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250-Year reconstruction of pollarding events reveals sharp management changes in Iberian ash woodlands

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Abstract

Key message **Tree-ring growth of pollarded narrow-leaved ash trees in Central Spain reveals traditional management cessation in 1970 and property-specific management patterns.**

Abstract Tree pollarding was a dominant management strategy of European forests for centuries creating open agroforestry landscapes with important cultural and environmental values. This traditional practice has been widely abandoned in last decades with a subsequent impact in terms of biodiversity and cultural loss. Central Spain hosts the largest and best-preserved area of pollarded narrow-leaved ash (*Fraxinus angustifolia* Vahl.) woodlands in Europe. The main aim of this research is to obtain rigorous historical records of pollarding frequency to get adequate information for traditional ash management. We used dendrochronological techniques to evaluate temporal changes of pollarding frequency and rotation length. We analysed the stand level synchrony and the effect of land property on pollarding activity from 322 trees growing in eight pollard stands in Central Spain. Pollarding events were unequivocally identified at tree level by a characteristic change in growth pattern. We identified 2426 tree-level pruning events with the first event dated in 1777. Historical pruning recurrence ranged between 5 and 10 years with higher pollarding frequency on private lands. Pruning events within each site were synchronous, suggesting the existence of a rotational schema within each stand. Pruning frequency decreased drastically in the 1970s matching with the depopulation of rural areas and the general abandonment of traditional practices. Pollarding practices have recovered in recent decades although with lower intensity and lacking the synchronic historical patterns. Providing technical and economic support to make this traditional activity profitably would have strong environmental revenue due the multiple ecosystem services provided by pollarded ashes.

Keywords Dendrochronology · *Fraxinus angustifolia* · Pollarding · Agroforestry system · Traditional management

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Introduction

Tree pollarding has been one of the dominant management strategy of many European forests for centuries (Petit and Watkins 2003; Read 2008). Pollarding involves lopping branches at a certain height above the ground, out of the reach of browsing livestock, to obtain a product from the tree (e.g., fodder, firewood, charcoal, osier wickers for basketry, timber or small-scale wood for tool handles; Read 2003). Moreover, pollarding does not require grazing restriction afterward for protecting the new sprouts from browsing as after coppicing trees down at ground level (Read et al. 2013). This multipurpose land management became a key component of subsistence farming economy in Europe (Sjölund and Jump 2013), enabling the maintenance of large open woodlands as agroforestry systems (Smith et al. 2012).

Pollarding was applied to a wide array of tree species (Read 2000; Rozas 2004; Rozas et al. 2008; Allende Álvarez et al. 2019; Camarero et al. 2022), and these practices were tightly controlled by traditional regulations and bylaws since at least the sixteenth century (Allende Álvarez et al. 2013; Gomez et al. 2016). As a result, pollard woodlands and trees out of woodlands constitute landscape elements of great cultural and conservational value that represent long-term sustainable land management systems (Grove and Rackham 2003; Haeggström 2007; Mansion 2010).

Sharp changes in demography, economic and agricultural activities, stock raising and forestry practices, linked to the industrialisation and rural depopulation during the last two centuries across most part of Europe, has caused the progressive abandonment or reduction of traditional multipurpose land uses, pollarding practices included (Read 1996; Moe and Botnen 2000; Leppik et al. 2011; Castro et al. 2012; Sjölund and Jump 2013). The practice of pruning trees at height is both costly and risky (Dujesiefken et al. 2005), and leaves and branches from trees are no longer a critical resource for local subsistence farming economies (Nordén et al. 2018). Consequently, pollarding practice has been progressively reduced or abandoned, and most former pollard woodlands have evolved into closed forests, or were transformed into forest plantations or agricultural lands, with this process intensifying during the latter half of the twentieth century (Pankhurst 2013). The few remaining pollard landscapes represent a true European cultural heritage which is often maintained only for their cultural value.

As a consequence of frequent pruning, and the globally recognized growth-lifespan trade-offs (Brienen et al. 2020), pollarded trees grow slower and live longer that uncut trees, especially in fast-growing species (Lonsdale 1996). In fact, in many European regions, pollarded trees are currently the oldest existing trees (Read 2000; Read et al. 2013; Nordén et al. 2018). Moreover, repeated cutting creates large and gnarled trunks, where rainwater collects in hollows creating packs of decaying wood that are appropriate niches for saproxylic organisms (Sebek et al. 2013; Zapponi et al. 2017; Doerfler et al. 2020). Thus, pollard woodlands are biodiversity storages preserving species associated with old-growth forests and hollow trees, being pollarded trees the main reservoir of these species in many areas (Skarpaas et al. 2011; Siitonen and Ranius 2015). Long-term persistence of pollards is strongly dependent on the maintenance of cutting practices, since growth of lateral branches on hollow trees promotes structural instability leading to breakages and eventually tree death (Read 2000). This management dependency makes the origination and preservation of aged managed woodlands possible, leading pollards as a reservoir of organisms linked to old-growth forest. Pollard management maintenance poses a strong conservation issue in those areas, where open pollard woodlands remain, but cutting practices has disappeared or become less frequent, triggering a gradual loss of large veteran trees and heading to an environmental and cultural impoverishment.

