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ORIGINAL ARTICLE

# Changes in Pyrenean woodlands as a result of the intensity of human exploitation: 2,000 years of metallurgy in Vallferrera, northeast Iberian Peninsula

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**Abstract** This research is based on the discovery of a large number of charcoal kiln sites and abandoned iron mines in Vallferrera (Axial Pyrenees, northeastern Spain). The study reveals that this region has been affected by the metal mining and smelting industry for at least 2,000 years, with maximum intensity in the eighteenth and nineteenth centuries, followed by abandonment of the activity. The region's woodland dendrochronology and historical records indicate that exploitation of wood charcoal for metalworking affected the past vegetation in the area and impeded the development of mature woodland. Our findings suggest that the greatest changes in vegetation and landscape history occurred at times of particular specialization in socioeconomic activities.

**Keywords** Late Holocene · Pyrenees · Palaeometallurgy · Charcoal kilns · Dendrochronology · Archival documentation

## Introduction

Recent studies show how anthracological (charcoal identification) research on the distribution of charcoal kiln sites provides a good palaeoenvironmental record of the impact of human activity on woods (Bonhôte et al. 2002; Ludemann 2003; Ludemann et al. 2004). The sites are especially useful for interpreting areas with abandoned metallurgical activity, because of its high consumption of wood charcoal (Davasse 2000), in the same way that they are a good archaeobotanical complement to multidisciplinary studies of environmental history (Davasse and Galop 1990; Davasse et al. 1997; Galop et al. 2002; Pèlachs and Soriano 2003; Monna et al. 2004; Pèlachs 2006; Vernet 2006).

One of the primary questions that palaeoecology attempts to resolve is the extent to which changes in the landscape are a consequence of human activity or of the internal dynamics of the natural system (Riera et al. 2004). This question is less problematic when there is some kind of evidence that relates human activity with woodland exploitation. Therefore, the study of the kiln sites contributes to resolving this research question and clearly shows that an activity such as charcoal production affects the woodland (Vernet 1997; Davasse 2000). The task, then, is to determine how far back in history it is possible to use charcoal studies to explain changes in the natural environment. Various multidisciplinary studies in places with a history of metallurgy show how the consequences of this activity can be traced back for millennia (Jouffroy et al. 2007; Bal 2006).

This article presents the results of an interdisciplinary study conducted in an abandoned mining area on the southern slopes of the Pyrenees at Bosc de Virós, Vallferrera, with the primary objective of determining: (1) the moment at which the impact of metallurgy took on importance in the composition, distribution and structure of the woods and (2) the origins of the woodland structure.

The study region was selected on the basis of numerous available sources of information: existing data on the potential age of the valley's metallurgical exploitation, which gives Vallferrera its name from the late Latin, *valle ferraria*, meaning a valley where iron is produced (Sancho

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1999); a review of places that dated charcoal intermixed with iron ore to 1770 ±40 years B.P. [cal A.D. 147–(253, 304, 314)–388] at the oldest dated site (Davasse 2000); historical data showing continuous metalworking activity from the eighteenth into the nineteenth century in this region (Bringué 1995; Esteban et al. 2003; Mas 2000) and published recommendations that the study of historical documentation be undertaken at the municipal administrative level or above to gather useful information about the region's natural surroundings (Panareda and Llimargas 1989; Marugan 2001), with special attention to the scale of analysis (Burt 2003).

## Regional characteristics

The study area lies in the northeastern part of the Iberian Peninsula, in an area near the borders of Spain, France and Andorra (Fig. 1). Vallferrera is on the southern slopes of the central Pyrenees. Its structural characteristics are determined by a syncline of Hercynian age which is orientated approximately east-west, with an axial plane that opens to the north with abundant minor folds and the presence of a few faults that later rotated during the Alpine orogeny. Figure 1 shows the main geological features of the region that is most characterized by schists (Poblet 1991). The primary mineral deposits in the area are from the Cambro-Ordovician period and are in faults associated with quartz veins, from which pyrite and calcareous pyrite were extracted (Mata-Perelló and Riba 1995) (Fig. 1).

The area studied is located at the transition between the Mediterranean and Atlantic climate zones. Average precipitation varies with the altitude, from 700 to 1,100 mm/year, while the average temperature varies from 10.1°C at the base of the valley (900 m a.s.l.) to −2.3°C at the highest point (2,700 m a.s.l.). The warmest month is July and the coldest is January, with average temperatures of 10.2°C to 19.3°C and −7.2°C to −2.7°C, respectively, according to estimates based on data in the *Digital Atlas of Catalonia* (Fig. 2; Ninyerola et al. 2000).

This valley is characterized by a dominant presence of *Pinus sylvestris* (Scots pine), combined with some isolated *Betula pendula* (silver birch) and more open areas with the shrubs *Cytisus oromediterraneus* and *Juniperus communis* ssp. *nana* (dwarf juniper) and grasslands of the vegetation

