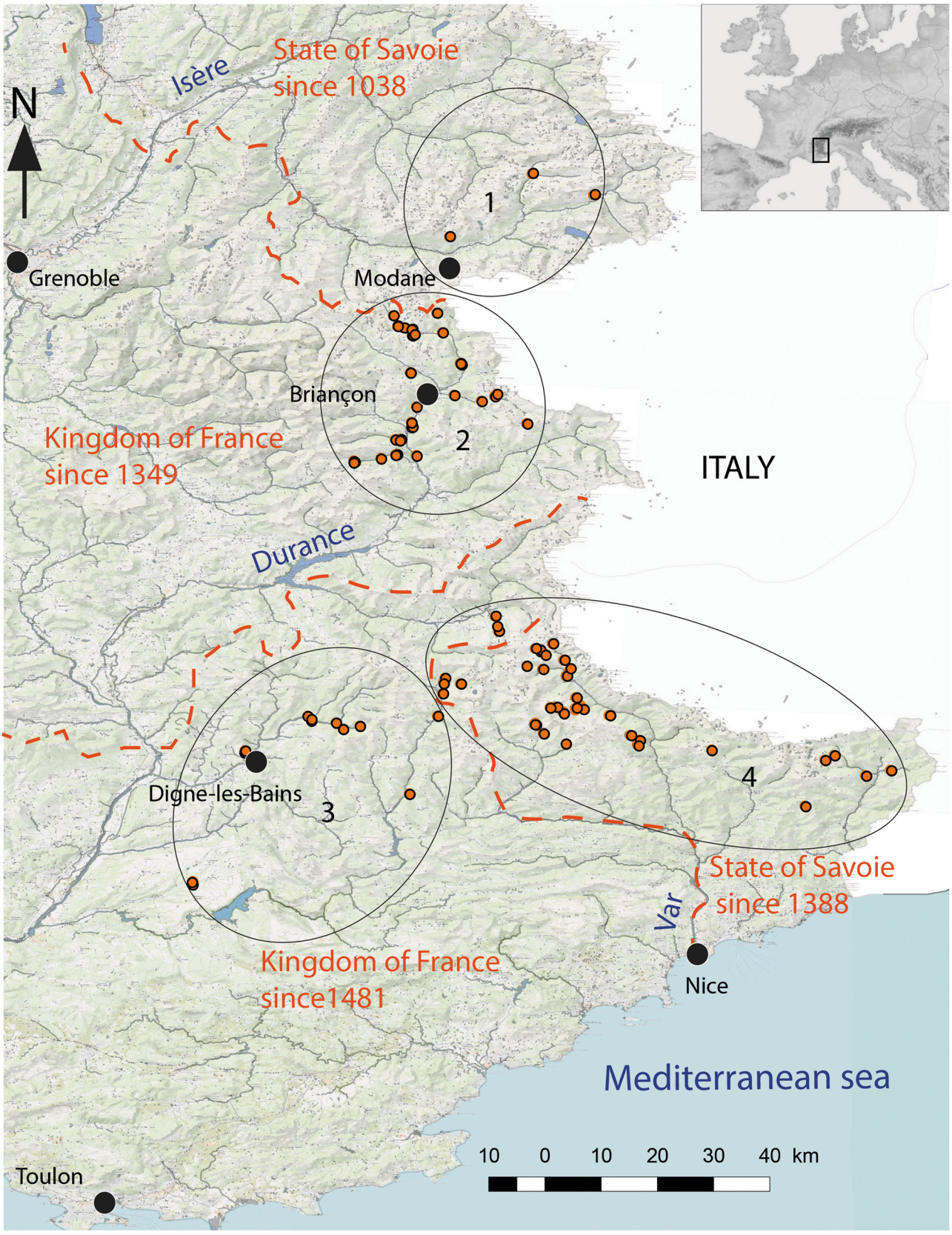

Fig. 1. Location of the 139 studied buildings in the French Alps. The red dashed lines correspond to former historical administrative borders. The ellipses represent schematically: 1. the Vanoise National Park; 2. the upper Durance Valley; 3. the middle Durance Valley; 4. the Mercantour National Park.

Table 1
List of larch data contributors per research areas (listed southward).

Area	Data contributors	Number of buildings	Number of tree-ring series	References
Vanoise National Park	Melaine Le Roy, Laurent Astrade	3	36	Le Roy et al. (2017)
Upper and middle Durance	Jean-Louis Edouard, Frédéric Guibal, Lisa Shindo	69	670	Edouard (2010b);Shindo (2016),Shindo et al. (2018)
Mercantour massif (National Park)	Jean-Louis Edouard, Vincent Labbas	67	588	Edouard (2010b);Labbas (2016);Burri et al. (2019)

Shindo and Giraud, 2021), the Besançon E method (Lambert and Lavier, 1992), or by applying a logarithmic transformation, in order to extract the common mainly climatic signal (Cook and Kariuktsis, 1990, Nicault et al., 2010). Dating was performed from 25 references (Vanoise National Park, Le Roy et al., 2017) to 49 references (Mercantour National Park, Labbas, 2016). Some of these references are only available in dating reports but the majority are published (Serre, 1978; Siebenlist-Kerner, 1984; Tessier, 1986; Edouard, 2010a; Labbas, 2016; Shindo et al., 2017; Belingard et al., 2019).