Nowadays, the Iberian Peninsula hosts the largest extension of pollard tree landscapes in Europe, with more than 3 million hectares of pollard woodlands known as *dehesas* (Moreno et al. 2007). *Dehesas* woodlands mainly dominated by *Quercus ilex* L. and *Q. suber* L. are widely represented in the low-populated rural landscapes of western Spain and Portugal (Pulido et al. 2001; Bugalho et al. 2018; Plieninger et al. 2021). However, relatively large and well-preserved pollard woodlands of narrow-leaved ash (*Fraxinus angustifolia* Vahl.) are also extensive in Central Spain. Pollarded ash woodlands persist at the foothills of the Guadarrama Mountains in the Central System, north of Madrid city. The high palatability of their leaves led ash trees to be treated as pollards for fodder across Europe; however, this practice has been progressively reduced with the historic drop in the stocks of extensive livestock and subsistence farming (Read 1996; Di Pasquale et al. 2004; Leppik et al. 2011). Therefore, the uninterrupted maintenance of traditional pollarding in ash, since at least Middle Age in areas close to a large city as Madrid is remarkable. The persistence of this practice is compromised not only due to a progressive urbanisation of the area and industrialization of the agriculture and livestock sectors, but also to the loss of traditional knowledge linked to the massive exodus of rural population along the second half of last century. Currently, we lack basic information on the historical frequency of pruning practice and its impact on tree growth. Rigorous historical records of the variation patterns of this silvicultural treatment are essential, since this information may be used to further apply the necessary treatments to preserve this valuable ecological and cultural landscape.

Dendrochronological techniques provide high-resolution information on environmental changes and disturbances occurring along the lifespan of trees (Speer 2010), which are widely used to reconstruct historical disturbance regimes in forests (Lorimer and Frelich 1989; Nowacki and Abrams 1997; Di Filippo et al. 2017). However, in contrast with the rich literature of natural forest dynamics reconstruction, the analysis of pollard events has received considerably less attention (Haas and Schweingruber 1993; Slotte 2001; Rozas 2004, 2005; Camarero et al. 2022). In this work, we reconstructed and analysed the historical sequence of pollarding events, and changes in their frequency and synchronicity in eight pollarded ash woodlands along the southern piedmont of Guadarrama Mountain in Central Iberian Peninsula. Our aim was to (1) characterize the wood anatomical markers of pruning events to enable the reconstruction of management patterns, (2) identify historical changes in pollarding frequency at tree and woodland levels, and (3) evaluate whether property type (public versus private) has affected
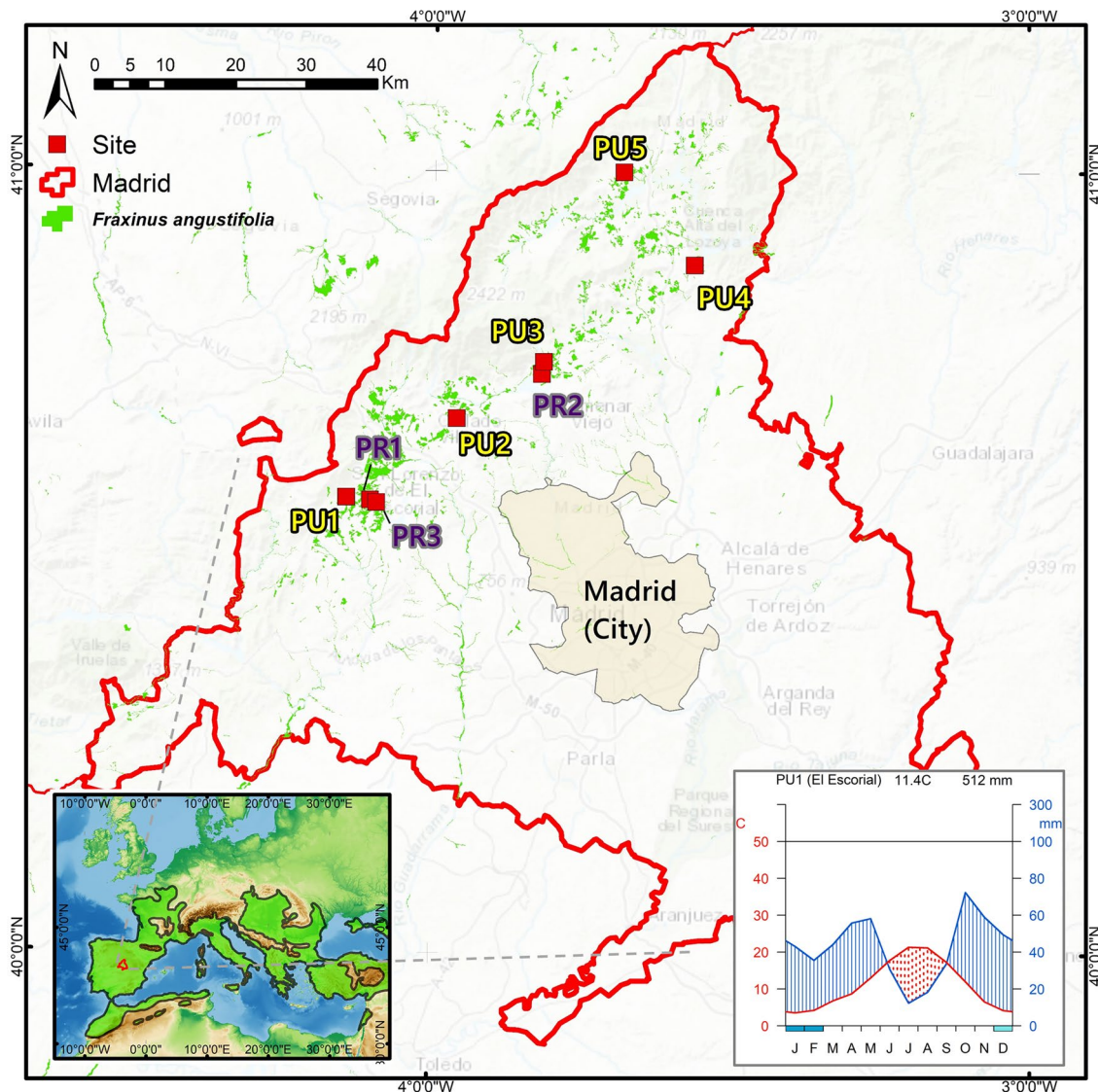
Fig. 1 Location of the eight pollarded woodlands (red squares) studied in Comunidad de Madrid, Spain (PU: public, PR: private), and distribution range of *Fraxinus angustifolia* in the central Iberian Peninsula (green area), according to Vallejo Bombín (2005). Inset map shows the location of the study area in Central Spain and the natural range of *F. angustifolia* in green (Caudullo et al. 2017). The climograph of PU1 site is shown

management practices to create a baseline for recovering these activities.

