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Forest structure and fire history in an old *Pinus nigra* forest, eastern Spain

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Abstract

Wildfires have decimated forests of *Pinus nigra* in the Mediterranean Basin in recent decades, but little is known about the fire ecology of this native species. We sampled three small relict forest sites on Sierra Turmell, Castellón, Valencia, northeastern Spain, to determine forest structure and past fire events. The forest was characterized by relatively large and old trees (mean 158 year, max 362 year). Fire history was affected by obliteration of some fire scars, but we determined 11 fire dates in the past 172 years. The minimum fire-free interval was 2 years, maximum 57 years. Fire dates were not linked with dry climatic conditions, possibly due to occupational burning by pastoralists. Compared to inventory data averages for *P. nigra* in northeastern Spain (Catalunya), the old forest at Sierra Turmell supported over twice the basal area and over 2.5 times the biomass, with a comparable advantage in terms of carbon storage. Carbon sequestration, on the other hand, was over six times higher in the younger forests. The relict forest at Sierra Turmell provides evidence of multi-aged forest structure persisting through numerous surface fires over several centuries. This example may be useful for guiding management of younger forests and for ecological restoration of degraded areas.

Keywords: Fire regime; Fire behavior; Age structure; Valencia; Catalunya

1. Introduction

Wildfires pose the greatest threat to the sustainability of pine ecosystems in the Mediterranean Basin (Barbéro et al., 1988; Tapias et al., 2001; Leone and Lovreglio, 2004; Pausas, 2004). Fire-climate relationships, resilience to disturbance, and ways in which humans can ameliorate environmental degradation have been identified as three of the top eight research needs for forests in the Mediterranean region (Scarascia-Mugnozza et al., 2000). Policies for conservation in the Mediterranean region range from the European Union to individual nations and localities; the overarching goals of Pan-European strategies focus on forest sustainability, protection of native species, and maintenance of the resource base (Leone and Lovreglio, 2004). However, it is difficult to develop strategies for conservation of native pine species because information on historical forest dynamics, fuel arrangement, and fire disturbance is very limited (Barbéro et al., 1988). At present, therefore, the historical fire regimes of fire-adapted Mediterranean pine forests are of great interest from many perspectives: ecological, management, and social.

Fire regimes in Mediterranean pine forests are poorly understood and have been largely inferred from morphological, chemical, and life history traits (Barbéro et al., 1988; Keeley and Zedler, 1998; Tapias et al., 2004). Based on life history and morphological traits, surface fire regimes are believed to have predominated in *Pinus nigra*, *P. sylvestris*, and *P. uncinata* forests (Tapias et al., 2004). Surface-fire-adapted species (hereafter referred to as "fire-adapted") do not have an effective canopy seed bank and seeds are susceptible to heat (Alvarez et al., 2007), so regeneration of *P. nigra* and *P. sylvestris* forests after wildfire has been poor (Habrouk et al., 1999), to the point of extirpation of some of these forests following fire (Pausas et al., 2004). These species are important

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ecologically (Camarero and Gutiérrez, 2002) and commercially, covering approximately 3.8 million hectares (ha) in the Mediterranean Basin (Leone and Lovreglio, 2004). Severe wildfires in recent years have been especially damaging in these forests (Pausas et al., 2004); between 1990 and 2000, over 25% of the *P. nigra* forests in Catalunya, northeastern Spain, were killed by severe fire and post-fire regeneration from seed has been minimal (Espelta et al., 2003).

Reliable quantitative information could be developed from direct measurement of fire-regime evidence, as done in North America and northern Europe, using fire-scarred trees dated with dendrochronological techniques (e.g., Zackrisson, 1980; Swetnam and Baisan, 2003; Wallenius et al., 2004), forest composition, age, and structure (e.g., Floyd et al., 2000; Niklasson and Granstrom, 2000), historical fire records (e.g., Fulé et al., 2003), and measurement of relict sites with relatively intact disturbance regimes (e.g., Heyerdahl and Alvarado, 2003). Some of these methods have been applied in the western Mediterranean Basin. For example, Bosch and Gutiérrez (1996) inferred regeneration dynamics of high-elevation *P. uncinata* stands in the Spanish Pyrenees from mapped plots; Lloret and Marí (2001) contrasted modern and medieval fire regimes using historical records of payments to firefighters; Rozas (2004) applied dendroecological methods to reconstruct age and human-caused disturbance to an old-growth pollarded oak woodland in northern Spain. The only published Spanish study using fire-scarred trees is by Vega-Hidalgo (2000), who reconstructed the fire regime of a *P. pinaster* forest in the Sierra Bemeja, Málaga, finding 13 surface fires between 1817 and 1991.

