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## Article

# Forest Exploitation and Wood Supply: A Dendroarchaeological Approach between the Massif Central and the Southern Alps since the Middle Ages

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**Abstract:** Numerous dendroarchaeological studies have been carried out in buildings in the south-eastern quarter of France, which has enabled us to lay the foundations for a first regional restitution of forest stands in the medieval and modern periods, based on the species, diameters, ages and growth rhythms of the trees used by humans. The 2369 pieces of dated softwood timber are mainly larch and fir from the Massif Central and the Alps mountains. Larch seems to have been used mostly locally in the Alps, whereas fir was certainly exported from the two regions to the lowland towns. Very little felling has been identified in the historically troubled 13th–14th century. For the moment we have not identified any fir trees used before the 15th century in the Alps, whereas they are present in the Massif Central from the 12th century. Growth of fir timbers show little variation over time while larch timbers present an increase in growth between those felled until the 12th century and those felled from the 15th century onwards. Finally, since firs from the Massif Central show a higher age trend than those from the Alps, this can serve as a model for identifying the source forests of the timber used in the Rhône valley.

**Keywords:** dendroarchaeology; fir; larch; Alps; timber; forestry



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## 1. Introduction

The restitution of forests on the scale of a site and its surroundings has most often been carried out by dendrochronologists for the protohistoric period and from waterlogged wood. The most famous examples concern the palafittic sites established around the lakes and marshes of the Alps and classified by Unesco (<https://palafittes.org/homepage.html>, accessed on 20 December 2021). Several of them have yielded up to several thousand pieces of wood in some cases [1–4]. The abundance of well-preserved, synchronous timber makes it possible to reconstruct the evolution of the appearance of the source forests as well as the silvicultural practices. By extension, it makes it possible to trace the human impact on the environment. However, to our knowledge, there are no studies on these issues over large areas for the medieval and modern periods. Two difficulties may explain this: (i) less archaeological wood on a site scale because it is less collected due to a lack of time and money or less well preserved, and, consequently, (ii) a large predominance of large archaeological timber, selected by humans and therefore less representative of the whole forest. Certain textual sources and graphic documents, which are not available for the Protohistory, provide us with additional information. However, knowledge of the appearance of the forests (dimensions and age of the trees in particular) and silvicultural

practices (leading to the closure and opening of the environments) often remains poorly informed for the medieval and modern periods, particularly on a regional scale. A large set of dendrochronological data from buildings in the south of France finally allow us to provide answers to the issue of forest exploitation and wood supply, and also to understand some of the anthropogenic factors behind the appearance of today's forests.

A particularity of these data is that they are composed of both timbers used in the mountains, close to the source forests [5–12] but also timbers that were exported to the lowland cities [13,14]. Indeed, since at least antiquity, humans have transported timber from the mountain forests to the lowland towns (see, for example, [15–19]). One of the main reasons is the law of supply and demand: there was quality timber in the mountain forests and a high demand in the lowland towns to construct and restore buildings. These lowland towns were poor in valuable forests due to their surrounding environment dedicated to agro-pastoral activities which led to early deforestation. The timber trade was almost exclusively upstream to downstream. Wood was mainly transported by water in the form of rafts of floated on “lost logs” because it required less energy and was faster and cheaper than by land [20–25]. In port cities, timber was also widely used for shipbuilding but that is a separate issue and we have chosen to focus here on the buildings.

For some of our archaeological sites on the plains, it is difficult to establish the trade routes and to know from which mountain region the wood that was used came. However, given that a large part of our data clearly comes from the Massif Central or the Alps, this is an opportunity to describe the characteristics of the trees that grew there. Thus, we can obtain a tool to characterise the supply routes for timber and the interrelation between towns, countryside and forests.