Materials and methods

Sites description

The eight woodlands constituted by narrow-leaved ash pollards that we studied are located on the southern slopes of the Guadarrama Mountains, Comunidad de Madrid, Spain, at altitudes ranging from 855 to 1067 m a.s.l. (Fig. 1). Climate is continental Mediterranean, with mean annual temperature ranging from 12 to 14 °C with a total annual

precipitation of over 650 mm, with dry and hot summers (Fig. 1). Narrow-leaved ash woodlands occupy flat areas with moderate and seasonally hydromorphic soils (Caudullo and Houston Durrant 2016). The high phreatic level in these soils supports highly productive grasslands with a long growing period, eventually drying only at July and August. Currently, these areas are usually grazed by cattle, albeit sheep were also common in the past. We sampled three privately owned and five public woodlands showing hints of historical pollard management (Table 1).

The large privately owned ash woodlands studied have a historical, architectural and cultural heritage of great interest. Among public owned woodlands, all but one belong

Table 1 Site characteristics and dendrochronological features of the private (PR) and public (PU) study sites along the Guadarrama mountains (Comunidad de Madrid, Spain)

Site	Site name	Latitude (°N)	Longitude (°W)	Altitude (m a.s.l.)	n trees	Time span	Mean length	Dbh ± SD (cm)	Ring width ± SD (mm)	Series IC	EPS
PR1	La Granjilla	40.58	−4.10	861	39	1859–2021 (1889)	90	84.39 ± 20.23	2.07 ± 1.05	0.63	0.92
PR2	Prado Herrero	40.74	−3.82	915	40	1782–2021 (1875)	88	88.10 ± 33.94	1.65 ± 0.94	0.56	0.85
PR3	Prado Nuevo	40.58	−4.09	855	40	1766–2021 (1856)	94	67.86 ± 25.30	1.60 ± 0.86	0.64	0.89
PU1	El Escorial	40.58	−4.14	929	39	1796–2021 (1866)	117	93.89 ± 25.24	1.80 ± 0.78	0.61	0.93
PU2	Moralzarzal	40.68	−3.96	968	39	1872–2021 (1882)	102	81.15 ± 17.94	1.84 ± 0.59	0.60	0.93
PU3	Soto del Real	40.76	−3.81	972	40	1916–2021 (1916)	86	45.99 ± 8.48	1.75 ± 0.71	0.61	0.95
PU4	Berrueco	40.88	−3.56	950	43	1816–2021 (1830)	130	76.24 ± 19.66	1.54 ± 0.52	0.64	0.95
PU5	Villavieja del Lozoya	41.00	−3.68	1067	42	1826–2021 (1837)	145	74.35 ± 32.21	1.34 ± 0.48	0.64	0.95

Site latitude, longitude and altitudes, number and mean length of tree-ring series, time span (indicating the first year with at least four trees), mean diameter at breast height (Dbh), characteristics of the tree-rings measured in ash trees, as well as mean ring width ± standard deviation (mm), series intercorrelation (IC) and expressed population signal (EPS) are shown

to town councils with one, PU1, being a National Property (Patrimonio Nacional). Therefore, most of the public ash woodlands studied are part of the catalogue of public utility forests, mainly as municipal "*dehesas boyales*", or "oxen pastures". These properties are often enclosures on commons of villages with a livestock tradition for feeding working animals. In the wider surroundings of Madrid, villages have often grown and evolved into extended peri-urban housing areas, and this conurbation occasionally even surrounds the common pastures left as green islands within.

### Sampling, ring-width measurement and chronologies computation

Sampling took place in summer–autumn 2021. Sampling was carried out following a wide transect in each of the ash woodlands studied. A minimum of 40 ash trees were selected at each of the 8 studied sites including only individuals with diameter wider than 20 cm and avoiding trees with external rot evidence. Trees available that met the specified criteria and were scattered across the chosen transect were selected for core extraction. A core was extracted at 1.3 m above ground level from each tree with a Pressler increment borer (Häglof, Sweden). We measured diameter and height from cored trees and georeferenced them using a submeter GPS device (Geo 7x, Trimble Ind., Sunnyvale, USA).

Cores were air-dried, glued to wooden mounts and surfaced with progressively finer grades of sandpaper for tree-ring analysis. Cores were digitized with CaptuRING® (García-Hidalgo et al. 2022) at 5897 dpi resolution and earlywood and latewood widths for each year were measured on the images with a precision of 0.004 mm with CooRecorder software (Cybys, Sweden). Cross-dating quality and measurement errors were checked and corrected using the software COFECHA (Holmes 1983). A mean chronology for each study site was calculated from those ring-width series highly inter-correlated. Three individual tree-ring width series out of 325 were omitted for further analyses due to low correlational values. At least 39 series corresponding to 39 trees per site were considered for further dendrochronological analysis (Table 1).