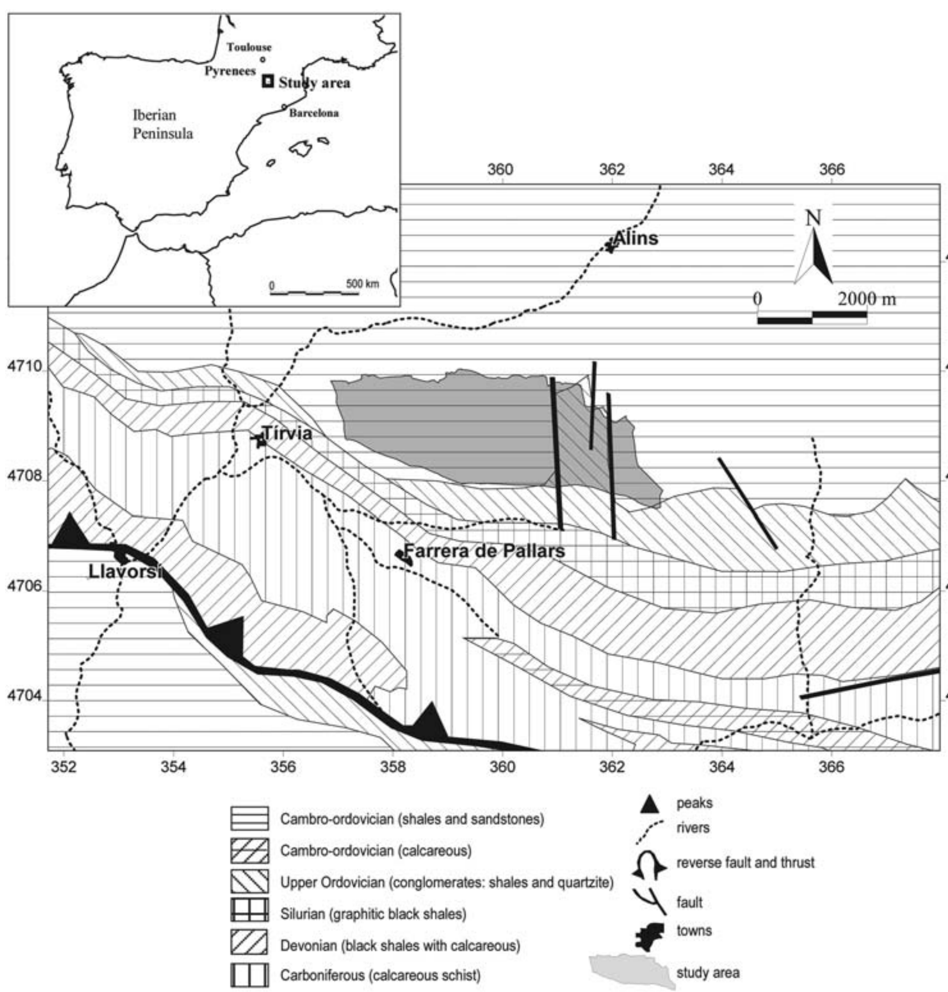


**Fig. 1** Site map showing the Bosc de Virós and the main geological features of this axial Pyrenean region

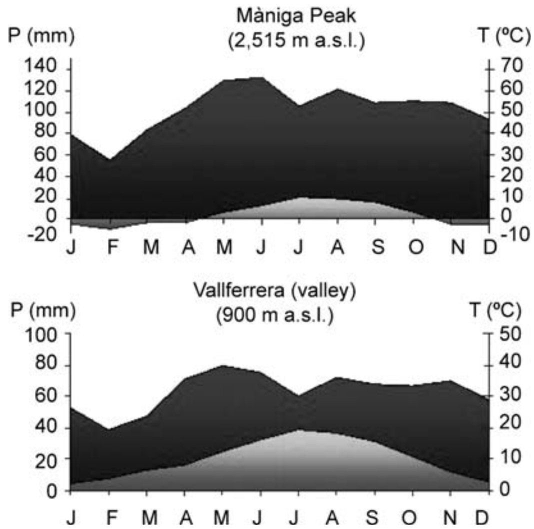


**Fig. 2** Diagram showing temperatures and precipitation, based on meteorological data from a ground station close to Vallferrera (Ninyerola et al. 2000)

order Brometalia erecti. Higher levels are dominated by *Pinus mugo* ssp. *uncinata* (dwarf mountain pine) (ICC 1999).

## Study area

Within Vallferrera, a large wooded area of 1,966 ha known as the Bosc de Virós occupies the entire northwest slope, extending from the valley floor at about 900 m to the ridge at more than 2,500 m. The range of altitude, more than 1,500 m, produces diverse bioclimatic environments. Plants appropriate to ravine vegetation are found along the river at the base of the valley, including *Fraxinus excelsior* (ash), *Corylus avellana* (hazel) and some *Quercus humilis* (deciduous oak) together with other deciduous taxa such as *Ulmus minor* (elm) and *Salix alba* (white willow), which surround a few cultivated fields that take advantage of the riverbanks. At about 1,100–1,200 m, *Pinus sylvestris* takes over abandoned agricultural areas and occupies the space of the oak and other deciduous trees. Between 1,500 and 1,800 m, *Abies alba* (fir) is dominant at various spots, although it shares the space with *Pinus sylvestris*. Between 1,600 and 1,800 m, the undergrowth has a great variety of trees: along with the pines there are also *Betula pendula*, *Abies alba* and a small but dominant patch of *Fagus sylvatica* (beech). *Pinus mugo* ssp. *uncinata* woods occupy the area above 1,800 m and only a few small highland meadows and rocky zones without vegetation break up the dominance of these pine woods all the way to the top of Màniga, the highest point in the study zone.

Bosc de Virós has a relatively moderate relief with an average incline between 10° and 25°, which is the product of contact between the dip to the north of the Cambro-Ordovician and Silurian materials of the Pallarès dome and the southern flank of the syncline, which resulted from the Alpine orogeny (Fig. 1). The slope, together with the effects of glaciation, has permitted large accumulations of sedimentary materials that, at the end of the Post-glacial period, supported the formation of rich, well-developed soils. The lower evapotranspiration and the greater moisture retention of shaded areas have also encouraged the establishment of a diverse woodland there.

# Materials and methods

## The study of charcoal kiln sites

The methodology for the anthracological study of charcoal kiln sites is well defined (Bonhôte et al. 2002; Chabal 1997; Davasse 2000; Dubois et al. 1997; Izard 1999; Vernet 1997). The distribution of sites, based on this research, shows the intensity and areas of changes to the landscape, supported by records available in public administration archives.

### *The charcoal kiln site inventory*

Within the 925 ha Bosc de Virós, the inventory of charcoal kiln sites began at an altitude of 1,200 m in an effort to exclude the greatest possible number of previously cultivated fields, and ended at 2,515 m, which is above the currently wooded area and includes the uppermost charcoal production sites. The area selected for this study was chosen to represent all of the main woodland types of the mountain and subalpine belt with *Pinus mugo* ssp. *uncinata*, *P. sylvestris*, *Abies alba*, *Fagus sylvatica* and *Betula pendula*, and the greatest possible number of iron mines.

The fieldwork to locate charcoal kiln sites was conducted on foot, with a *Trimble Pocket Pathfinder* GPS at an accuracy <1 m. The goal was to establish a descriptive profile, compiling the dimensions, current vegetation and principal characteristics of each site (Izard 1992). This approach located 942 kiln sites, distributed from 1,200 to 2,230 m. 15 of these sites also had evidence of direct production of iron ore as slag piles, in an area with evidence of more than 89 mine entrances and 15 huts related to the mines or to metallurgy in general (Fig. 3).

### *Site selection*

The 942 kiln sites were classified by size and current vegetation type, and a random sample was drawn from these categories. Table 1 reflects the dominant presence of