2.5. Timbers diameter and cambial ages observation

Diameter estimation and cambial age analysis are frequently used in forestry and dendrotypological approaches (Billamboz, 2011; Capano et al., 2021). The distribution of diameters as a function of felling dates, and thus as a function of time, illustrates possible changes in the size of the trees used. In addition, this information allows to study the diameter chronological variability at the time of harvesting. This quantitative information was pointed out using the same approach employed in the Southern French Alps (Shindo et al., 2018). As the pith is almost always present on the samples (or not very distant, as less than 20 rings are missing at most) and there are few, if any, rings missing at the periphery (waney edge is present), the estimated diameter is very close to the actual diameter. The diameter of each timber was estimated from the ring width series (Fig. 4). Timbers were grouped into 20-year time windows according to the most recent measured ring, and then their diameters were presented in boxplots. These plots show the minimum median and maximum values of the cambial ages of each group as well as the first and third quartiles (25 % and 75 %). The cambial ages, i.e. the number of rings in the trunk, were also represented according to 20-year time windows, in the form of boxplots (Fig. 5). Our corpus doesn't include squared pieces likely to have lost a significant number of rings that may lead to chronological uncertainty about the felling date. In addition, evidence of drying of the timbers after placement of the structural elements (such as shrinkage cracks or the presence of bark) suggests that the timbers were used immediately after felling the trees.

3. Results

3.1. Felling dates over times

Numerous clusters of felling dates were identified from the 11th to the 20th century CE (Fig. 3). This testifies an almost continuous activity of building construction, repair, maintenance, and transformation during the last millennium in the French Alps.

The oldest felling phases are dated to the 11th century (Fig. 3). However, there are only 14 timbers dated to this century, with wood originating from pastoral barns located between 1800 and 2000 m a.s.l. The felling dates are more numerous from the 12th century onwards, particularly at the end of the 12th century and the beginning of the 13th century. During the 14th century, we observe a significant drop in the number of felled trees, and even a virtual absence of dated wood, particularly between 1320 and 1380 CE, with only two dates (Fig. 3). From the first half of the 15th century onwards, felling dates are more numerous. A prominent felling phase stands out in the early 16th century (Figs. 3 and 4). This is partly a bias originating in a large amount of timber coming from a single building in the upper Durance Valley. Overall, felling increases until the middle of the 19th century, then decreases significantly in the early 20th century and became virtually absent from the 1960s.

3.2. Timber diameters

Our results show that larch timbers used in rural buildings have a median diameter of about 21 cm from the 11th to the 20th century (Fig. 4). The median varies from 14 cm (1520 CE) to 32 cm (1260 CE). It should be noted, however, that the 1520 s timbers are predominantly originate from a single barn that delivered a large number of samples and may induce a bias. Minimum and maximum values must also be considered. The average minimum diameter is 14 cm and varies from 6 for the smallest piece of wood in the 1700 s to 28 cm for the smallest diameter in the 1260 s. The average maximum diameter is 36 cm and varies from 19 cm in the 1440 s to 49 cm in the 1620 s

As mentioned earlier, the sample depth is restricted during the 14 t^{h} century, specifically between 1320 and 1380 CE. Few timbers are dated within the time windows 1340–1360 CE, which makes it impossible to exploit these data. This can be assimilated to a break phase and leads us to examine the values for the Middle Ages and for the Modern Period. From the 11th to the 13th century, the median diameter is 24 cm and 26 cm on average. From the 15_{th} to the 20th century the median diameter is 19 cm and the average diameter is 20 cm. The average minimum diameter during the first period is 18 cm. The average maximum diameter during this period is 25 cm and therefore very close to the median diameter. During the second period, the average minimum diameter is 10 cm and the average maximum is 36 cm.

Overall these diameter variations reflect the variety of timbers collected: beams, purlins, lintels, props etc. By extension, this reflects the different stands exploited with trees that would vary from about 10 cm to more than 40 or even 45 cm. The number of trees is smaller during the Medieval Period (11th-13th century) than during the Modern Period (15th-20th century). However, the wood used was considerably larger in diameter in the 11th and 13th centuries than in the later period.

3.3. Timbers cambial age

The chronological distribution of cambial ages (i.e. the age of trees at the time of felling) from the 11th to the 20th century indicates that trees are felled on average around 109 years, with the median at 134 years (Fig. 4, middle panel). The average minimum age is 71 years and the median minimum is 51 years. The average maximum age of the felled trees is 269 years, with a median age of 260 years, which is relatively comparable. The observation over this period therefore indicates that the trees felled are of very different ages. However, the graph also reveals that these mean and median ages vary substantially over time.