Pruning event identification

The extensive loss of the photosynthetic tissues associated with pollarding affects tree-ring formation (Haas and Schweingruber 1993; Schweingruber 2007), leading to abrupt and sustained growth depressions in the ring-width pattern (Rozas 2005; Bernard et al. 2006). Previous literature indicates that pruning in ash is associated with the formation of a distinctive second ring of smaller earlywood pores occurring instead of the formation of a typical most dense latewood (Haas and Schweingruber 1993). In the particular
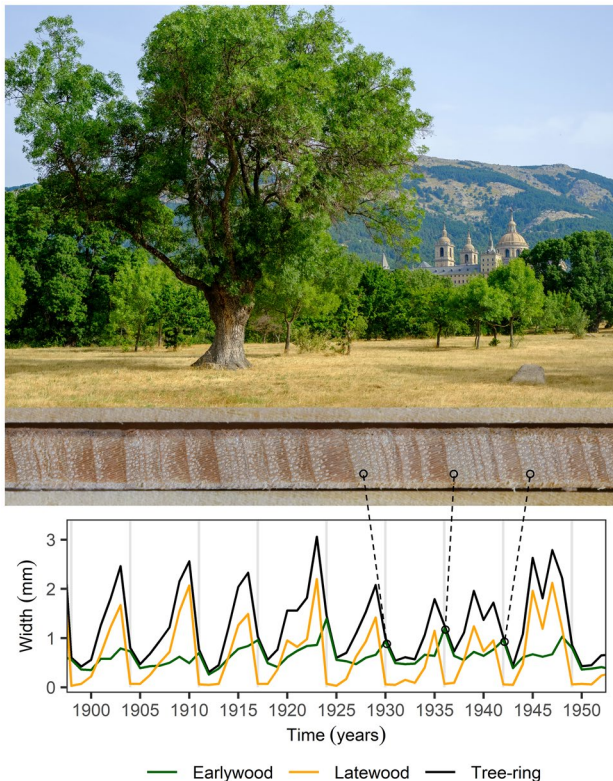
Fig. 2 Wood-anatomy changes in narrow-leaved ash (*Fraxinus angustifolia*) wood cross section associated with pruning events. Differences in tree-rings growth when carrying out pollarding treatments (vertical shaded lines depict dated pruning events). The inset image shows one of the sampled ash plots (PU1) in the vicinity of the Royal Site of San Lorenzo de El Escorial

case of pollarded narrow-leaved ashes in Central Spain, the traditional management applied caused a different wood formation pattern. Since pollarding for fodder occurred in summer, at the end of the growing season, no resprouting took place until the next season, and no distinctive second ring of smaller earlywood pores was formed. A sudden growth reduction was observed the subsequent year after pruning, and earlywood width was not altered this year, but latewood is almost absent. Total ring-width decreased in the 2–3 following years after pruning, in comparison with the pre-pruning period, forming only narrower rings composed mostly of earlywood. After this period, latewood width and total ring width gradually increase over the next 3–4 years. Therefore, all these characteristics together allowed identifying all pollarding events carried out on each sampled ash throughout the tree life span (Fig. 2).

We dated discrete pruning events with an annual resolution on individual time series. A value of 1 was assigned to the first year in which tree rings presented hints of pruning, as indicated above. Otherwise, a value of 0 was assigned. For the subsequent analyses at site level, we considered a period comprised between the first year with at least four trees per site and the year 2021 (Table 1). With this data set, stand pruning recurrence at each sampling site was calculated as follows:

$$\text{Plot pruning recurrence} = \left[\frac{1}{k} \sum_{t=n-k+1}^{n} \left(\frac{1}{j} \sum_{i=1}^{j} \text{pruning events}_i \right)_t \right]^{-1}$$
(1)

where k defines the time-span in years of the moving average ($k = 10$), t is the sequence of years within the period in which the pruning event is computed, n is the focal year in which the mean value of pruning events is computed, i is the tree of interest and finally, j is the number of trees in a sampling plot. The inverse step (x^{-1}) allows us to convert discrete event information into a temporal scale indicating, therefore, the average elapsed time in years between two pruning events.

In addition, changes in pruning synchrony were assessed by means of a data set accounting for the total number of pruning events for every year and site grouped in 10-year wide periods lagged by 5 years moving time-windows. In each time-window we computed the variance (observed σ^2) of the matrix consisting of events (1) and no events (0) per year. We also created two additional proxy data sets to assess the minimum and maximum variance (min σ^2 and max σ^2) possible on time-windows based on the existing pruning events. Decadal minimum variance was computed on a data set in which the total number of decadal events is homogeneously distributed along years. Decadal maximum variance was computed similarly in a data set with events concentrated in the minimum number of possible years. We calculated these values to reflect the real synchrony in relation to maximum and minimum possible pruning synchronies. Event synchrony was addressed for each window as follows:

$$\text{Pruning synchrony} = \frac{\text{observed}\sigma^2 - \text{min}\sigma^2}{\text{max}\sigma^2 - \text{min}\sigma^2} x100$$
(2)

The effect of land property and time in pruning recurrence was tested using a binomial generalised linear model. The model accounted for the first-order interaction between land property type (two-level factor variable; public and private) and time segmented in three 50-year windows (1871–1920, 1921–1970, 1971–2020; three-level factor variable). Time segmentation was done to assess historical difference in management, corresponding to different historical periods. Response variable was the data set of discrete events series at individual-scale. This model depicts the probability of finding a pruning event in a tree during a given land property type and during a given period. All analysis were performed in R environment (R Core Team 2021).

Results

We analysed 34643 tree-rings in the sampled trees, among which we identified 2426 pruning events at tree level along a 250-year period. Mean length of the analysed tree-ring series along a period with at least four trees per site, was 106 years, ranging from 88 years in PU2 to 145 in PU5 (Table 1). Several long-lived mature trees with more than 200 years were identified within the study areas. Since we were not able to reach the pith due to core-borer length limitations or presence of decomposed wood in the innermost parts in the largest trees, actual tree age was underestimated in several individuals. Average tree ring width ranged from 1.34 mm per year in PU5 to 2.07 mm in PR1 (Table 1). Series intercorrelation ranged from 0.563 to 0.643, and EPS values equal or superior to 0.85 in all sites indicated an adequate common signal among trees and high replication level (Table 1). The first pruning treatment was dated in 1777 in PR3.

Site level pollarding frequency, calculated in the period covered by at least four trees, could be analysed since the mid-nineteenth century for all the study sites (Table 1, Fig. 3), e.g., since 1830 in PU4. Pruning in privately owned plots occurred every 5–7 years until the 1970s decade. Three of the public sites (PU2, PU4, PU5) had a slightly longer pruning recurrence of up to 10 years, whereas PU1 and PU3 public sites showed even higher pruning recurrence until the 1970s decade. PU1, El Escorial site, showed a significant reduction of pruning events during the 1875–1915 period, probably related to decisions on its management by the Spanish Crown in 1875, just after the end of the first Spanish Republic (1873–1874).