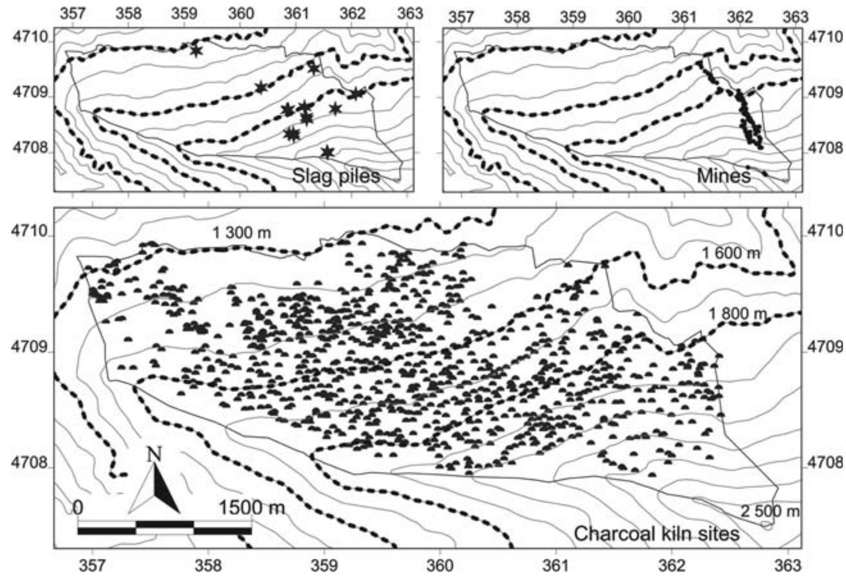


**Fig. 3** Distribution of charcoal kiln sites, mines and slag piles in the Bosc de Virós

*Pinus sylvestris* between 1,200 and 1,599 m, a mix of *P. mugo* ssp. *uncinata*, *Abies alba*, *Fagus sylvatica* and *P. sylvestris* between 1,600 and 1,799 m and the dominant presence of *P. mugo* ssp. *uncinata* between 1,800 and 2,230 m. Figure 4 shows the distribution of these trees. To test the hypothesis that the sizes of the charcoal kilns were directly related to the quantity of charcoal produced in them, they were measured in 1 m increments and grouped into four types: the smallest, 3–5 m long (type A); two medium sizes, 6 m and 7–8 m long (types B and C, respectively) and larger kilns, 9 m or longer (type D). Table 2 shows the number of sites studied in each category.

*Sample collection*

An adaptation of the methodology of Davasse (2000) was used at Bosc de Virós. A 0.5 m$^2$ hole was dug, slightly off-centre in the charcoal kiln, seeking the maximum depth of rubefaction, or soil discolouration related to high temperatures, while avoiding the mixture of carbons in the centre of the charcoal kiln. From each hole, samples were taken at 5 cm depth intervals until the base was reached, whether bedrock or other materials at the lowest levels affected by the heat of the kiln.

Only the lowest levels of each kiln site were used for laboratory analysis, manually sieved using three sizes of screen, 5 mm, 2 mm and 0.5 mm. This permitted the classification of the charcoal and recovery of samples larger than 5 mm, which were used for $^{14}$C dating.

*$^{14}$C dating*

$^{14}$C dating was performed on 32 randomly selected samples. Altitude categories were unequally represented as a result of variations in the diversity of taxa (Fig. 4) and to guarantee that kiln sites of all sizes would be represented in each altitude category (Table 3).

Random sampling was complemented by charting the location of slag piles around well-defined charcoal kiln sites, permitting the design of an altitude transect of five charcoal kilns (Fig. 3) containing all of the characteristics considered in structuring the random sample. This approach was intended to guarantee the dating of the kilns, since direct smelting of iron ore near the mines is a very

**Table 1** The current composition of tree species growing around the charcoal kilns at three altitude ranges, given as absolute values and percentage of sites

| Altitudes (m) | Charcoal kilns | Species present in the charcoal kilns | | | | |
|---|---|---|---|---|---|---|
| | | *Abies alba* (Aa) | *Fagus sylvatica* (Fs) | *Pinus sylvestris* (Ps) | *Pinus mugo* ssp. *uncinata* (Pu) | *Betula pendula* (Bp) |
| 1,200–1,599 | 414 | 75 (18%) | 92 (22%) | 401 (97%) | 5 (1%) | 39 (9%) |
| 1,600–1,799 | 311 | 214 (69%) | 175 (56%) | 159 (51%) | 133 (43%) | 20 (6%) |
| 1,800–2,230 | 217 | 36 (17%) | 6 (3%) | 4 (2%) | 211 (97%) | 33 (15%) |
| Total | 942 | | | | | |

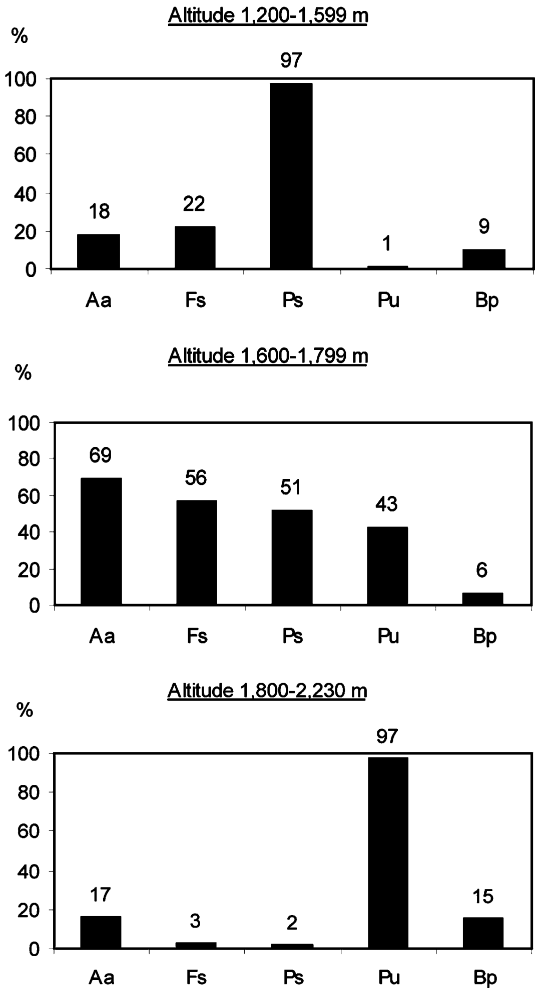


**Fig. 4** The current composition of tree species growing around the charcoal kiln sites at three altitude ranges, given as percentage of sites. Aa, *Abies alba*; Fs, *Fagus sylvatica*; Ps, *Pinus sylvestris*; Pu, *Pinus mugo* ssp. *uncinata*; Bp, *Betula pendula*

**Table 2** Sizes of charcoal kilns at three altitude ranges

| Altitudes (m) | Charcoal kilns | Types of the charcoal kilns | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| 1,200–1,599 | 414 | 41 | 246 | 114 | 13 |
| 1,600–1,799 | 311 | 20 | 185 | 83 | 23 |
| 1,800–2,230 | 217 | 14 | 85 | 66 | 52 |
| Total | 942 | 75 | 516 | 263 | 88 |

*A* 3–5 m, *B* 6 m, *C* 7–8 m, *D* 9 m or more in length

old practice (Cantelaube 2002; Dubois 2002), and Davasse (2000) has shown a relationship between slag and the late Roman age based on $^{14}$C dating of only one site (Fig. 5). A total of 37 charcoal kilns were dated using the conventional radiometric technique and $^{14}$C accelerator mass spectrometry (Table 4 and Fig. 5).