## 2. Material and Methods

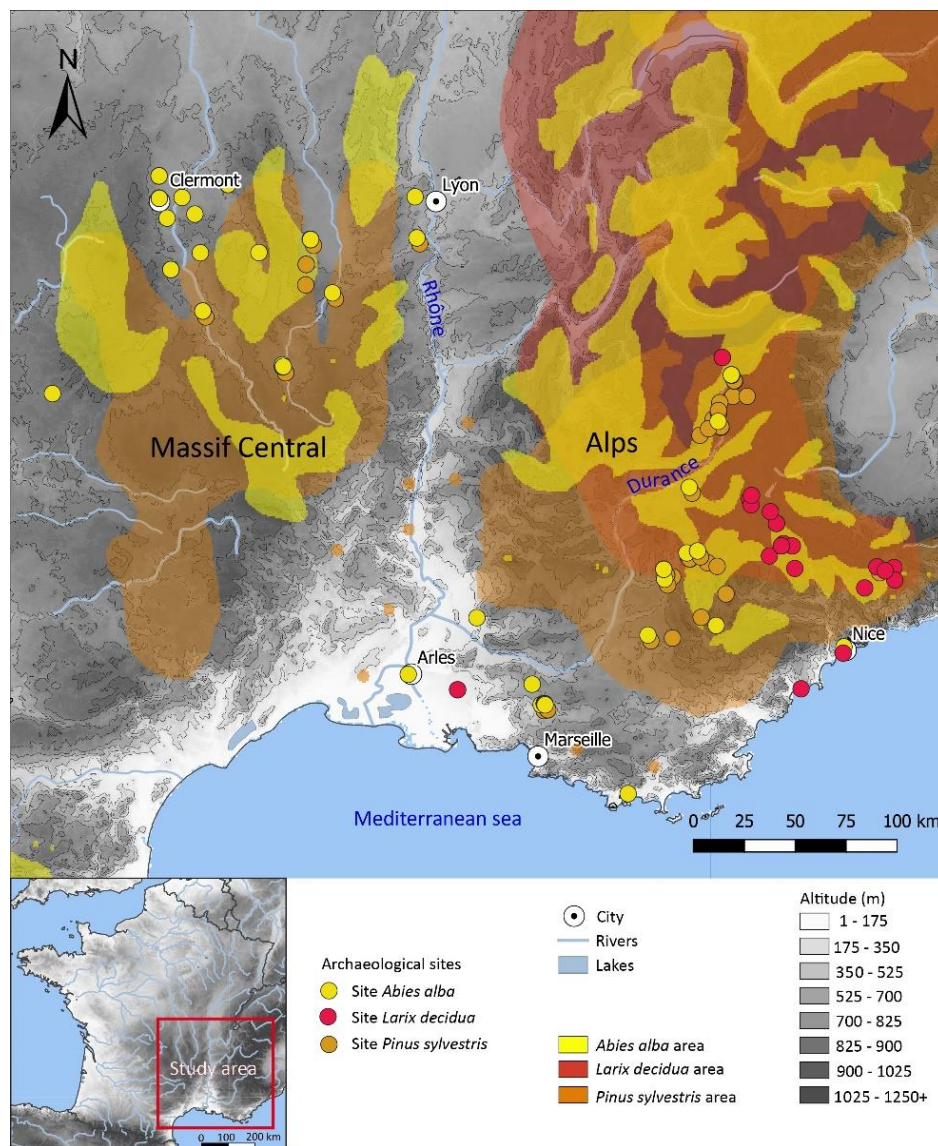
The geographical areas selected are the Massif Central and the southern French Alps, and their piedmont plains, in Southern France. They are two mountainous massifs, separated by the Rhône axis, a valley structuring the physical and economic landscape for past and present societies [26,27]. These mountainous areas are home to forests of resinous trees like larch (*Larix decidua* Mill.), fir (*Abies alba* Mill.), Scots pine (*Pinus sylvestris* L.), Cembro pine (*Pinus cembra* L.) and spruce (*Picea abies* L.). Today, fir and Scots pine are present in the forests of the Massif Central and the Alps, while larch grows only in the Alps (Figure 1). These three species grow at different altitudes, firstly Scots pine (between 400–2000 m a.s.l.) and fir (400–1800 m. a.s.l.) and then larch at the highest altitudes (1200–2400 m. a.s.l., [28]). We investigated different kinds of buildings. Some were still occupied, others were abandoned or in ruins. Their common feature is that they all retained resinous timber in their structures, which we collected.

The dendroarchaeological samples were taken during research programmes and during archaeological prescriptions, before restoration work, for example. Two hundred and seventy-nine built sites have therefore been sampled for dendrochronology.

We sampled 2369 archaeological timbers in total: 1577 larches, 671 firs, 97 Scots pines, 17 Cembro pines and seven spruces. We used a Pressler manual increment borer (Haglöf company, Långsele, Sweden), a Berliner Dendro-Bohrer or a Rinntech electric core drill (respectively, PFUNDT-Schneidwerkzeugmechnik company in Berlin and Rinntech company in Heidelberg Germany), and sometimes, when timbers were removed from the structure, a section was cut with a chainsaw.

In the laboratory, wood species were determined [29] and ring-widths were measured using the incremental measuring table LINTAB and TSAP-Win software [30] or CDendro and CooRecorder program (Cybis company, Saltsjöbaden, Sweden) with 0.01 mm accuracy. In each case, several rays per sample were measured and then averaged in order to obtain suitable dating series. Then, with different dendroarchaeological software (DENDRON IV, [31] and SYLPHE, [32]), tree-ring series were indexed using the “Corridor”, a polynomial indexation which takes into account the amplitudes of the inter-annual variations while preserving the average frequency variations ([31,33] in French; and presentation in English

in [34]), or the “Except from Besançon”, a seven-year moving average that does not take into account the largest and smallest rings, and the ring to be corrected in the calculation of the average [35].



**Figure 1.** Map of the 279 archaeological sites (circles) represented with their predominant species (fir, larch or Scots pine). In the background, the current cover of forest stands.