The observed pollarding pattern showed only slight temporal differences in pruning frequency until the 1970s. For example, the average pruning frequency was extended to 15 years (e.g., 1920s, 1930s) or reduced to 7 years (e.g., 1940s) in PU5, to continue being carried out every 10 years until the general decline of the pollarding activity in the 1970s (Fig. 3). Since the 1970s decade a sharp decrease of pruning activity was evidenced leading to extended pruning turns. Pruning treatments were recovered in most sites during the 1980s decade, albeit at a lower and most irregular frequency.

Pruning synchrony was assessed for each site and decade (Fig. 4), except for those periods with infrequent events, i.e., with less than one event per decade. Pruning was synchronous across trees from the nineteenth century to the first half of twentieth century. Privately owned plots have high synchrony until the 1930–1950s, generally above 75% of the trees pruned in the same years, whereas pruning in public plots was more unevenly distributed for
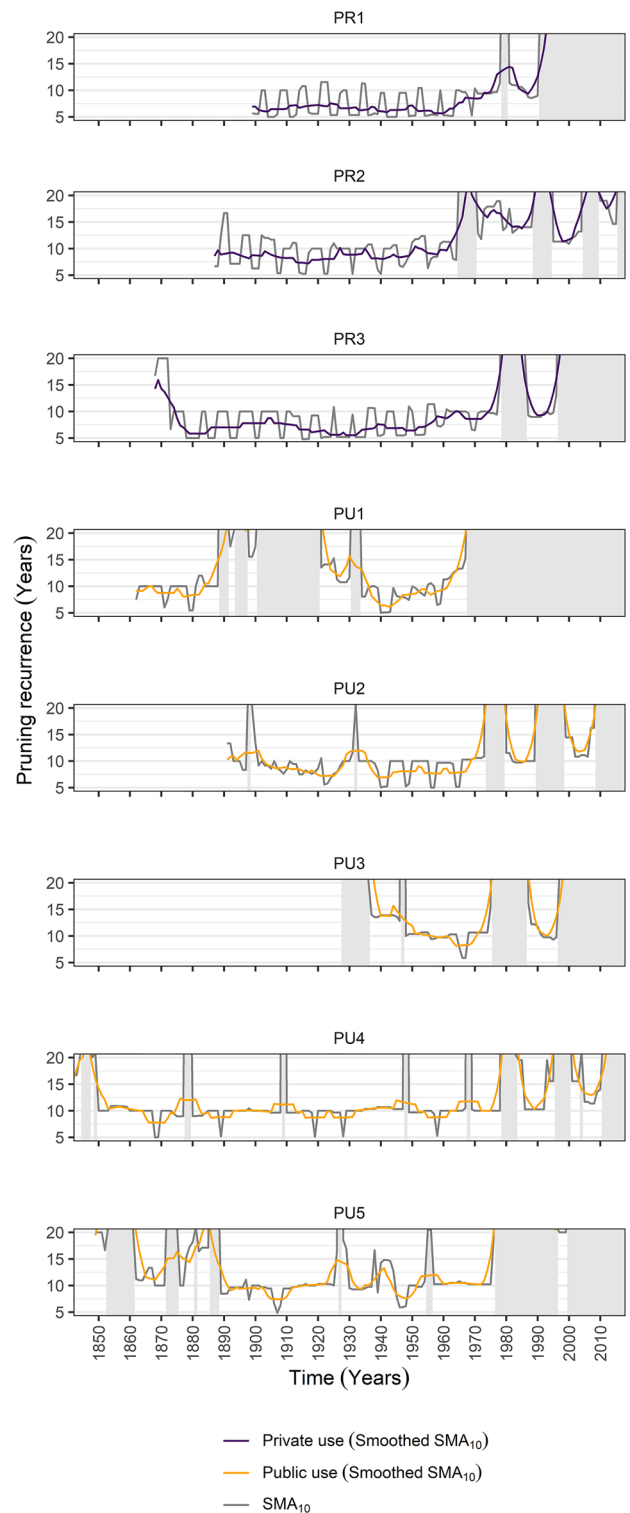
Fig. 3 Pruning recurrence of sampled plots defined as the inverse of the site-averaged 10-year simple moving average (SMA_{10}) of trees within every private or public study site. Shaded areas depict periods with pruning recurrence higher than 20 years
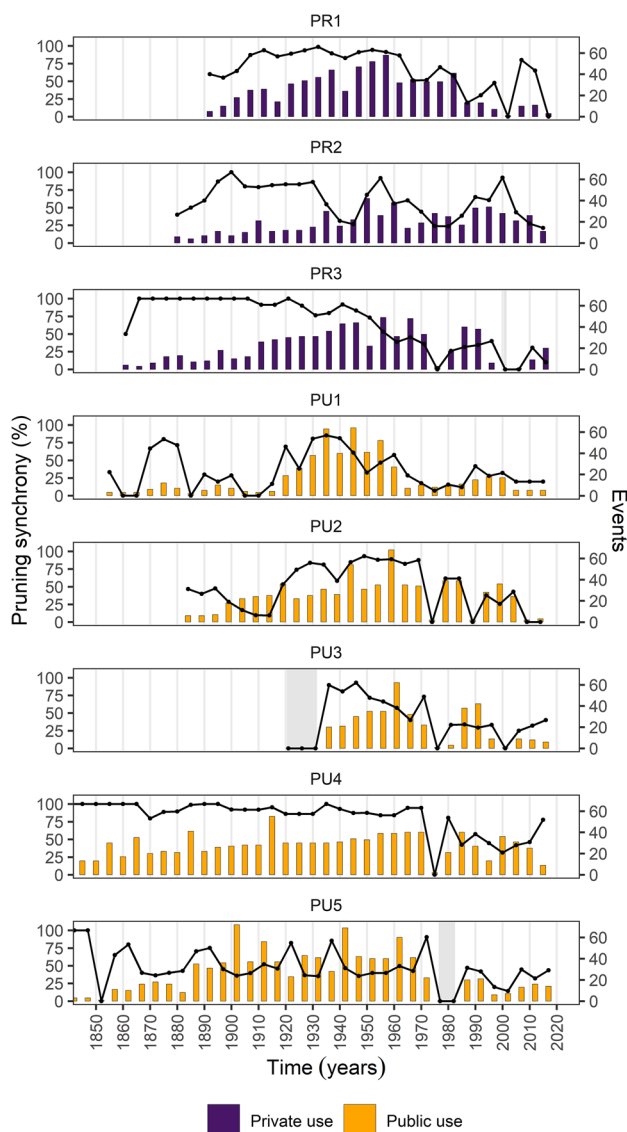
Fig. 4 Pruning synchrony (%) observed for each private (PR) or public (PU) site. The number of decadal pruning events (histogram) is shown centred at the middle point of the 10 years moving windows. Shaded areas indicate periods without pruning events