**Table 3** Number of charcoal kiln sites chosen for sampling, by altitude and size

| Altitudes (m) | Charcoal kiln sites | A | B | C | D | Total |
|---|---|---|---|---|---|---|
| 1,200–1,599 | 414 | 1 | 5 | 2 | 1 | 9 |
| 1,600–1,799 | 311 | 1 | 9 | 4 | 1 | 15 |
| 1,800–2,230 | 217 | 1 | 3 | 2 | 2 | 8 |
| Total | 942 | 3 | 17 | 8 | 3 | 32 |

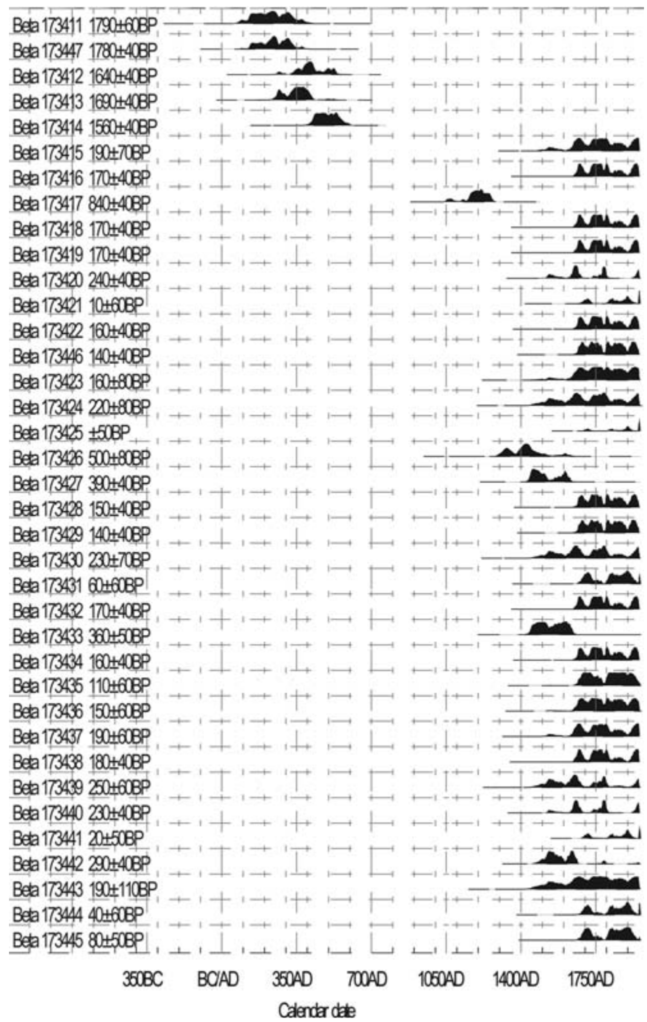


**Fig. 5** Radiocarbon dating results for Bosc de Virós samples

## Dendrochronological analysis

The dendrochronological study was conducted throughout the entire community property of Virós d'Araós, a homogeneous entity from a public administration perspective and therefore subject to the same woodland management through time. In addition, all four main species were represented in the woodland around Virós d'Araós: *Pinus mugo* ssp. *uncinata*, *P. sylvestris*, *Abies alba* and *Fagus sylvatica*, allowing a determination of the ages of various

**Table 4** Results of radiocarbon dating of wood charcoal at 37 charcoal kiln sites in Bosc de Virós

| Kiln site number | Sample code Beta | Age (yr BP) | Cal age (A.D.)[a] | Intercepted age cal A.D. | Media probability[b] |
|---|---|---|---|---|---|
| SLAG I | 173411 | 1790 ± 60 | 90–400 | 240 | 234 |
| SLAG II | 173447 | 1780 ± 40 | 130– 370 | 240 | 247 |
| SLAG III | 173412 | 1640 ± 40 | 340–530 | 410 | 414 |
| SLAG IV | 173413 | 1690 ± 40 | 250–430 | 380 | 353 |
| SLAG V | 173414 | 1560 ± 40 | 410–600 | 530 | 492 |
| 0 | 173415 | 190 ± 70 | 1520–1950 | 1670–1780–1800 | 1771 |
| 1 | 173416 | 170 ± 40 | 1650–1950 | 1680–1770–1800–1940–1950 | 1778 |
| 2 | 173417 | 840 ± 40 | 1060–1270 | 1210 | 1200 |
| 3 | 173418 | 170 ± 40 | 1650–1950 | 1680–1770–1800–1940–1950 | 1778 |
| 4 | 173419 | 170 ± 40 | 1650–1950 | 1680–1770–1800–1940–1950 | 1778 |
| 5 | 173420 | 240 ± 40 | 1530–1950 | 1660 | 1666 |
| 6 | 173421 | 10 ± 60 | Modern | Modern | 1852 |
| 7 | 173422 | 160 ± 40 | 1660–1950 | 1680–1740–1800–1930–1950 | 1784 |
| 8 | 173446 | 140 ± 40 | 1660–1950 | 1680–1730–1810–1930–1950 | 1809 |
| 9 | 173423 | 160 ± 80 | 1530–1960 | 1680–1740–1800–1930–1950 | 1786 |
| 10 | 173424 | 220 ± 80 | 1480–1950 | 1660 | 1737 |
| 11 | 173425 | 0 ± 50 | Modern | Modern | 1875 |
| 12 | 173426 | 500 ± 80 | 1300–1620 | 1420 | 1419 |
| 13 | 173427 | 390 ± 40 | 1430–1630 | 1470 | 1503 |
| 14 | 173428 | 150 ± 40 | 1660–1950 | 1680-1740–1800–1930–1950 | 1800 |
| 15 | 173429 | 140 ± 40 | 1660–1950 | 1680–1730–1800–1930–1950 | 1809 |
| 16 | 173430 | 230 ± 70 | 1490–1950 | 1660 | 1717 |
| 17 | 173431 | 60 ± 60 | Modern | Modern | 1838 |
| 18 | 173432 | 170 ± 40 | 1650–1950 | 1680–1770–1800–1940–1950 | 1778 |
| 19 | 173433 | 360 ± 50 | 1440–1650 | 1500 | 1544 |
| 20 | 173434 | 160 ± 40 | 1660–1950 | 1680–1740–1800–1930–1950 | 1784 |
| 21 | 173435 | 110 ± 60 | 1660–1960 | 1700–1720–1820–1840–1880–1920–1950 | 1823 |
| 22 | 173436 | 150 ± 60 | 1650–1950 | 1680–1740–1810–1930–1950 | 1800 |
| 23 | 173437 | 190 ± 60 | 1530–1950 | 1670–1780–1800 | 1773 |
| 24 | 173438 | 180 ± 40 | 1650–1950 | 1670–1770–1800–1940–1950 | 1775 |
| 25 | 173439 | 250 ± 60 | 1490–1950 | 1650 | 1654 |
| 26 | 173440 | 230 ± 40 | 1530–1950 | 1660 | 1740 |
| 27 | 173441 | 20 ± 50 | Modern | Modern | 1860 |
| 28 | 173442 | 290 ± 40 | 1490–1660 | 1640 | 1571 |
| 29 | 173443 | 190 ± 110 | 1460–1960 | 1670–1780–1800 | 1751 |
| 30 | 173444 | 40 ± 60 | Modern | Modern | 1844 |
| 31 | 173445 | 80 ± 50 | Modern | Modern | 1838 |

[a] Calibration 2 sigma, 95% (Stuiver et al. 1998)

[b] Calib Rev. 5.1 beta (Stuiver and Reimer 1993)

trees in an area that was also homogeneous from geological and ecological points of view (ADF 2002a, b).