The sample depth is restricted for the 14th century, specifically between 1320 and 1380 CE. Similarly, replication is too low between 1340 and 1360 CE to provide observable data. Therefore, the observation can also be divided into two periods: for the Middle Ages and for the Modern Period. The age of the trees in the 11th to 13th century appears to be significantly higher (twice as high) than in the 15th to 20th century. This difference is seen in the average median age of the harvested stands as well as in the minimum ages. However, the maximum age of felling is relatively similar between the two periods.

Two additional observations can be made. The first is that during the Middle Ages, the age of the felled trees increases while the trend appears more stable during the Modern Period. The median age of about 150

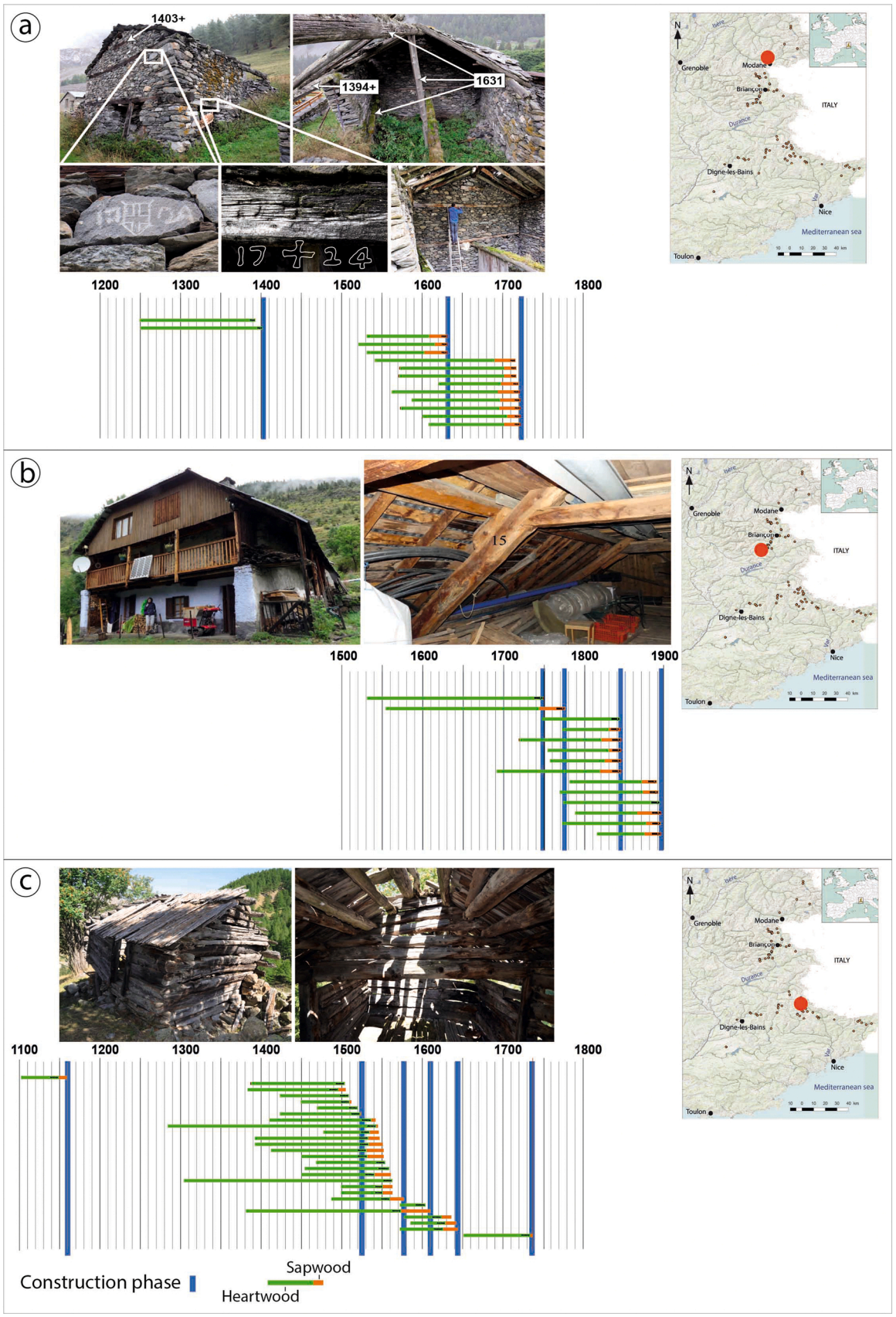

Fig. 2. Three examples of dendro-archaeological studies carried out in the French Alps and included in the present contribution. (a) Parc national de la Vanoise, Modane, 1860 m a.s.l.; (b) Parc national des Ecrins, Freissinières, 1790 m a.s.l.; (c) Parc National du Mercantour, Saint-Dalmas-le-Selvage, 2010 m a.s.l.