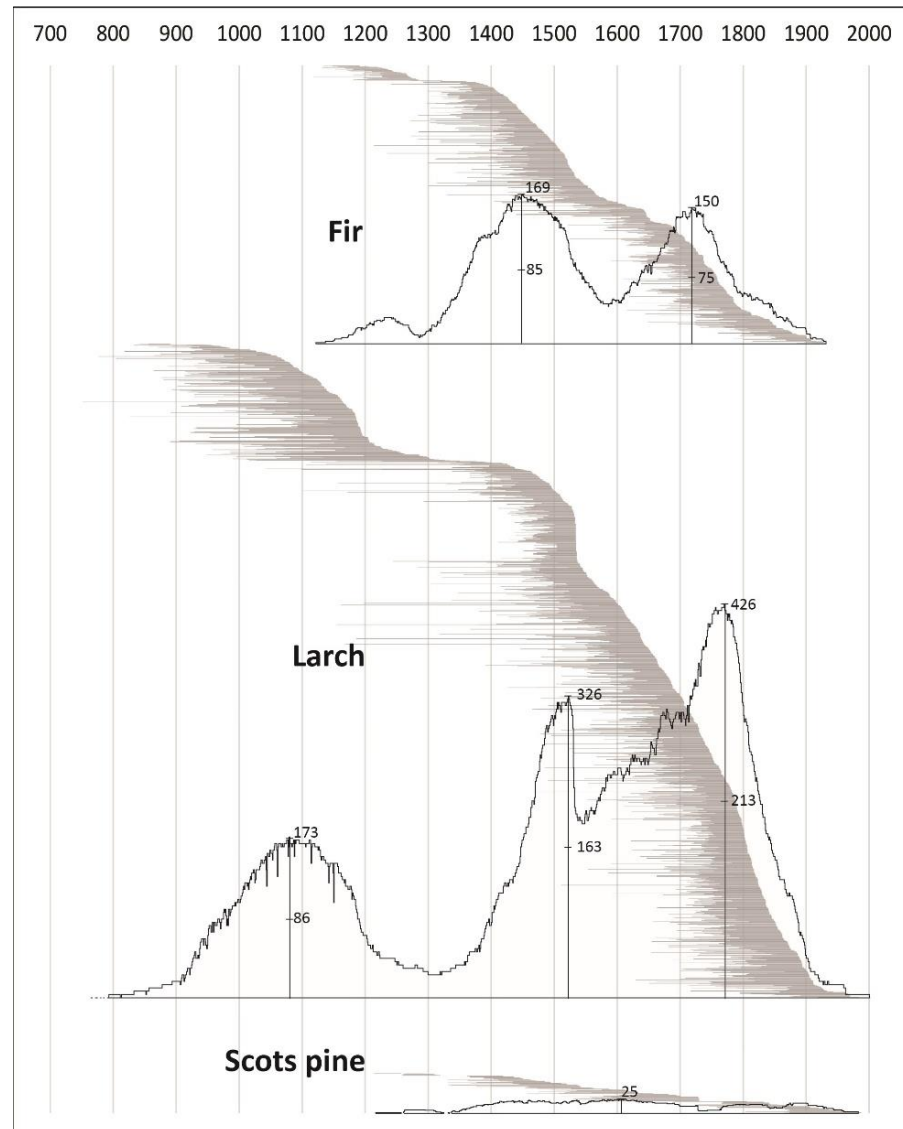
Once indexed, the curves were cross-dated using the Student test ( $t$ ). This parametric test, widely used in mathematics and archaeology, is used to compare two continuous quantitative series [36–39]. It indicates the degree of affinity between two dendrochronological series based on a correlation coefficient. In dendroarchaeology, there is no minimum threshold set for the  $t$  value for a result to be considered acceptable. Each synchronisation is different. As a general rule, values above five are adopted and those between three and five are considered on the basis of the replication of results.

On our samples, not all piths are present, but in the vast majority of cases few or no rings are missing. As the height of the sample in the tree is not exactly known, the juvenile phase may be truncated by a few years, even 10 to 20 years. However, given the large dataset at our disposal, the reading and interpretation of the studied parameters is possible.

First, we represented the fir, larch and Scots pine dendrochronological series in a block diagram (there are not enough series of spruce and Cembro pine to make it relevant)



(Figure 2). Each horizontal bar corresponds to a piece of wood, its length is a function of the number of rings preserved and thus of the age of the tree at the time of felling. These series are arranged according to their felling dates. The curves shown in transparency on the block diagram indicate, for each species, the coverage of the dendrochronological series, that is to say the number of rings available per year. The higher the value, the more data are available for the year in question.