*Woodland plots*

Field work conducted in 2002 and photointerpretation of the 1993 1:5,000 scale orthophoto map using the Miramon program (Pons 2002) allowed identification of woodland patches with equal coverage and a variety of areas with homogeneous vegetation, for a total of 496 homogeneous patches.

*Sampling and sample extraction*

Within each patch, one 314 $m^2$ sample plot (20 m in diameter) was selected to gather an inventory of species by diametric class at 2 cm intervals. Tree size was recorded at a height of 1.30 m (Burriel et al. 2004). When the inventory was complete, at least two and not more than five trees were selected for each species and diametric class in the plot; these were drilled with a 5 mm Pressler auger to gather evidence of the growth rings. Wherever possible, the wood sample was collected in a north–south or south–north direction and in a favourable part of the incline.

*The ages of trees*

The approximate number of growth rings in each wood sample was determined (Schweingruber 1988), recognizing that it takes a few years for the tree to reach the height at which the sample was extracted and also that when extracting a sample it is difficult to locate heartwood (Burriel et al. 2004).

Data from public documents

Municipal documents of the town of Alins, housed in the historical archives of Sort *comarca* (AHCSo), were useful in selecting a variety of information about the exploitation of natural resources in the smaller communities of Ainet d'Araós and Ainet de Besan, which own the Virós woodlands. During archival research, a variety of interesting information was found in the following sections: *General Administration*, particularly the books containing minutes of local government meetings; *Finance*, particularly land records and annual budgets, which contain various information about fires; auctions of wood, timber, and animal; illegal exploitation of woodland products, etc.; *Public Health*, with references to sanitary and veterinary inspections that reveal the numbers of some types of domestic animals, such as in the records of home butchering of pigs; *Construction and Public Works*, with references to various infrastructure elements that could be related to woodland use, since an extensive network of roads was needed to remove cut trees from the woods; *Public Safety*, which contains details about the inhabitants of the area and a description of their trade or employment, which in turn gives insight into woodland practices; *Military Service,* with its description of the goods subject to military requisition that shows how wood and metal were valued at the end of the Civil War; and *Agropastoral Services*, the most useful section of all, with its broad range of information related to herding, in particular, but also to agriculture and woodland management.

The time period covered by these documents begins in the nineteenth century, although the quantity and quality of the information increases after the end of the Spanish Civil War in 1939, probably as a result of the greater discipline and administrative control that resulted but also because information was lost and/or destroyed during the war.

## Results

The age of the charcoal

The 37 $^{14}$C-dated charcoal kilns (Table 4, Fig. 5) allowed us to establish various periods of human activity and to relate them to the location and size of each kiln. We identified three time periods to measure the intensity of charcoal-producing activity (Table 5):

(a) Cal A.D. 90 to 600: All five of the kiln sites identified in this group were active between the decline of the Roman Empire (late Roman Period) and the beginning of the early Middle Ages. The slag piles next to these charcoal kilns show that there was direct smelting of iron at the mine in the third and fourth centuries in the Bosc de Virós, although the activity was of low intensity.

(b) Cal A.D. 1060 to 1660: All five charcoal kilns from this period are from the late Middle Ages and the early modern age. The oldest site is from the thirteenth century (cal A.D. 1210) and the most recent from the seventeenth century (cal A.D. 1660). The intensity of the activity was low to medium.

(c) Cal A.D. 1660 to 1950 (including out of range or modern): most of these 27 charcoal kilns were active from cal A.D. 1660 until 1950. Therefore, the period from the end of the seventeenth and beginning of the eighteenth century until the twentieth century, with very highly intense activity, is related to the metallurgy boom and the installation of various ironworking sites or forges in the valley. Six kilns were dated to 1950 and are therefore considered twentieth century sites. Their intensity is low.

In addition, from cal A.D. 530 to 1060, a notable absence of charcoal samples seems to demonstrate a drastic reduction in activity during that period.

With respect to altitude, the results demonstrate that the relationship between the sites and the intensity of charcoal production has varied a great deal throughout history:

(a) In all three of the periods identified, charcoal production occurred at all of the altitudinal range categories for the various tree species.

(b) During the late Roman period, based on the location of the kiln sites associated with slag piles (Fig. 3) and the $^{14}$C dating, it is possible to conclude that charcoal production was most intense above 1,800 m, where it is likely that the iron mines were concentrated.

**Table 5** Altitudes and lengths (type) of charcoal kiln sites at specific points in history

From cal A.D. 90 to 600
Late Roman Period

| Beta Code | Beta-173411 | Beta-173414 | Beta-173413 | Beta-173412 | Beta-173447 |
|---|---|---|---|---|---|
| Altitude (m) | 1,317 | 1,587 | 1,764 | 1,956 | 2,175 |
| Length (m) | 10 (type D) | 8 (type C) | 8 (type C) | 12 (type D) | 6 (type B) |

From cal A.D. 1060 to 1660
Late Middle Ages–Early Modern Age

| Beta Code | Beta-173442 | Beta-173427 | Beta-173433 | Beta-173426 | Beta-173417 |
|---|---|---|---|---|---|
| Altitudes (m) | 1,495 | 1,604 | 1,648 | 1,669 | 1,923 |
| Length (m) | 6 (type B) | 7 (type C) | 6 (type B) | 7 (type C) | 10 (type D) |