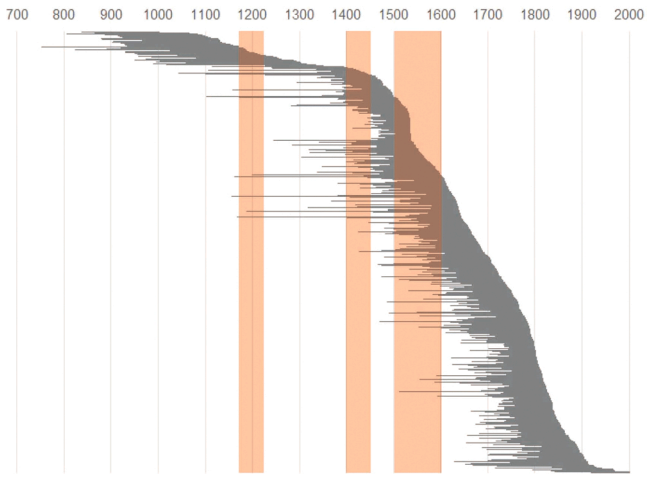

Fig. 3. Bar plot of the 1294 larch tree ring series, arranged according to the last measured ring. Each horizontal bar corresponds to one timber and each vertical bar corresponds to a major felling phase.

years in the middle of the 11th century reaches 308 years in the 1320 s. The second concerns the maximum ages of the logged stands. The oldest trees of the corpus were felled in the first half of the 17th century (Fig. 3 and Fig. 4, middle panel). There are two significant decreases: the first one occurring in the middle of the 17th century and a second decrease in the maximum ages from the 1840 s

4. Discussion

4.1. Representativeness of the samples

4.1.1. Diameter measurements

In forestry research, diameter measurements are made at 'breast height' (DBH), also taking into account tree height and density. In these studies, often only DBH is measured (McGhee et al., 2016). Furthermore, some authors point out that measuring DBH can lead to some inaccuracy, due to the height considered (Brokaw and Thompson, 2000).

In this work, diameters were estimated summing the ring widths in the tree ring series. In the vast majority of cases (more than 95 %) the sections and cores were taken from debarked parts or with waney edges. The pith is also present in the same proportions. The sections are usually cut from the wider end of the timber. As the bark is not present in most cases, the diameter of the archaeological wood necessarily differs by a few cm from the DBH which includes the thickness of the bark. Moreover, compared to the DBH, the extraction height of the sample on the stem is unknown in the dendro-archaeological material. Missing rings are common in larch, with outbreaks of the larch budworm (*Zeiraphera griseana*) being one of the main causes (Saulnier et al., 2017). Therefore, in the case of cores, two samples were taken in the widest part of the timbers, preferably on opposite radii and, as far as possible, at a distance from each other. The aim is to ensure that all growth rings are present (Edouard, 2010a, 2010b). The diameter measurement is therefore derived from an individual series that is the average of two elementary series from two different locations on the tree. Larch timbers used for rural buildings are, in most cases, cut from the log (Burri et al., 2019). In the case of larch used in rural mountain buildings, the log comes from the first 15–20 m of a trunk (Labbas, 2016).

4.1.2. Spatial and temporal distribution of felling dates

The temporal distribution of the felling dates reveals that the majority of the tree-ring series is dated from the Modern Period. Regarding the Medieval Period (until 1320 CE), there are very few dates ($n = 16$) before the 12th century. It is during the Middle Ages that the rural communities appear in the texts through charters of privilege granted by the local lords, mainly in the Southern Alps (Lassalle, 2008). Though the dendrochronological corpus is smaller than for the Modern Period, the replication increases from the 12th century onwards. The 12th and 13th century are marked by an overall increase in population in urban centres, but also in rural areas (Baratier, 1961; Pécout, 2008). Conversely, a significant decrease in timber felling occurred (mainly 1320–1380 CE) during the crisis period (economic, health, political) which affected all of Europe (Ljungqvist et al., 2018; Izdebski et al., 2022). The intensity of trade between rural and urban areas could therefore be further questioned.

About 75 % of the samples are thus concentrated over the Modern Period. From the end of the 19th century the dates become rarer and almost absent in the second half of the 20th century. In the 19th and first half of the 20th century, these dates reflect the last felling that took place during the period of forest minimum extent (Vallauri et al., 2012) but not the end of the occupation of the high mountains. The beginning of the 20th century marks an economic transition characterized by a gradual abandonment of traditional activities. However, mountain pastoralism continued throughout the 20th century in the French Alps but without creating new constructions or repairing agro-pastoral huts (Labbas, 2016).

Regarding the spatial distribution of dates, the vast majority of data comes from the Southern Alps (Durance Valley and Mercantour National Park). The Northern Alps (Vanoise National Park) only provide 40 dates from the 14th century. For the Medieval Period, the majority of the data come from the Durance Valley. The studies conducted in the Mercantour National Park also provide data for the 11th-13th century period, but in smaller proportions. For the Modern Period, the data come from the northern and southern French Alps but mainly from the southern Alps. For this period from the 15th to the beginning of the 20th century the number of dates is equivalent between the Durance Valley and the Mercantour National Park. Historically, these territories were part of different political and administrative entities. It is therefore appropriate to discuss the results distributed according to these different territories.