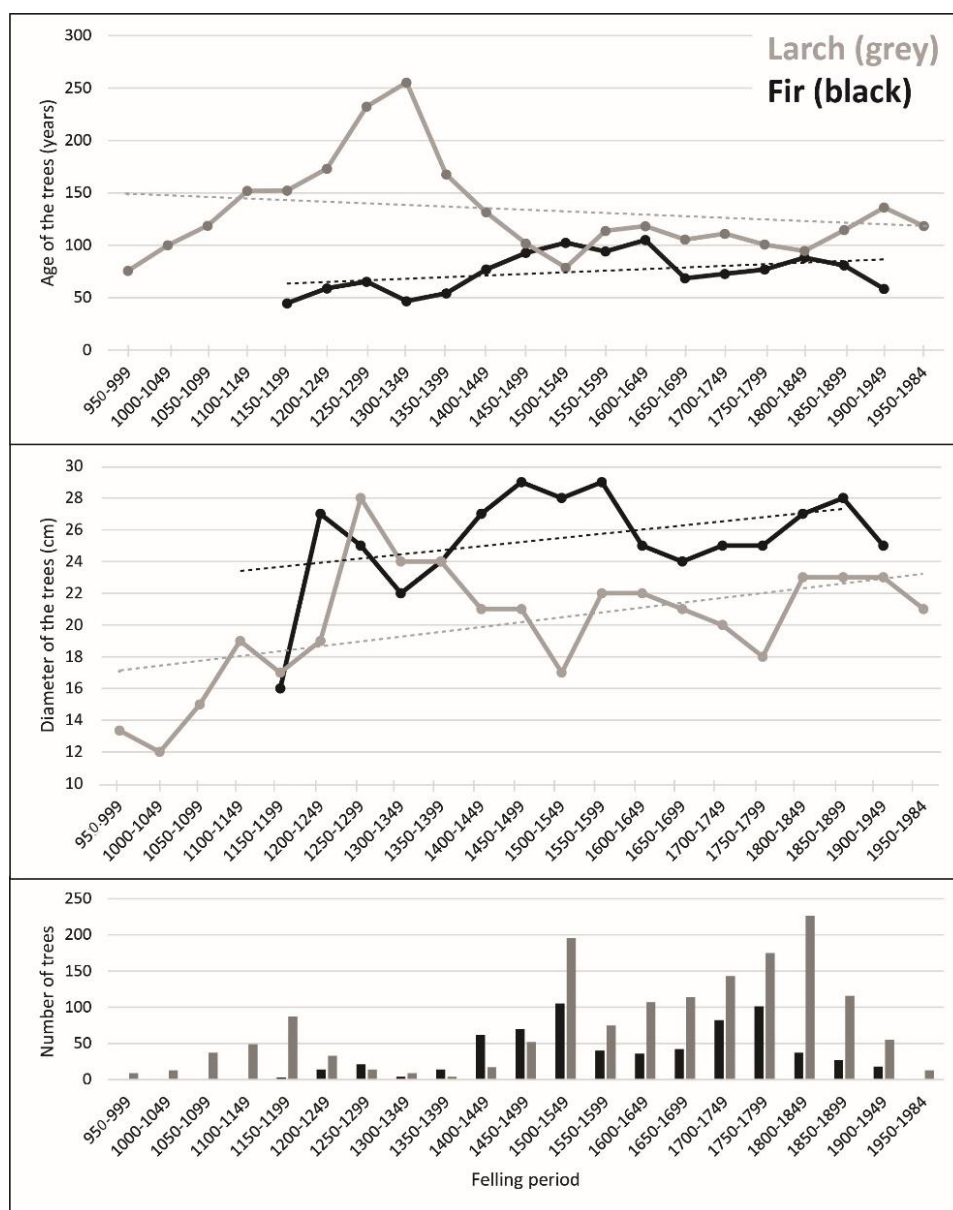


**Figure 2.** Block diagram of the 2345 individual archaeological series of dated fir, larch and Scots pine, arranged according to the felling dates. Each horizontal bar corresponds to a timber. Their coverings over time (number of rings available per year) are shown on top.

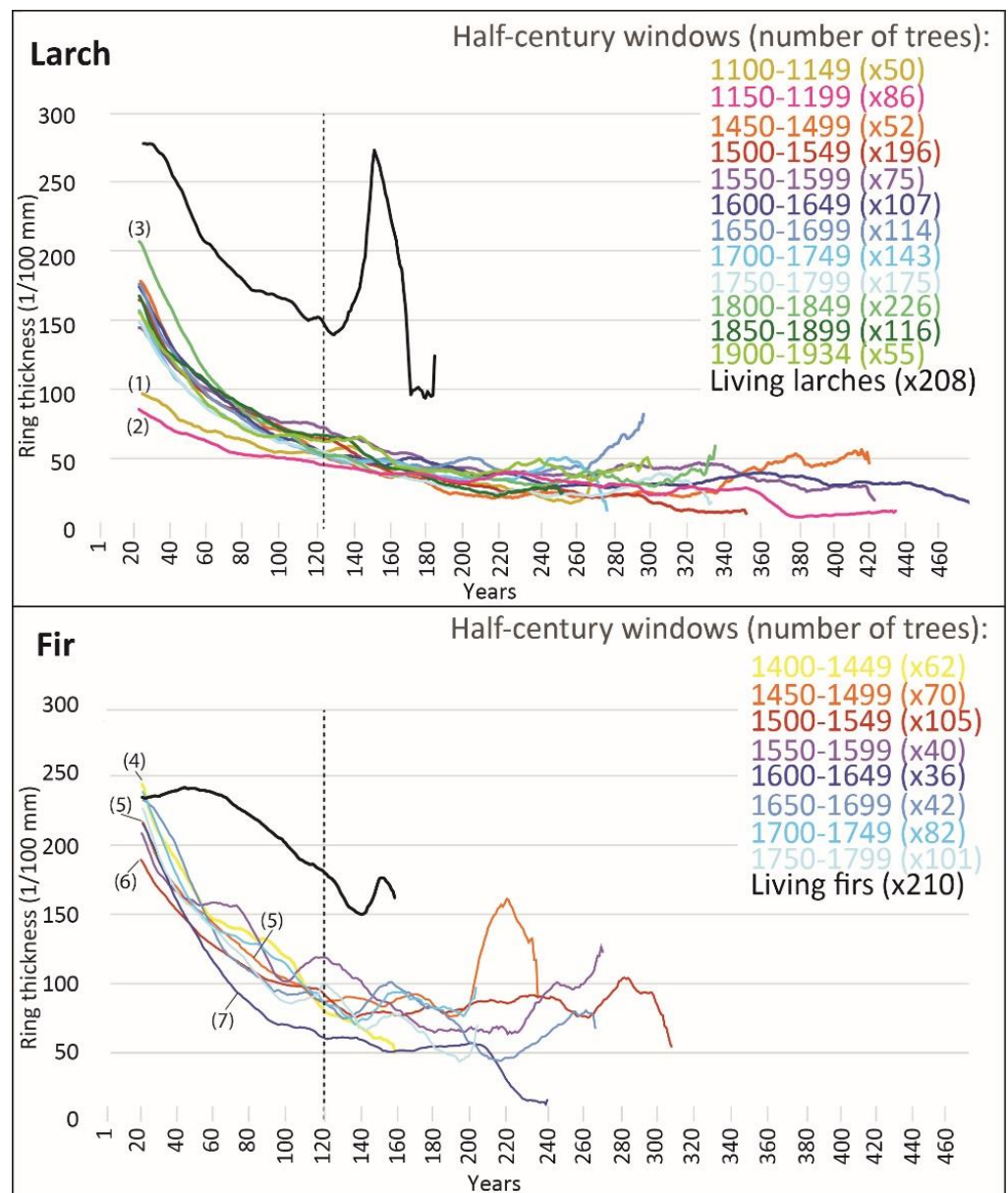
Then, we worked on larch and fir, species for which the number of series is relevant. For these species, we calculated the minimum diameters of the trees as well as their minimum cambial ages (Figure 3) and then, their age trends (Figure 4). In order to be more easily readable, all the age trends were smoothed using 20-year moving averages, which is why the curves only start at the 20th year. To calculate these age trends, trees were grouped by half-century windows, according to the date of the last ring, to make the human selection visible through the felling date. These groups were kept only if the number of trees inside was higher than 40, explaining periods without age trends. In the last part of the study, we make a geographical comparison between the two regions (Massif

Central and Alps), using only fir, with all periods combined (Figures 5 and 6). However, in this case we did not calculate fir age trends by the half century because the numbers were insufficient to be representative.