this period. Some public sites showed highly synchronous pruning events, such as PU4, but others exhibited periods of low synchrony, as occurred in PU2 in the 1900–1920 period. The most irregular and asynchronous pruning pattern was observed in both public and private sites since the 1970s, and matching the reduction in the number of events. Nevertheless, synchronized pruning events were also carried out during the last decade, as the high synchrony percentage in PU4 during the current century showed.

To gain a better understanding of the interplay between pruning recurrence and synchrony patterns we graphed them simultaneously for each study site including the number of pollarding events occurring annually (Supplementary

material, Figs. S2–S8). As an example, in the private study site PR3 we found a total of 316 pruning events among all the analysed series (Fig. 5). Periods with contrasting management were identified by changes in the frequency between pruning events throughout the study period (Fig. 5a). In the second half of the nineteenth century, pruning treatments were intensified and hence the recurrence between two pruning events was reduced from 15 to 5 years. This frequency remained steady until the beginning of the twentieth century. During the first half of the twentieth century, the period between successive pruning events remained almost constant between 5 and 7 years. Less frequent pruning events were observed from 1950 to 1970, carried out with a 7–9-year interval. After 1970 management regime changed with very few pruning events and less synchronous. Pruning activity resumed in the 1980 decade, but synchrony was not restored. Since then, pruning activity has remained sporadic and asynchronous (Fig. 5b).

During the last 150 years, pruning activity differed along the analysed periods and between public and private sites (Fig. 6). Model gave not support for the interaction between land property regime and time as mediators of pruning probability (Tables S1 and S2). Significant differences in the estimated marginal means were found regarding land use factors and between the two posterior and the current time period. Pruning significantly decreased since 1971 in comparison with the two previous periods. Pruning activity in private lands always maintained higher than in public sites, nevertheless, these differences have been getting close over time.

Discussion

Pollarding ash trees for fodder mainly occurs in summer when drought reduces the availability of fresh grass for cattle pasture (Haas et al. 1998; Vandermeulen et al. 2018) and fodder quality is optimal (FRAXIGEN 2005). This traditional practice enables livestock to withstand the most critical period of the year under Mediterranean climate, and at the same time reduces the costs of supplementary feeding acquisition (Halstead 1998; Papanastasis et al. 1998, 2008; Papachristou et al. 1999). Literature on ash species pollarding in Central Europe indicates that latewood formation is arrested after summer branch cutting with a characteristic small-vesseled band of earlywood produced to support branches resprouting in the same season (Haas and Schweingruber 1993). However, pollarded ash trees in Central Spain did not show this characteristic false ring. Such difference can be attributed to regional summer climate conditions when pruning activities take place. In contrast to the mild and relatively wet summers in Central Europe, summer in our study area is characterised by a hot and dry period that considerably limits ash resprouting ability and cambial