4.2. Relationship between diameter and age of harvested trees

When timber exploitation exceeds the regeneration capacity of forests, the desired diameters become rarer (Blondel and Girardclos, 2018). The evolution of the age and diameter of trees at the time of felling therefore gives an idea of the impact of logging on forest structure (Billamboz, 2011; Bernard, 2003; Girardclos and Petit, 2011).

4.2.1. Construction patterns

Remacle (2007) perceives a formal mutation of the houses in Val d'Aosta (Italy) during the 15th century. The houses are gradually gaining in height. The agricultural and domestic functions were then spread over several floors. However, studies conducted in the French Alps (Edouard, 2010a, 2010b; Labbas, 2016; Shindo, 2016; Le Roy et al., 2017) do not indicate the same conclusion. On the contrary, the construction patterns appear to be stable, probably at least since the 12th century. (Labbas, 2016). However, the wood conservation can introduce bias into the observed and analyzed timbers. The larger wood pieces (logs, beams, etc.) remain the best preserved over time. The surviving elements from the 11th-14th century are therefore less representative of the constituent parts of the buildings than those from the Modern Period.

4.2.2. Timber trade influence

In general, the timber trade puts pressure on forest resources over the considered period. Mountain forests have been heavily exploited for timber needs and exported to cities or to the coast (Braunstein, 1988; Bernardi, 1995; Domínguez-Delmás et al., 2018; Fabre, 2017). The Durance Valley fir, also characteristic of mountain forests, was massively exploited and used in the settlements of the lower Rhône and Durance Valleys in the Medieval and Post-Medieval Periods (Bernardi,