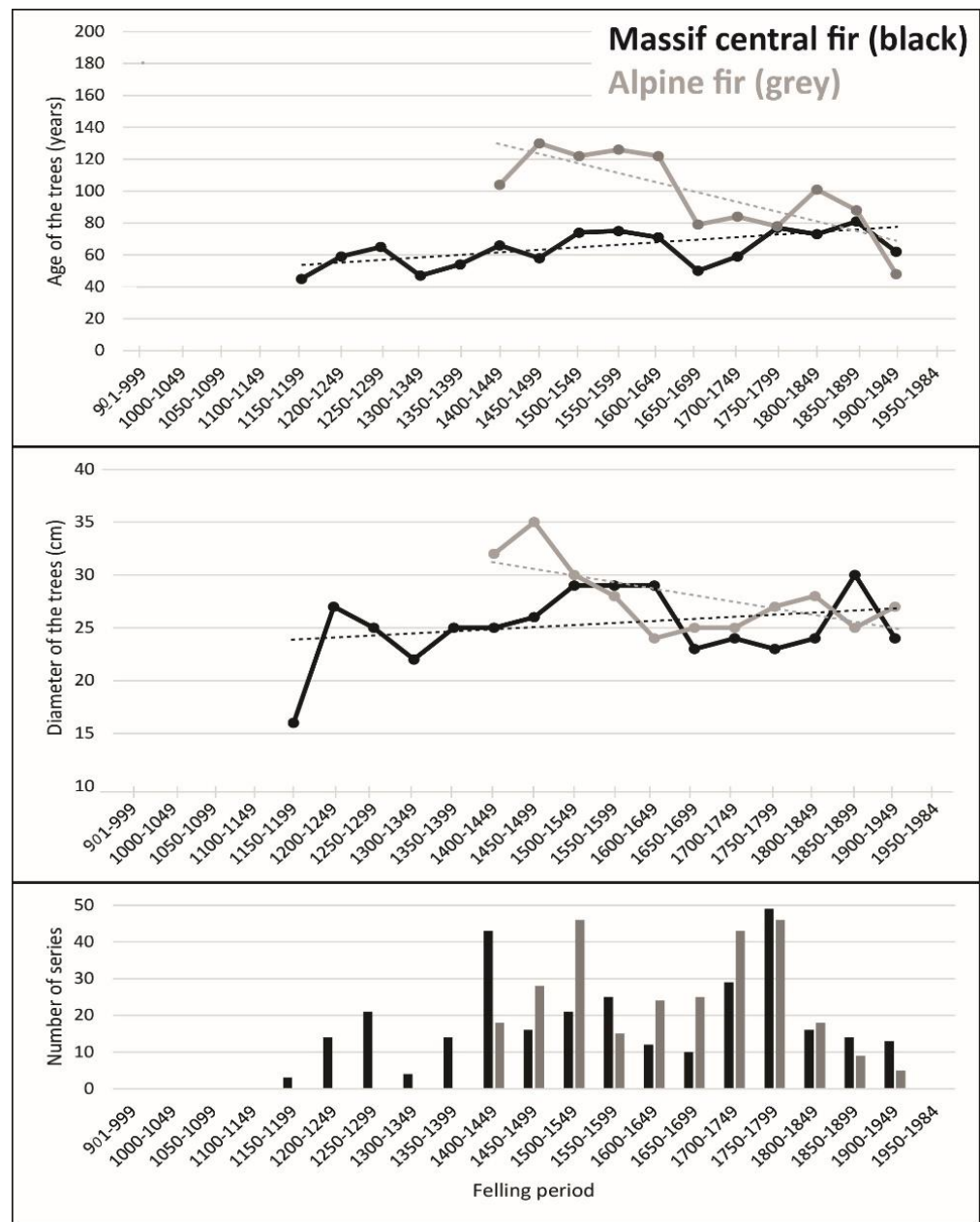
For comparison, we also used dendrochronological series from living trees: 208 series of Alpine larch, 132 series of Alpine fir and 78 series of Massif Central fir. We selected only living trees that started growing from 1850 onwards so that they reflect current growing conditions. Some of these series are published [9,40–42], others are unpublished. However, they all come from our study area and have been shown to be relevant in numerous dendrochronological studies over the last few years by providing accurate dating (The data on live fir trees collected in the Massif Central have not yet been synthesised, but this work is in progress. It takes into account the published data from [43] and also unpublished data from Loïc Francon, Lianne Gouma, Arthur Mathonnat and François Blondel.).



**Figure 3.** Comparison of the characteristics of archaeological larch (in black) and archaeological fir (in grey) over time. From top to bottom, tree age, tree diameter and number of trees, according to 50-year time windows based on the date of the last ring. In dotted lines, the associated trend curves.