From cal A.D. 1660 to 1950
Modern Age (Forge Boom)–20th century

| Beta Code | Beta-173445 | Beta-173415 | Beta-173441 | Beta-173440 | Beta-173443 | Beta-173439 | Beta-173444 |
|---|---|---|---|---|---|---|---|
| Altitudes (m) | 1,387 | 1,391 | 1,476 | 1,497 | 1,520 | 1,535 | 1,547 |
| Length (m) | 5 (type A) | 10 (type D) | 6 (type B) | 6 (type B) | 6 (type B) | 8 (type C) | 6 (type B) |
| Beta Code | Beta-173438 | Beta-173437 | Beta-173436 | Beta-173432 | Beta-173435 | Beta-173434 | Beta-173431 |
| Altitudes (m) | 1,551 | 1,603 | 1,659 | 1,680 | 1,684 | 1,714 | 1,714 |
| Length (m) | 7 (type C) | 5 (type A) | 6 (type B) | 6 (type B) | 6 (type B) | 6 (type B) | 6 (type B) |
| Beta Code | Beta-173430 | Beta-173424 | Beta-173428 | Beta-173423 | Beta-173429 | Beta-173425 | Beta-173420 |
| Altitudes (m) | 1,717 | 1,740 | 1,757 | 1,763 | 1,788 | 1,791 | 1,816 |
| Length (m) | 6 (type B) | 8 (type C) | 6 (type B) | 10 (type D) | 6 (type B) | 7 (type C) | 6 (type B) |
| Beta Code | Beta-173421 | Beta-173419 | Beta-173418 | Beta-173422 | Beta-173446 | Beta-173416 | |
| Altitudes (m) | 1,841 | 1,854 | 1,893 | 1,935 | 1,990 | 2,004 | |
| Length (m) | 6 (type B) | 7 (type C) | 8 (type C) | 6 (type B) | 5 (type A) | 10 (type D) | |

(c) During the Middle Ages, on the other hand, charcoal production was concentrated at an intermediate altitude of 1,600–1,799 m.
(d) In the modern age, the intensity of charcoal production was much higher all over the entire slope and there is no apparent difference between the various altitudinal ranges.

The dimensions of charcoal kiln sites in relationship to various points in history can be described as follows:

(a) The three small-sized charcoal kiln sites analysed (Type A: 3–5 m long) are from the most recent charcoal-producing time periods. No small sites from earlier times were found. If these results are compared with the 6 m kilns (Type B), we observe that they were not abundant in earlier time periods either.
(b) Medium-sized charcoal kiln sites, Types B and C, were found to some extent in all historic periods. During the "forge boom", Type C (7–8 m long) was the most abundant ($\sim$40%).
(c) Larger kiln sites (9 m or longer, Type D) were found during the "forge boom", but this size has also been dated to the late Roman period and the late Middle Ages.

## The age of the wood

The 496 homogeneous patches in the Virós d'Araós wood made it possible to determine the maximum and minimum ages of 366 *Pinus sylvestris*, 74 *Abies alba*, 62 *P. mugo* ssp. *uncinata* and 19 *Fagus sylvatica* (Table 6).

Although the average life expectancy of *Pinus mugo* ssp. *uncinata* can be 500–600 years, of *P. sylvestris* 600 years and *Abies alba* 400 years (Costa et al. 1998), the majority of the individual trees which were sampled began their life during the twentieth century, except for the *Abies alba*, which dated to the end of the nineteenth century. This confirms the idea that this is a woodland of young trees. Even though individual *Pinus mugo* ssp. *uncinata* were dated to 1835, *P. sylvestris* to 1822, *Abies alba* to 1789 and *Fagus sylvatica* to 1907, none of these pre-date the maximum charcoal production period. The majority of the individuals that were alive prior to 1900 are located at an altitude between 1,600 m and 1,800 m (Fig. 6).

**Table 6** The ages of sampled trees in Virós d'Araós

| Species | Virós d'Araós | | | | |
|---|---|---|---|---|---|
| | Number of cases | Maximum age | Minimum age | Average | Average first year |
| *Pinus sylvestris* | 366 | 180 | 4 | 72 | 1930 |
| *Abies alba* | 74 | 204 | 21 | 112 | 1890 |
| *Pinus mugo* ssp. *uncinata* | 62 | 167 | 22 | 102 | 1900 |
| *Fagus sylvatica* | 19 | 95 | 46 | 71 | 1931 |

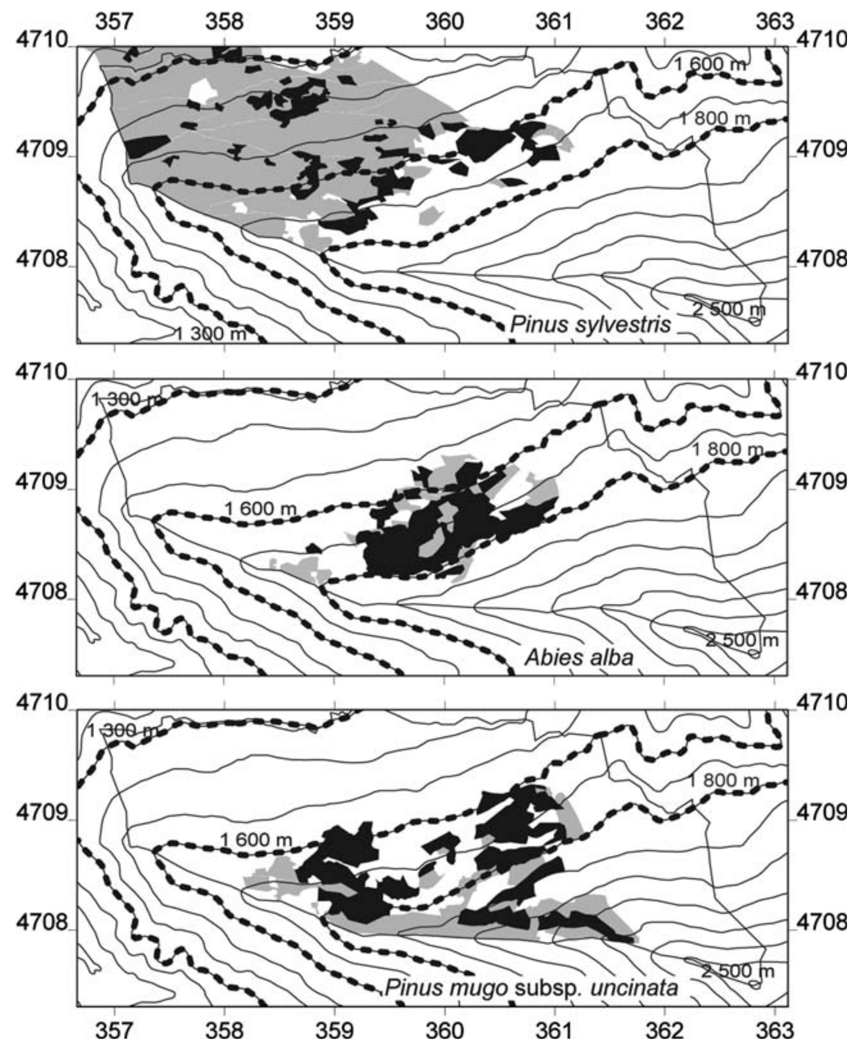


**Fig. 6** The main woods growing before 1900. *Black*, growing before 1900; *grey*, present distribution

Woodland use

Analysis of documentary data about the Bosc de Virós confirms the abandonment of metallurgy in the second half of the nineteenth century. The Disentailment Law (1855) that left the woods in the hands of Virós communities explains the state of the woods as described in 1876: "*que consta de monte bajo, abedul y pino carrascal y otra clase de pinos; recorrido en todos sus limites, se ha encontrado en buen estado escepto los tres puntos donde sufrieron un incendio este verano que es inutil*" ["…which consists of scrub with birch and pine and another class of pines; inspected to all of its boundaries, it was found to be in good condition except for the three places where it suffered from a fire this summer and is useless"], AHCSo: Ainet de Besan archives, 2g.