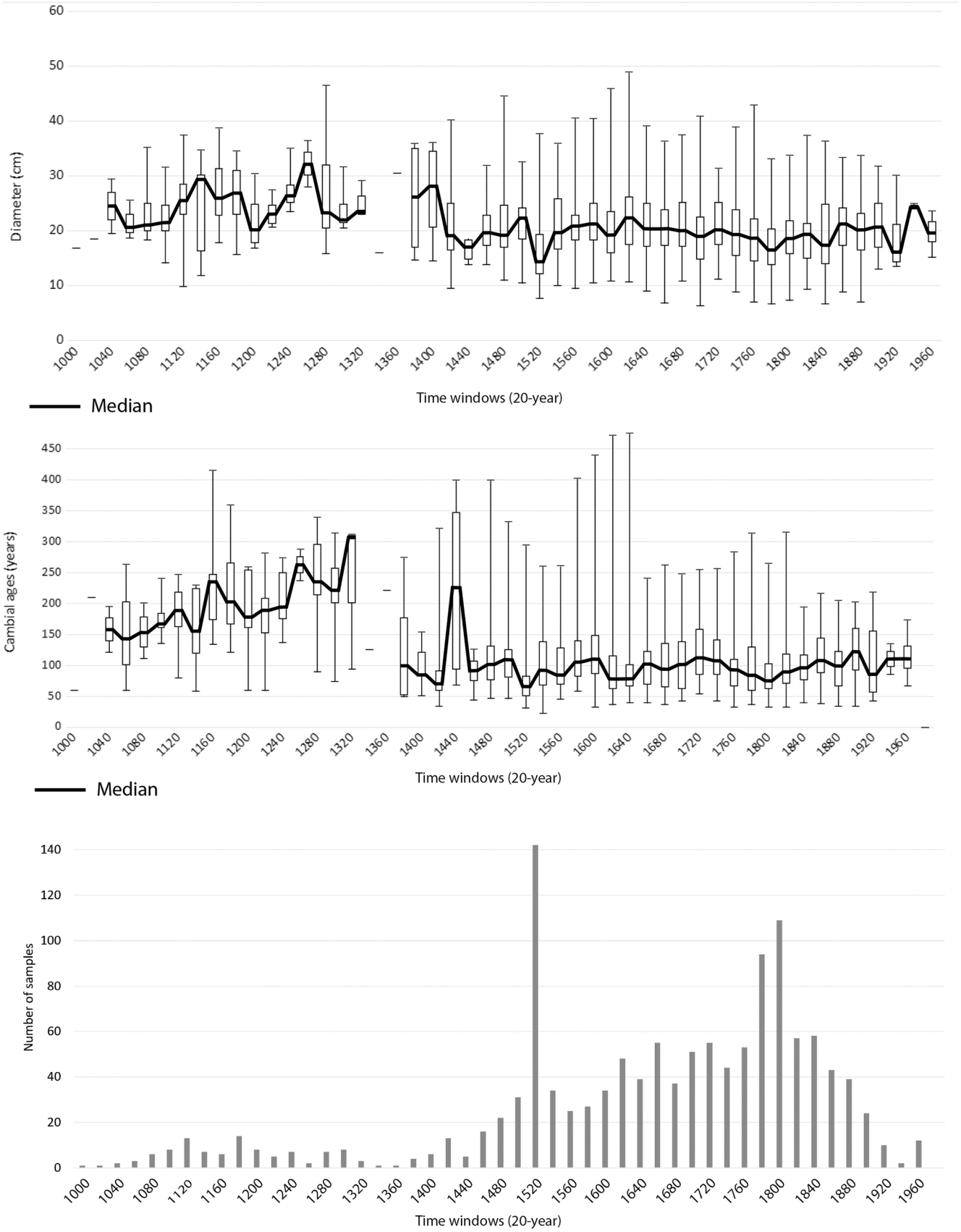

Fig. 4. Top panel: Box-plot of larch timbers diameters used from the 11th to the 20th century CE at studied buildings (20-year time windows). Middle panel: Box-plot of larch felling ages from the 11th to the 20th century at studied buildings (20-year time windows). Bottom panel: Bar diagram of the larch samples (n = 1294) used in this study. Each bar represents the number of dated series per 20-year time window.

1995; Bouticourt and Guibal, 2008; Shindo and Claude, 2019). In the Mercantour massif, the larch and fir exploitation is attested by written sources from the late Middle Ages (Boyer, 1990). In some valleys, these species were particularly sought after and exported to the coasts.

The few written records on timber sizes mostly refer to trade and in particular to the length of timbers or logs (Fouilland and Furestier, 1999; Gili, 2018; Nicolas, 2007; Burri et al., 2019). Nethertheless, in some cases, the wood piece's width is indicated in the texts. This is for example the case for roof planks in the Southern Alps in the 15th and 16th centuries (Burri et al., 2019). The texts indicate widths of 10–13 cm, but these are probably boards intended for regional trade. In comparison, archaeological data from rural buildings show greater widths of 16–23 cm. In the middle of the 18th century, in the Mercantour, trees intended for trade and specifically for the manufacture of planks were classified into three sizes: the largest, called "*tavolieri*" of 38 cm, the medium, called "*carantieri*" of 28 cm and the smallest called "*falchettieri*" of 20.5 cm in diameter (Ortolani, 2006). The part of the tree exploited for commercial timber is the log, between the base and the tree-crown (Gili, 2018).

This part of the tree is assembled into rafts, floated to regional markets and used to produce the various timber parts needed for construction (Shindo and Claude, 2019). A standardization of the wood parts appears necessary to rationalize this supply process. The log is also the most used piece in rural construction. The data on diameters in modern times indicate that the woods has an average diameter of 20 cm (min $\simeq$ 10 cm, max $\simeq$ 36 cm). The average and maximum values appear to be quite comparable to those found in the literature. As the architecture of mountain buildings and cities is different, this would indicate an influence of trade on local practices.

In several cases it is found that the bases and tree-crowns are also used for specific purposes (Labbas, 2016). Indeed, several mentions in the texts indicate that it is usual to leave the tree crowns in the forest when felling (Ortolani, 2006; Nicolas, 2007). Therefore, larch crowns, stripped of their branches, were used in subalpine barns in the Southern Alps to make sandpits or roof purlins with a diameter of 8–16 cm (Labbas, 2016). These observations help to explain the use of small-diameter timber identified in mountain buildings.

4.2.3. Demographic influence

There's a relationship between the extension of forests, cultivated land and demography (Morin et al., 1996). Ljungqvist et al. (2018, 2022) also highlight the relationship between demography and construction activity. European population doubled between the year 1000 CE and the beginning of the 14th century, then dropped by half between 1300 CE and the middle of the 15th century. Data from Morin et al. (1996) indicate a negative correlation between population number and forest area. In eastern Provence, Pécout (2008) and Carrier (2014) report a higher demography at the beginning of the 14th century in the rural mountain areas than in the coastal areas. For the Southern Alps, it was not until the end of the 17th century that the demography was comparable to that of the first half of the 14th century (Baratier, 1961).

Our data indicate an increase in felling activity from the 11th to the beginning of the 14th century (Fig. 3, bottom panel). The significant drop in felling thereafter reflects a generalized phenomenon at European level. In south-eastern France, pandemics and famines continued until the end of the 15th century, dividing the population by three or four depending on the area (Aurell et al., 2005). The resumption of activity, visible in our data from the end of the 14th century, seems to be perceived around 1415 CE at European scale (Ljungqvist et al., 2018). From the 15th century felling increases until the beginning of the 19th century. During the 19th century the population reached its highest level in rural areas and the forest its lowest level (Vallauri et al., 2012). The first half of the 20th century results in a "man shortage" in the French Alps (Blanchard, 1949). This time marks the final period of so-called "traditional" agro-pastoral occupation.