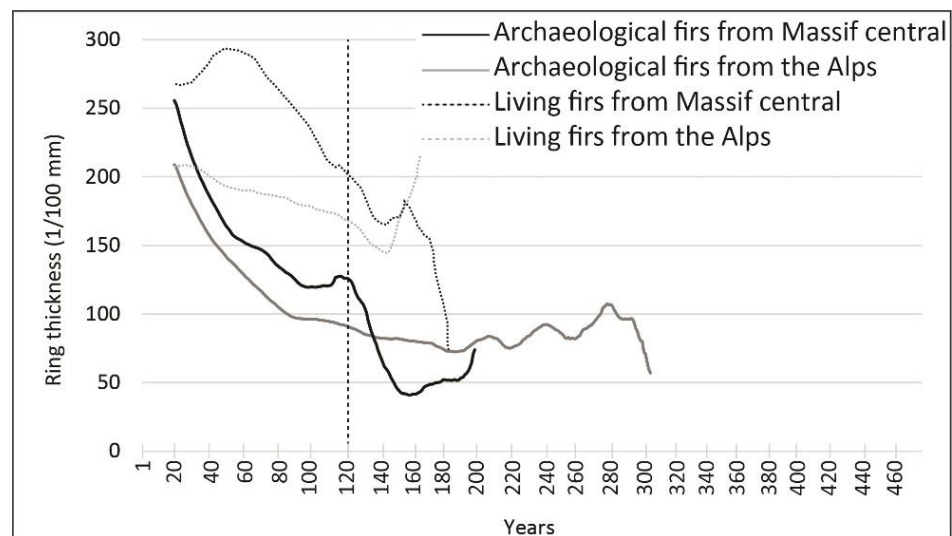


**Figure 4.** Age trends of archaeological larches (**upper part**) and firs (**lower part**) according to 50-year time windows, based on the date of their last ring, each in a different colour. The age trends of the actual trees are shown in black. After the 120th year (vertical dotted line), the age trends are less representative. The small numbers in brackets on the curves refer to explanations in the text.



**Figure 5.** Comparison of the characteristics of archaeological Alpine fir (in grey) and archaeological Massif central fir (in black) over time. From top to bottom, tree age, tree diameter and number of trees, according to 50-year time windows based on the date of the last ring. In dotted lines, the associated trend curves.





**Figure 6.** Age trends of Massif Central firs (in black) and Alpine firs (in grey). For comparison, the age trends of the current living trees are shown in dotted curves. After the 120th year (vertical dotted line), the age trends are less representative.

### 3. Results

#### 3.1. Spatial Distribution of Species Use

In the past, Scots pine and larch seem to have been used only in sites in the immediate vicinity of their growing areas in the mountains (Figure 1). Nevertheless, this is not entirely true. We have indeed identified larch in two sites close to the Mediterranean Sea, in the cities of Nice and Cannes. We also identified a few beams of Scots pine in buildings in the plain (but these beams are not dated, so they do not appear on the map). Fir is the only species used in abundance both in mountainous areas and in the plains, in buildings close to the rivers Durance (Aix-en-Provence city) and Rhône (Arles city).

#### 3.2. Felling

The block diagram (Figure 2) illustrates that there was continuous felling from the 10th century to the present, but little felling from the very end of the 13th to the end of the 14th century, for both fir and larch. It seems that the same is true for Scots pine, even if the number of trees is too small to be truly representative (only seven pre-15th century Scots pine series).

The coverage of our data (transparent curves on the block diagram) indicates that the mid-15th and early 18th centuries have the most data for the fir series, and the late 11th, early 16th and mid-18th centuries for larch. This does not necessarily mean that there was a lot of felling in these periods, but only that we have access to a large number of samples for these periods, which are particularly well represented. In contrast, the low number of felling events identified at the end of the 13th–14th century coincides with a low amount of available tree rings.

#### 3.3. Diameter-Age Correlation

Over time, the archaeological timbers (larch, fir, Massif Central fir and Alpine fir, Figures 3 and 5) show almost synchronous variations in age and diameter. This means that when age increases, diameter also increases, and vice versa. The two notable exceptions to these synchronous variations are (i) the first half of the 14th century for larch, when the age of the felled larch increased compared to the end of the 13th century, but the diameters decreased and (ii) the first half of the 20th century for Alpine fir, when their ages decreased while their diameters increased compared to the late 19th century. However, in both cases, the number consists of less than ten trees, which should be confirmed by enlarging the sample size.

If we consider the general trends of these age and diameter variations (dotted lines on Figures 3 and 5), the ages of the larches decrease slightly over time while their diameters increase (Figure 3). This means that younger and younger larches were used, but with increasing dimensions, i.e., larches that grow faster and faster. As for the firs, their ages and diameters increase slightly over time (Figure 4); thus, firs are increasingly older and larger.

### 3.4. Types of Growth

The age trend (Figures 4 and 6) of all trees decreases with age according to a classic process described by many authors for a long time [3,44–46]. After the 120th year (represented by a dotted line in the age trend figures), the number of rings included in the averages decreases significantly and the age trends are less representative. We have chosen to draw them anyway, but we did not take them into account in our reflections.

If we look at the larch (upper part of Figure 4), it is the older trees, from the 12th century that grew the slowest since their age trends (curves (1) and (2)) are lower than all the more recent ones. There is not enough data in the 13th and early 14th centuries to calculate age trends so we cannot know how the age trend changed during this time. From the 15th century to the early 20th century, larches grew more rapidly. Of all the archaeological timbers, the larches felled in the first half of the 19th century have the highest age trend (curve (3)). However, it's the current larch trees that are growing the best, better than archaeological timbers.

Concerning fir trees, the age trends of the archaeological timbers are relatively similar over time (lower part of Figure 4), however, there is a progressive decrease in age trends from the 15th to the first half of the 16th century (curves (4), (5) and (6)). Firs felled in the first half of the 17th century (curve (7)) have one of the fastest decreasing age trends: from about their 50th year they show the slowest growth ever. Like the larches, all the archaeological fir trees differ markedly from those of present-day living fir trees.