Woodland clearance and the immaturity of the woods are evident in the scrub, with *Betula* sp., a pioneer that takes advantage of clearance to recolonize the woodland, as did *Pinus sylvestris* in all likelihood, since it had nearly

30 years to regenerate itself after the end of the metallurgy in 1850. It is important to note that beech is not even mentioned, nor deciduous trees in general, even though the category "*otra clase de pinos*" [another class of pines] probably would have included some remnant firs and in all probability they would have survived the maximum human impact.

The available records confirm continuous woodland product exploitation during the twentieth century, which can be divided into several phases (Fig. 7):

(a) The first phase is from the end of the Civil War until 1960 (years 1938–1939 to 1958–1959). Authorizations for wood auctions and village income from the sale of wood show that the harvest never surpassed 1,000 $m^3$ of timber in any year. This does not seem to be a time when the intensity of woodland exploitation was very high, although we must take into account the fact that construction had not yet begun on many of the roads through the woods that now exist.

(b) The second phase takes in the entire decade of the 1960s (years 1959–1960 to 1969–1970). During this period, timber extraction increases in intensity until it is slightly higher than the 1,000 $m^3$ threshold in some years. The harvested trees were larger in diameter and the road network expanded because truck transport was now possible. In the village of Tírvia, for example, the first "truck for transportation" was declared in the tax records for 1962.

(c) The decade of the 1970s defines the third phase (years 1970–1971 to 1979–1980). Timber extraction clearly increased after year 1973–1974, when the highest wood extraction of the century was documented. A heavy snowfall in the winter of 1973 resulted in frozen trees that broke and split a considerable quantity of wood, which led to a disaster declaration for a large portion of the Pyrenean woods, in a band from 1,600 to 1,700 m.

(d) The fourth phase brings us to the late 1980s (1980–1987), when community funding became more diversified and, as public administration became more decentralized in the post-Franco era, and no longer depended solely on centralized exploitation of natural resources. Even given this fact, however, the high level of woodland access during the preceding period, together with mechanization, resulted in continued extraction of a large volume of wood.

Public documents also confirm the use of Bosc de Virós for grazing by 500–1,000 sheep that without doubt played an important role in the regeneration patterns of various woodland species. Even so, in all of the cases analysed, the trees cited in timber auction documents between 1939 and 1987 are always *Pinus* sp., *P. mugo* ssp. *uncinata* and

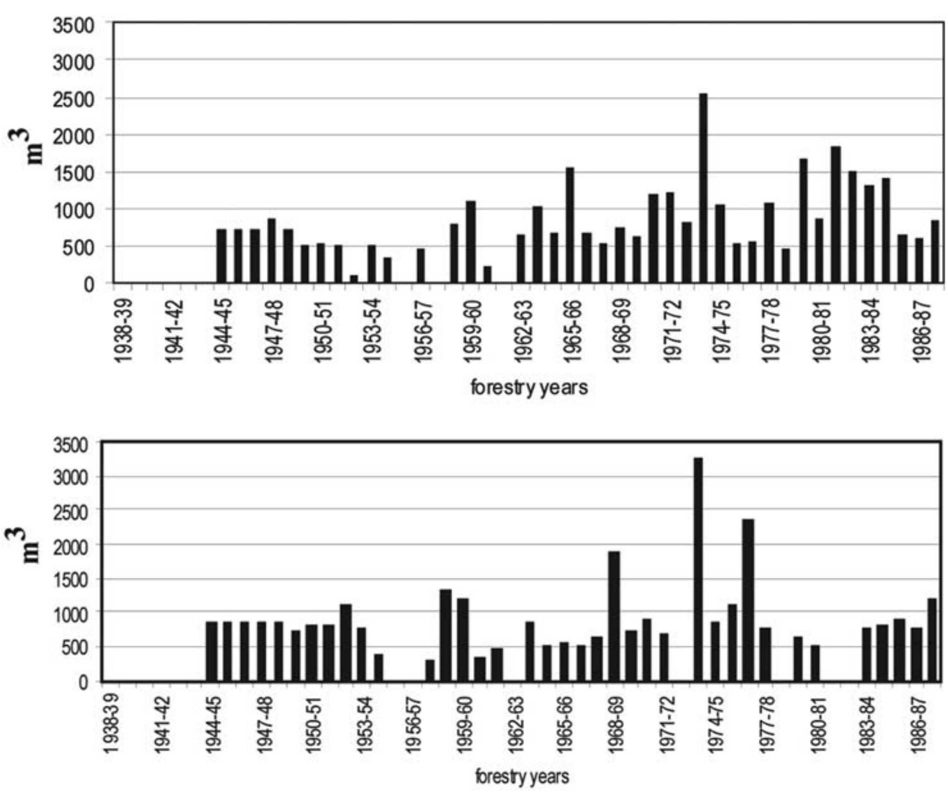


**Fig. 7** Amount of timber in $m^3$ taken from Bosc de Virós. **a** Virós d'Araós. **b** Virós d'Ainet de Besan

*P. sylvestris*, reflecting the primary management of these conifers that was favoured by the woodland industry.

## Discussion

Together with dendrochronological dating and a variety of documentary sources, the pressure exerted by charcoal production allows identification of the phases of differing intensity in woodland use (Pèlachs 2005):

Cal A.D. 240 to 530

All the charcoal kiln sites from the late Roman period were found thanks to the presence of slag piles, which show that iron was smelted there. Their distribution is characterized by proximity to outcrops of iron ore and, therefore, their locations are at different altitudes, ranging from 1,317 m to 2,174 m depending on the different mineral veins. If we accept slag piles as good indicators of smelting, we could hypothesize that the 15 kiln sites with slag piles in the study area had extensive impact from the metallurgical activity at the time, even without slag excavations to confirm this approach. For this reason, we believe that the disturbance caused by charcoal production might have been very localized but very intense at particular points in time.

Cal A.D. 531 to 1209

For a long time period, from the seventh to the twelfth centuries, we found no remains of wood charcoal. Even though we cannot discount the possibility that there might be some from this period among the total 942 kiln sites that we located, our current state of knowledge suggests that the impact on the woods from charcoal production during these six centuries was low or nonexistent. Historical records show that feudal activity was largely based on grazing herds (Esteban et al. 2003) and the feudal lords' control of iron smelting (Verna 2001).