If demography explains variations in the number of felling dates, it could also be a factor in explaining the harvesting ages. Thun and Svarva (2018) perceive an increase in tree growth as a result of the 14th century plague and the regeneration of trees on abandoned farmland. The average age of the harvests could coincide with the logging recovery of the late 14th century, lower than in the early 14th century. In addition, from 11th to 13th century, the increase in the age of the exploited forests could indicate that the old stands are exploited when the young and mature forests are felled and no longer regenerate. Thus, when the population increases, the pressure on the forests also increases. This pressure leads to the exploitation of new sources of wood, especially old-growth stands that were previously unexploited. There are no old trees left after a harvesting phase. This was the case both in the late Middle Ages and in the first half of the 17th century. The relatively stable diameters in the long term linked to higher ages in certain periods could also be explained by higher altitudes supply sources. However, during the Modern Period, the average age of the harvested trees is relatively stable over this multi-century period and would therefore imply another explanatory factor.

4.3. Geographical comparison

French Alps scale assessment may mask locally perceptible variations which we hereafter examine according to past administrative divisions (see Fig. 1). To illustrate this comparison, we use tree ages at harvest (Fig. 5).

4.3.1. Regional variations

From the 11th to the end of the 13th century, the increase in harvest ages is mainly observed in the Dauphiné (upper Durance Valley). However, although there is less data, the variations observed in Eastern Provence from the middle of the 12th to the beginning of the 14th century also indicate an increase in harvesting ages. The 14th century's gap can be observed in the Savoie States as well as in France, which confirms the situation observed in Europe. The felling dates of the 15th century are mainly observable for the Savoie States. The high values found in 1440 s nevertheless come from three buildings in a Mercantour valley (Fig. 4, in the bottom). In contrast, the 16th-20th century period is represented in both territories. In Savoie, from the 16th century, the age of the harvested trees fluctuates between 65 and 125 years and overall around 100 years until the beginning of the 20th century. The observation is relatively similar in France. Two differences can be noted: the maximum ages of the trees harvested and oscillations of the median more pronounced in Savoy. In the States of Savoie, the maximum ages of harvesting varied between 250 and 450 years until the end of the 17th century, then between 150 and 200 years until the beginning of the 20th century. In the Kingdom of France, these maximum ages varied between 160 and 300 years until the 1820 s, then stabilized between 160 and 190 years until the beginning of the 20th century. This raises the question of whether there is an influence, possibly reciprocal, of commercial regulations on local uses in these two territories.

There's a significant common decrease in the age of trees harvested in Savoie and in France after 1620 CE. The other periods of decrease and increase perceived in Savoie are relatively stable in France. These variations close to the decadal scale do not appear to be correlated with a constantly increasing demography during this period. These differences could nevertheless be explained at a micro-scale, in the particular socio-economic trajectories of the localities.

4.3.2. Trade pressure and regulations

According to the historical literature, in the Duchy of Savoy, as in the Kingdom of France, there was a particular focus on wood for shipbuilding and therefore on high mountain forests (Perrillat, 2011). In the second half of the 17th century, the authorities of both territories intensified the control and tightened the regulations on the exploitation of forests, in particular mountain forests, which were also covered by traders (Perrillat, 2011; Thiéfaine-Soudain and Thiéfaine, 2020).

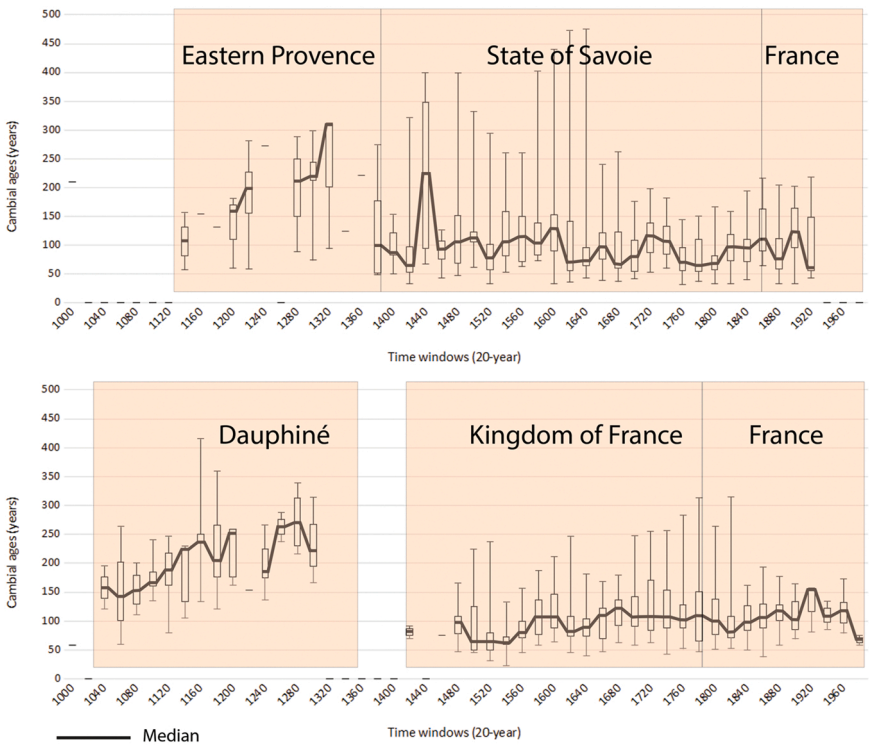

Fig. 5. Logging activity in each administrative region from the 11th to the 20th century CE. Top panel: cambial age variations in the Eastern Provence and State of Savoy. Bottom panel: cambial age variations in the Dauphiné , Kingdom of France and France.