Fig. 5 Ensemble of pruning events analyses for PR3. **a** Sample depth (number of trees), pruning frequency as the average recurrence time in which pruning events are repeated (pruning recurrence, smoothed with a Gaussian kernel $K = 5$) and number of events that occurred at each year (pruning events). Shaded areas indicate decades without pruning events. **b** Evolution of synchrony patterns (pruning synchrony) and number of pruning events (pruning events) in 10-year periods with 5-year moving windows
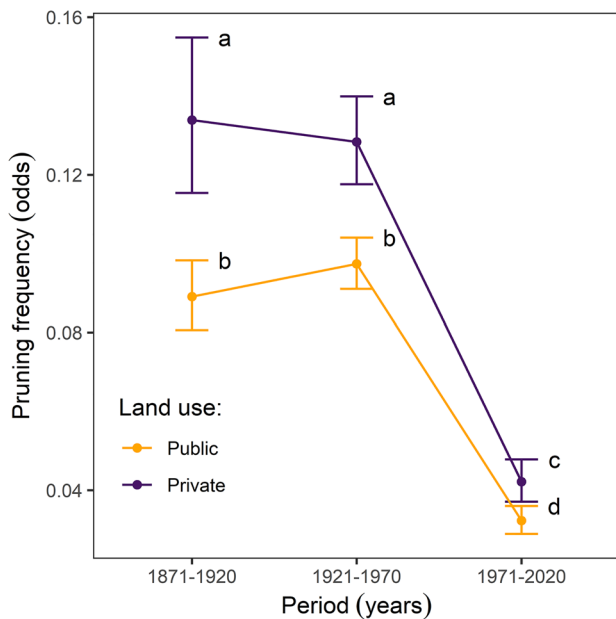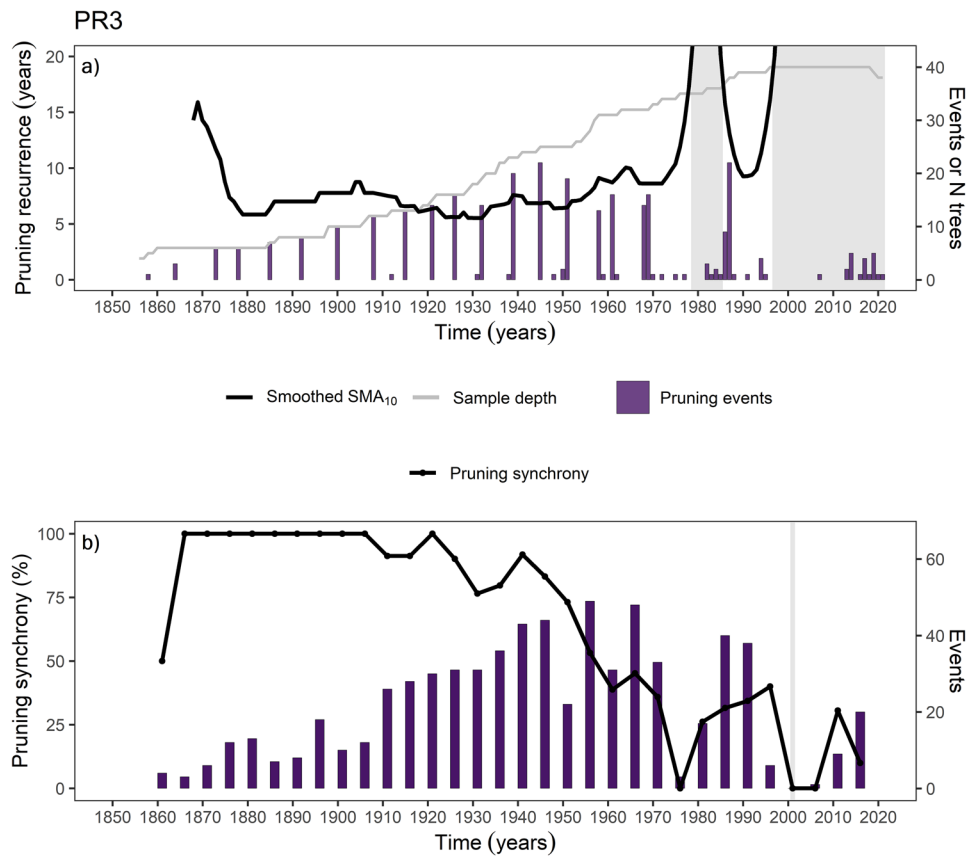
Fig. 6 Model-estimated probability of pruning (odds ratios with standard errors) over 50-year time periods by land use (public or private sites). Different letters indicate significant differences in mean pruning frequency at $p < 0.05$ level

resumption. Thus, resprouting is delayed until the start of the next growing season (F. Castro *pers. obs.*), when wet and mild conditions in spring enable the production of a wider than usual earlywood (Fig. 2), probably to support new sprouting and the treetop reconstruction. Such regrowth drains tree resources as appreciated in the low density of this ring with a low proportion of fibres than the latewood. In fact, the next two or three annual rings are almost completely composed by earlywood, probably because of a higher effort devoted to branch resprouting than to radial growth. After these years, latewood formation is gradually recovered until pre-cutting rings latewood growth levels are reached (Fig. 2).

Historical pruning recurrence in narrow-leaved ash woodlands of Central Spain ranged between 5 and 10 years (Fig. 3). The frequency of pollarding is highly variable worldwide, depending on species, the obtained product, site quality or local traditions. When the main purpose is to obtain wood for charcoal production, firewood or increase fruit production on slow-growing species, inter-pruning cycles are longer, ranging 10–50 years in beech (Dagley and Burman 1996; Read 2000), 15–20 years in Spanish holm oak (Gómez Gutiérrez and Pérez Fernández 1991) or 10–76 years in deciduous oaks (Rozas 2004; Haneca et al. 2009). In contrast, when the objective is fodder production,

species of high palatability are usually selected and cutting cycles are shorter. In the United Kingdom, ash and holly were cut for fodder at 5–10-year frequency (Spray 1980), but frequency could be even higher (2–6 years) in common ash trees in Switzerland, Sweden or Northern Spain (Haas and Schweingruber 1993; Read 2003). The slightly lower frequency of narrow-leaved ash pruning could be related to the more limiting summer conditions, which imply a lack of the current year resprouting ability. In any case, the relative high frequency can be attributed to the rapid growth rate of ash, as well as to a fodder-oriented production that requires a shorter recovery period than a fuel or construction wood-oriented management.

Our reconstruction of pruning events reflected a sharp reduction of this management practice since the 1970s, with a sporadic recovery in last decades, but lacking the synchronic and systematic pattern that we observed in the previous periods. Land ownership was also relevant, with higher historical and current cutting frequency and synchrony found in privately owned woodlands than in public lands. Pollarding in Central Spain occurred few years after pre-pollarding secondary growth rates were almost completely recovered. Besides, pruning frequency in a population was strongly synchronized among trees, since most of the trees within a site were simultaneously cut in the same years. Since livestock needed fodder every summer, our results suggest that probably ash woodlands were subdivided into smaller management units to ensure a yearly fodder production through a rotational schema (Gómez-Sal et al. 1992; Díaz et al. 1997; Moreno and Pulido 2009). Results suggest that trees sampled belonged to one management unit in most of the sites (but see results from PU5 in Fig. 4). This means that the simultaneously pollarded trees belonged to the same cyclical pollarding unit within a rotational schema.