### 3.5. Massif Central et Alpes

Finally, as fir has been used in the Alps and in the Massif Central, we compared the characteristics of trees from these two regions. Age trends of firs in the Massif Central are higher than in the Alps (Figure 6). Archaeological firs, as present-day living firs, grow faster in the Massif Central than in the Alps. From an archaeological point of view, fir seems to have been used formerly in the Massif Central (from the 12th century) and it appears in Alpine buildings from the 15th century (Figure 5). From the 16th century onwards, fir diameters are comparable in both regions, but Alpine firs are older than Massif Central firs (Figure 5).

## 4. Discussion

Our current vision of the use of timber in the past is truncated because we can only study the timber that has been preserved up to now, and the timber which we sampled. Moreover, some areas are investigated more than others according to the opportunities that are offered (see Figure 1), such as certain Alpine valleys (Clarée, Bléone and Tinée) or certain urban areas (Clermont-Ferrand in the Massif Central, Aix-en-Provence in the plain). However, it is a constant issue in archaeology, trying to be as exhaustive as possible with necessarily incomplete data.

### 4.1. Locally Used and Exported Species

In the Massif Central, fir is the most commonly used wood for buildings, while larch is the most common in the Southern Alps (Figure 1). These trees were widely used in construction in the two massifs since the Middle Ages for their straightness and good mechanical properties [47]. Thus, they were employed for the structural parts of buildings, such as walls, partitions, floors and roofs. Spruce was used very little because it was not present before the 19th century plantations [48,49]. Other resinous species used in construction at high altitudes are: Scots pine in the Massif Central, fir, stone pine and Scots

pine in the Alps. These species are not visible on the map because they are in minority or not dated. If we go down in altitude, we find fir and Scots pine buildings in the pre-Alps. Then, on the plains, the buildings studied seem to be made only of fir. However, it should be noted that Scots pine is also used to some extent, but as it is still difficult to date due to a lack of reference material, so it does not appear systematically on the map. If mountain fir and Scots pine were certainly exported to lowland towns (see for example [14]), this was also the case for the larch. Larch is mainly found in the cities of the south-east, in the Alpes-Maritimes [13,50]. Anthropogenic pressure is constant at high altitude [51–53], limiting wooded areas to those that are steep, difficult to access and unsuitable for agro-pastoral activities. Ancient texts and archaeological findings attest to the exportation of Alpine larch to the plains in ancient times for shipbuilding [15,54] and in medieval times for building [17]. One may therefore wonder why it is so little visible today. This may be due to an architectural reality where larch is not used as much as it used to be, a lack of sampling in these lowland buildings and/or the disappearance of these larch elements following restoration.

#### 4.2. *Little Felling in the 14th Century*

While there has been continuous felling from the 10th century to the present day, the 14th century is an exception. This hiatus in the 14th century has already been documented for Alpine larch [55], but it also seems to exist for fir, and perhaps for Scots pine, even if the number of the latter species is too low at the moment. This low number of fellings may be linked to the decrease in the number of new constructions and therefore to the demographic and economic conditions of the time. Indeed, this period was marked by wars, famines and epidemics [7,56–59]. Moreover, F. C. Ljungqvist et al. [60] have shown that this hiatus also existed on a European scale and that it was linked to the plague episodes. This is therefore a period when the rate of new construction was clearly slowed down by a fall in population, thereby limiting the exploitation and the need for timber.

Paradoxically, although the dendro-archaeological data indicate a drop in felling from the second third of the 14th century, the written records nevertheless reveal frequent logging in this time period [17,61]. However, this exploitation can be tempered by the fact that it is perceived through restrictions on felling [27,61]. It may have taken some time to be applied in practice, especially in the rural areas of the medium and high mountains. These restrictions are found in the texts both in the mountains [27] and in the plains [61].

#### 4.3. *Assumptions and Attempts to Reconstruct Silvicultural Practices*

In our opinion, the variation in the diameters of harvested trees reflects the state of openness or closure of the environment. In fact, in open environments, diameters tend to increase, whereas in closed environments they tend to decrease. The age of the trees at the time of felling only reflects the time at which humans decided to fell them, it is not a selection criterion [62]. From the dendro-archaeological data, it seems impossible to say whether they were deliberately preserved or spared until they were felled.

The diameter and age variations of our archaeological wood are on the whole synchronous over time (diameter and age increase or decrease simultaneously). Higher values reflect indeed an opening of the environment and cutting of older trees, whereas lower values reflect a closing of the environment and cutting of younger trees. One might have expected younger trees to be felled in open areas because they grow faster (and conversely, older trees to be felled in closed areas because they grow slower), but this is not what our data showed. One explanation for this phenomenon would be a certain time lag between the causes that led to the appearance of a forest (such as population and felling increases) and the effects on trees felled later in the same forest, which have been preserved to our day (see e.g., [63] who studied old trees in open areas).

The fact that in the first half of the 16th century the larches and Alpine firs used in the constructions have smaller diameters and are younger than those used before may therefore reflect a closure of the environment and the selection of younger trees (Figure 3).

However, this could coincide with history. After the troubles of the Hundred Years' War (a succession of conflicts between France and England during the 14th and the 15th centuries), the population decreased and the forestry exploitation was reduced [64]. As a result, the forests became denser [65] and may have closed. On the other hand, the fir trees used in the Massif Central at the same time show an opposite profile: larger diameters and ages, i.e., forests that are opening up and less frequent felling. This is confirmed by pollen studies carried out in several places in the Massif Central, which indicate a clear decline in forest areas in favour of the extension of agro-pastoral activities [51,53]. The highland landscape is therefore open with heterogeneous forest areas.