However, this control of logging would be more effective in the Kingdom of France, partly due to a higher number of inspectors (Perrillat, 2011). It is difficult to say whether these regulations are reflected in the variations shown in Fig. 5. Indeed, there is a significant decrease in old-growth logging in the State of Savoy but not in the Kingdom of France, which appears paradoxical in relation to the historical findings. In contrast, the variation observed for France in the 1820 s (a decrease in maximum ages) occurs at the same time as the introduction of the Forestry Code in 1827 CE, which imposes even greater regulation of felling (Dumoulin, 2002). To confirm the hypothesis of a link between this regulation and the significant decrease in felling of old trees, it would be necessary to analyse the locally available archives for the localities concerned.

In the Middle Ages, Southern Alps' rural mountain communities granted forestry concessions to traders, often for several thousand trees and for several years (Boyer, 1990). The forest heavy exploitation in the 13th and the 15th centuries led the community authorities to strongly regulate the commercial exploitation but also the local practices (Boyer, 1990). Although the timber trade brought money into rural areas, it also led to the restriction of local practices (Ronda and Perez, 2001). Directly or not linked to demography or external demand for wood, restrictions on cutting wood for domestic use were also observed in Savoie (Northern French Alps) in the late Middle Ages (Mouthon, 2015). At the same period, similar restrictions are also identified in the Mercantour massif where felling is limited to 12 trees per year for each family (Boyer, 1990). The regulations imposed in these different territories have therefore probably influenced the uses and even the harvesting strategies of the rural populations.

The various forms of felling regulations indicate relatively comparable causes and effects on the forests being used. On the other hand, while population variations also have an influence on felling and tree growth, the demographics of these areas indicate significantly different trajectories.

In the Dauphiné and in particular in the upper Durance Valley, the population reduction is estimated at 72 % between 1339 and 1476 CE (Prost, 2007). The literature also indicates a slight demographic recovery at the end of the 14th century which preceded the epidemic and famine episodes of the 15th century. The 14th century gap is well marked in the distribution of dates for Dauphiné and France. The presence of felling dates at the beginning of the 15th century could also coincide with the short demographic recovery observed in this area. In the Mercantour, felling resumed at the end of the 14th century. Aurell et al. (2005) reported that the population decline in this area was less severe than in the plains and coastal areas, and may have been shorter. Demography would therefore appear, as on a European scale, to be a factor correlated with construction activity in rural mountain areas.

The 14th-century felling gap would also mark a transition period in the exploitation of mountain forests and by extension a transformation of the economy. This economic transformation led to a drop-in population and profound socio-economic changes (Carrier, 2014). At the end of a long process, this transition which also marks the passage from feudalism to capitalism (mercantilism), was accomplished during the 18th century (Pichard, 2001). This transition of economic structures would originate in the mid-17th century with a new form of state management of forest resources (Fruhauf, 1980; Pichard, 2001).

5. Conclusions

Our analysis of diameters, cambial ages and felling dates distribution of larch timbers used in mountain buildings in the French Alps allows these conclusions to be drawn:

a) The evolution of the number of dates are correlated with population fluctuations, which corroborates findings at the European scale (Ljungqvist et al., 2018, 2022), but also with the age of felled trees.
b) regional trade probably influences the stem diameters used in constructions in the immediate vicinity of forests;
c) logging regulations can be perceived through variations in the age of harvested trees;

d) the 14th-century gap in forest exploitation, identified by a drop in felling dates, would also mark a transition period in the exploitation of mountain forests and by extension a transformation of the economy.

The larch used in rural buildings in the French Alps appears to be an indicator of economic changes over the long term. This archive thus supports the interrelation between rural and urban societies in the past. We also note the difficulties of using these parameters to distinguish regional differences. The spatial and temporal distribution of the data confirms the need for further dendro-archaeological research in rural areas. Indeed, research efforts are more concentrated on urban than rural areas, while the rich rural cultural heritage is threatened by degradation.

Finally, other parameters than those used here could be scrutinised for deciphering forest management more precisely. European larch growth releases have been studied to track abrupt environmental changes (Izworska et al., 2022). In addition, growth release and suppression induced by anthropogenic action have been identified in oak trees (Rozas, 2005; Muigg et al., 2020). These approaches involving calculation of growth release and suppression could also be carried out on the archaeological larch tree rings corpus to determine exploitation cycles over time.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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