Land ownership affected pruning frequency with cutting cycle ranging from 5 to 7 years in private lands to 10–15 years in public properties, with this difference being maintained along the whole studied period, even under current management with a low pruning frequency. The issue of forest ownership has recently received growing attention in both research and policy ambits (Ficko et al. 2019; Weiss et al. 2019). The objectives and motivation of forest owners to manage the pollarded stands vary substantially, depending on the products and services provided, but there are also considerable geographical variations due to cultural reasons. Public forest owners generally actively manage their woodlands according to multi-purpose political, societal, conservational and business objectives, whereas there is less variation in the purpose of private woodlands. In public woodlands, while the local and shared production of natural resources was widely true before rural emigration, new social trends seek for environmental objectives such as the preservation of highly valuable cultural and aesthetic landscapes over the demand for income from private agroforestry uses. On the contrary, private woodland owners try to reach greater economic efficiency in forest management (i.e., higher harvesting frequency to maximize benefits), leading to shorter exploitation turns. Interestingly, we observed few signs of tree degradation in private lands in comparison with public ones, despite higher pruning recurrence.

Until the 1950s, we observed a fairly regular pruning pattern, evidencing a most systematic management carried out in these agroforestry systems. Traditional management of ash trees collapsed at the 1970s with a generalized and drastic decline of pollarding activity. This period matches with the rural exodus and urbanization of the society, and the strong upsurge of Spanish economy (De la Torre and García-Zúñiga 2014), with a rapid internal population reorganization that transformed radically rural landscapes driving a rapid abandonment of traditional activities (MacDonald et al. 2000; Rozas et al. 2008; Lasanta et al. 2021). As a consequence, many farmers and landowners abandoned traditional farming practices highly valuable for cultural heritage conservation (Plieninger et al. 2021). Albeit Madrid province received a huge number of immigrants, this phenomenon was concentrated in the capital and its conurbation. Population in rural Guadarrama piedmonts either declined or remained stable until the large increase in the 1990s (Hewitt and Escobar 2017), whereas rural economy shifted from the primary to the third sector intended to second residences construction and services.

One of the major concerns of pruning abandonment is the effect of cutting cessation on tree health and life expectancy of the pollard trees (Rozas 2005; Rotherham 2013; Sjölund and Jump 2013). Many pollarded stands have disappeared due to land-use changes (Götmark 2013) and most of the still existing populations have developed oversized branches on hollow trunks with a core of decaying wood that could collapse easily (Pankhurst 2013). Repeated cutting produces injuries in the trees and creates a bolling trunk of uneven shape (Read 2000). In fact, pruning-abandoned trees generally showed higher and unbalanced crowns, increasing the possibility of heavy branches breaking. The southern slopes of Guadarrama mountains have many surviving pollarded trees, and some of them are older than 200 years. We identified pollarded trees exceeding 250 years in the studied populations, which confirmed that periodical managing ensures high productivity and enables tree longevity, being currently the oldest living trees in the studied area. With respect to the time window in which pruning activity can be successfully recovered after its abandonment, our study brings valuable information on the ability of trees to return to pollarding cycles after 30-year periods without management, as, for example, 1885–1916 in PU1. Although, our approach is

skewed, since we do not retrieve information on failure rates (i.e., dead trees after pollarding were reinstated), but it provides an estimation of available period for pruning activity recovery.

In general terms, we observed an evolution from the initial, synchronous and uniform treatments carried out until the mid-twentieth century, which was more intense in private stands, to irregular and asynchronous management patterns in recent decades. An increasing synchrony of pruning has been detected in some publicly owned woodlands responding to the current conservation efforts to restore and maintain functional pollarded open woodlands. Future management of pollarded woodlands is dependent upon availability of resources and staff with enough knowledge and experience to maintain this valuable resource which remains common in several Mediterranean, Balkan and Scandinavian countries. Having competent well-trained foresters is, therefore, a prerequisite for successful management and long-term survival (Pankhurst 2013), particularly to restore lapsed pollards which require a more sophisticated treatment (Read et al. 2013, 2021). Ash dieback (*Hymenoscyphus fraxineus* (T. Kowalski) Baral et al.) is also a concern for ash populations in Spain, including *F. angustifolia*, with potential impact in pollard populations, as the recent report of the presence of the pathogen in Spain remarks (Stroheker et al. 2021). Moreover, to recover and preserve pollarded stands, managers should be able to access site history for the trees especially if the last pollarding date is unknown. In this sense, we prove that dendrochronology is very appropriate to reconstruct the variation of management patterns over the history of these pollarded woodlands.

Traditional management in pollard ashes has the ability to provide valuable livestock food while maintaining a biodiverse ecosystem thanks to the creation of diverse wildlife niches. Unlike other pollarding systems, where cessation of traditional activities marked a no return point, pollarding has been recovered in most of the sites albeit at lower frequency and without the traditional synchronic approach (Fig. 5). This might be a consequence of the easy application of pollarding in our study area being technically easier, since cutting is performed at a relatively low height of at least 2 m above the ground and ash occupy flat areas, where machinery can operate. Narrow-leaved ash woodlands have optimal conditions to restore pollarding activity (Read et al. 2021), providing technical and economic support to make this traditional activity profitably would have strong environmental revenue. It would contribute to preserve this rich cultural landscape, its venerable trees and its associated biodiversity, while simultaneously, by reducing the need of supplementary food, it would also contribute to the reduction of the environmental impact of meat production, one of the largest greenhouse gas emission issues (IPCC 2022).

Conclusions

The unequivocal dating of pruning events in Central Spanish pollarded ash woodlands enabled to track changes in pruning frequency since the nineteenth century. Traditional management involved a 5–10-year rotation interval with a synchronous pruning within management units and higher frequency in private lands. This management schema collapsed in the 1970s decade during the rural exodus and urbanization of population of inner Spain. However, after several decades of almost no pollarding activity, pruning has recovered due to economic and/or conservational purposes in most of the stands albeit with much lower intensity and without the characteristic synchrony of traditional management patterns. Supporting this recovery would have multiple benefits, such as preserving historical and environmental values, but may also contribute to the reduction of the environmental impact of meat production.

Declarations

Conflict of interest The authors declare no conflict of interest.

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