Cal A.D. 1210 to 1368

This period is defined by the presence of a charcoal kiln site dated cal A.D. 1210, more than a century before the installation in 1368 of the first authorized iron works in the valley (Verna 2001). Although the existence of just one site makes it difficult to determine the importance of this period, the fact that charcoal production was found at an altitude of 1,923 m suggests at least two possible interpretations:

(a) The first is based on location, since we cannot discard the possibility that this was an attempt to take advantage of an area that had been used during the late Roman period in an effort to work iron ore. In any case, although we found no slag associated with this kiln, there was a slag pile close by. In this instance, the smelting method had to be direct production.
(b) Of course, a lone charcoal kiln site is hardly reason to imagine some metal smelting; it could be that the kiln was actually for some other charcoal-burning activity. However, it would be difficult to understand why this other activity would take place at such an altitude and not closer to the village, unless the goal was to hide the activity or to produce a particular type of charcoal. If the latter, at this altitude the desired species would have been *Pinus mugo* ssp. *uncinata*. Clearly, however, the intensity of charcoal production during this time was minimal and very local.

Cal A.D. 1369 to 1499

Beginning with the installation of the first water-powered forge in the valley in the fourteenth century, the amount of iron smelting increased rapidly. During the fifteenth and sixteenth centuries there was a local increase in charcoal kilns. Charcoal production took place between 1,600 and 1,700 m, and so affected a lower, better-defined part of the woodland than in preceding time periods. Dependence on proximity to iron ore was probably not as great at this time as previously and therefore wood and access to the forges took on greater value. The pressure of charcoal production in this period is considered moderate.

Cal A.D. 1500 to 1749

The number of kiln sites identified in this period is the same as in the preceding one, but there is one detail that suggests that the intensity of charcoal production was on the rise: the fact that the kilns are found in a broader altitude range, from 1,500 to 1,800 m. The pressures of charcoal production are considered high at this time.

To understand this situation, we must analyse the known historical data from Vallferrera and its surroundings, since the Genoese forge was introduced to the neighbouring valley of Ariège, in France, between 1560 and 1570 (Izard 1999) and a period of severe over-exploitation of the woodlands in all of the northern valleys lasted until the seventeenth century. This favoured the development of technical solutions to address the lack of affordable energy resources and secure the quantity of charcoal needed to produce the same quantity of iron (Izard 1999). Therefore, a first approach was to adopt a new method of injecting air into the forge, in which bellows forced air through a horn-shaped nozzle into the smelting hearth. The adoption of this system, known as the *trompa*, or hunting horn, apparently occurred between 1659 and 1670 and is considered by many researchers to be the fundamental characteristic of the Catalan forge (Solans 1991).

In addition, the political changes in the distribution of ironworking that resulted from the Treaty of the Pyrenees (1659) between France and Spain required greater development of deposits like those of Vallferrera in the southwestern Pyrenees, away from the sites in the eastern Pyrenees (now France) that had been used until that time.[1] This is confirmed by the development of various sites for iron-working activities between 1646 and 1665 along with the increased number of forges, some of which used the Virós woods (Bringué 1995).

Cal A.D. 1750 to 1850

Despite the calibration difficulties of $^{14}$C dating (Table 4), there is no doubt that the increase in charcoal kilns during this period is very great. We found 17 kiln sites scattered across very diverse altitudes. In addition, in this period we found the greatest variety in site dimensions, since our research allowed us to date the largest of the kilns to this time. In the same way, the charcoal production pressure meant that this was also the point in time when the smallest of the kilns were developed. This great variety in charcoal kilns and associated characteristics would have greatly increased the pressure on the woodland, since the disturbance of the various plants would be at a maximum. We considered the charcoal production pressure to be very high and related to the boom in metallurgy and forges.

This analysis is compatible with the historical information that explains the importance of the forges as they increased in number between 1750 and 1850, when they become concentrated, and then disappeared by 1880 (Mas 2000); the records clearly show that the owners of these businesses and their neighbours experienced a large number of conflicts arising from the intensive use of the woods (Bringué 1995).

Cal A.D. 1850 to 1950

After the "forge boom", the pressure on the woods diminished, even though the number of charcoal kilns remained high. The pressure from charcoal production during this period is considered to have been high, probably explained by a certain cultural inertia in choosing charcoal production as a vocation: once the metalworking period ended, charcoal remained an important energy source well into the twentieth century.

The analysis of woodland use throughout the twentieth century reveals some particularly intense episodes, particularly after the 1960s, when technical capacity improved and the woodland was much more exploited than in the preceding period. According to records from the time, the 1973 snowstorms were an extraordinary occurrence that brought down a large quantity of trees, which then had to be hurriedly removed (Fig. 7).

Of course, it is somewhat difficult to believe that the only reason for this ecological disaster in a plant type well adapted to these occurrences should be attributed to an exceptional winter. Our findings show the impact of woodland management policies during the 1950s and most of all the '60s: the morphological structure of the woodland became incapable of withstanding winter storms that may not in fact "exceptional" for this region; in fact, a decade earlier in 1962, extremely heavy snowfall did not produce a similar loss of trees. Be that as it may, it is certain that one of the largest timber harvests recorded in this study period occurred just at the moment when the tree population had reached historic lows and all of the weight of woodland management fell to a central administration. Even so, this does not remove all responsibility from the local community that did not manage to conserve a valuable resource after it had recovered from the disturbance caused by ironworking.

In summary, the study of charcoal kilns and iron mines, together with historical records, helps to explain the history of the intensity of human use of woodland vegetation in the Bosc de Virós, clearly demonstrating the following:

- There is at least a 2,000 year history of metallurgical activity in the Bosc de Virós.
- The most widespread and intense exploitation of the Bosc de Virós occurred between cal A.D. 1750 and 1850, as a consequence of a great trend towards metalworking in Vallferrera. This point in history is the origin of the current woodland structure of the Bosc de Virós and had a strong impact on the vegetation and landscape of the Virós zone.
- Throughout the twentieth century, increasing use of the woodland assisted by improvements in technology contributed to keeping the woods young, while woodland management based on species selection contributed to the regeneration of *Pinus sylvestris* and *P. mugo* ssp. *uncinata*.

Environmental history has contributed to a very precise interpretation of the current landscape, enabling us to conclude that the most important disturbances of the past 2,000 years of plant and landscape history were concurrent with periods of socioeconomic specialization. For this

[1] The Treaty of the Pyrenees, a peace accord signed November 7, 1659, by representatives of Philip IV of Castile and Louis XIV of France, ended the war that had started between the two kingdoms in 1635, giving France control of the "comtat del Rosselló", including Conflent, Capcir and Vallespir, and the eastern half of the Cerdanya range, important territories with respect to metallurgical activity that had belonged to Spain up until that point.

reason, the present woods are the result of metallurgical specialization during the eighteenth and nineteenth centuries and woodland use during the second half of the twentieth century.

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