The larch trees felled in the 12th century had the greatest difficulty in growing, but this low growth rate was never reached again afterwards (see curves (1) and (2) on Figure 4). These trees began to grow between 751 and 1150, i.e., during a period with cold summers in the French Alps, particularly around 840, 950, 1020 and 1120. This also corresponds to the Oort solar minimum between 1040 and 1080 [66]. This difficult climatic period does not seem to have been favourable to the growth of Alpine larches.

The number of larch trees felled in the 13th and 14th centuries that have been preserved is very small (this is why their age trends have not been calculated). The 13th century corresponds to a period of overexploitation of forests in the Massif Central [67] and to a decrease in forest species associated with an increase in cultivation in the Alps [49]. However, the diameters and ages of the larches from this period suggest that these trees, which were used during this troubled period, were particularly large and old (Figure 3). Nevertheless, this does not mean that all of the larches of that time were like this. The large size of the preserved larches may explain why they have been conserved in the buildings to this day, contrary to the smaller wood, which are more sensitive to erosion and more easily used as fuel, and whose preservation over the centuries is less obvious.

The best growth of archaeological larches is in those felled in the first half of the 19th century (1800–1849), at least until they are 60 years old (see curve (3) on Figure 4). These larches are also the ones with the largest diameters since medieval times, as well as relatively low ages. The majority of these larches started to grow between 1720 and 1740, so until 1780–1800, i.e., during their first 60 years of life, their growth conditions were very favourable. There are historical reasons for this. Indeed, the 18th century saw the intensification of forestry regulations with, for example, the obligation to restock the forests of Briançon in 1723 [68] and the “Réformation des Eaux et Forêts”, i.e., the inspection of the state of the forests in 1725, which led to felling bans [64]. This seems to have been a favourable period for the growth of young larches, which were felled about a hundred years later, in the first half of the 19th century.

As for the fir trees, their age trends over time show little variation, so it seems that these trees grew in a relatively similar way from the 15th to the 18th century (Figure 4). The slight decrease in age trends between the early 15th century and the first half of the 16th century (curves (4), (5) and (6)) is difficult to explain with our current knowledge. As early as antiquity and the Middle Ages in the Massif Central, following the overexploitation of forests at lower altitudes and the development of agro-pastoral activities, humans went to fell trees at higher altitudes [69–71]. If we consider the same case for the 15th to the 16th century, this would explain the presence of fir trees with increasingly slow growth as humans came to exploit them at higher and higher altitudes and the growing conditions up there were more difficult. It was in fact from the 16th century onwards that several pieces of legislation testify to the growing concern of the Royal power for the protection of forests. The latter is often linked to the acceleration of deforestation [64].

The numerous conflicts of the 17th century generated a very high demand for wood, especially for war fleets. It might explain why the archaeological firs felled in the first half of the 17th century (curve (7) in Figure 4) have the slowest growth of all those studied. They might have been taken from previously preserved highland and/or closed forests [72].

In general, between the 12th century and the beginning of the 20th century, the fact that the archaeological fir trees were larger and older (Figure 3), could therefore be explained by

the felling of old fir trees growing in increasingly open environments. Since access to the resource is easier than in dense and closed environments, a better selection of fir trees to be felled is therefore possible.

#### 4.4. Massif Central and Alps

The use of fir in Alpine buildings, more than two centuries later than in the Massif Central, can of course be explained by a bias in our Alpine data. However, it may also be a reality. Fir is attested to in the Alpine pollinic diagrams as early as 4686–4369 Cal BC [49], although in smaller quantities than larch and especially pine. Then also, according to palynological analyses, fir stands were destroyed between the 9th and 11th–13th centuries in some areas of the southern Alps [73]. The firs first used in the southern Alps in the 15th century do not therefore come from completely new stands, some fir trees clusters could have been preserved. In addition to the scarcity of firs from the 13th century onwards [73], a second explanation could be that before the 15th century, fir trees from the southern Alps were mainly used for export [17] and larch was preferentially used in high altitude buildings. Thus, the pre-15th century Alpine fir beams would have disappeared during the major modern restorations of lowland buildings, as in the 17th and 18th centuries in Aix-en-Provence [14].

In general, firs in the Massif Central grow faster than those in the Alps: they have similar diameters, but are felled younger than the Alpine firs, and this is reflected in their higher age trends (Figure 6). Fir exploitation may have been more intensive in the Massif Central than in the Alps. There may also have been more favourable growing conditions in the Massif Central. However, we do not know whether these are solely environmental, in particular by taking into account the altimeter factor, or whether they have been favoured by silvicultural practices, such as opening up the environment. Synthesis analyses for softwoods, and in particular fir, are still lacking for the Massif Central.

An application of this distinction could be a dendro-provenance tool. For example, the fir trees used in the lowland buildings of the lower Rhone valley, such as in Avignon city [22], can come from both the Massif Central and the Alpine forests. Their age trends could thus be a good tool for hypothesising their provenance.

## 5. Conclusions

At the end of this study, there are three perspectives envisaged. The first concerns the need to carry out specific dendroarchaeological research in the range of the Alpine fir, i.e., in the montane level, in order to confirm or disprove its absence in buildings before the 15th century. The second perspective would be to provide better information on silvicultural practices based on the timber (Scots pine and fir) for the Massif Central area. The comparison of dendrochronological corpuses has indeed shown a data gap between the Massif Central and the Alps. The third perspective would be a detailed study of the characteristics of the wood used in different types of buildings, according to their location (rural or urban) and their category (civil or religious). This would allow the identification of potential differences in supply and quality, depending on the final destination of the timber.

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