Our goal in the present study was to expand upon the limited information on fire-adapted Mediterranean forests by determining historical structure and fire disturbance of relict *P. nigra* forests in northeastern Spain. The feasibility of fire-regime reconstruction in the Mediterranean Basin has been discounted on the basis of long-term human disturbance and little evidence of old forests (Lloret and Marí, 2001). However, *P. nigra* can live for many centuries (Tapias et al., 2004) and has been used extensively for dendroclimatology (Fernández et al., 1996). Human disturbance has been a critical ecological and evolutionary force throughout the world, but in the Mediterranean Basin the intention would not be to determine "pristine" forest conditions; instead, the important issue is to reconstruct fire regimes in the recent centuries prior to the abrupt changes associated with the modern period of industrialization and climate change (Pausas, 2004). Unfortunately, because *P. nigra* grows at lower elevations, the native forests have been almost entirely converted to non-forested land uses or to tree plantations, obliterating evidence of the historical forest structure.

Through searches of forest inventory data and discussions with foresters and ecologists in the northeastern Spanish autonomous regions of Aragón, Valencia, and Catalunya, we identified just a few possible locations where old *P. nigra* stands might exist. Visiting these sites, we found that old trees only persisted on steep cliff faces or rock outcrops; accessible trees had been cut long ago. However, at the crest of the Sierra Turmell in Castellón, northern Valencia, we located a small remnant forest of old *P. nigra* trees. We took advantage of this unique site to ask the following questions: (1) What were the structural characteristics of the old forest in this dry region? (2) Could fire-regime attributes be reconstructed from fire-scarred trees and age distributions? (3) What was the relationship between climate, fire, and tree growth? Finally, (4) could the historical features of the old forest be useful for modern management planning in the context of changing climate and fire hazard?

2. Methods

2.1. Field methods

The study sites were located at approximately 1000 m elevation in the Sierra Turmell, Castellón province (lat 40°35′N, lon 0°4′E), on public lands managed by the Generalitat Valenciana. The longest climate record in the region, with data beginning in 1920, was from the Morella weather station (970 m elevation). Data were missing for numerous years; we used records from other weather stations at Sant Mateu (325 m), La Pobla de Benifassa (705 m), and Xert (515 m) to develop a complete regional record from 1944 to 2005 (Fig. 1). In the overlapping period of record 1961–1991, average annual precipitation at these stations ranged from 573 to 779 mm and average annual temperature was 11.1 °C at Morella and 14.5 °C at Sant Mateu (Vallejo et al., 2001). Soils were shallow and rocky, predominantly formed from limestone and dolomite parent material.

The old *P. nigra* forest covered an area of only approximately 12 ha at the crest of the mountain (Fig. 2). The surrounding environment included grass and shrublands, planted trees (*P. sylvestris*), and bare rock. A wildfire in 2001 burned up the western slope below the study area, causing high mortality in the lower forest stands but burning as a surface fire through the study sites. We selected three study sites of approximately 3 ha each, located in the center of the three least steep and most densely forested areas. The sites were grouped

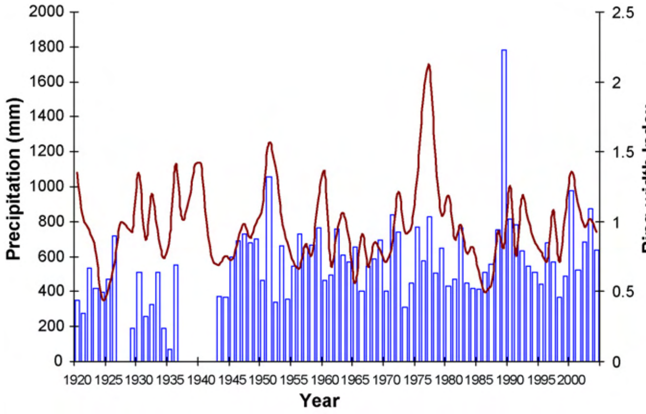

Fig. 1. Precipitation data (vertical bars) from the Morella weather station. Missing data were supplemented from three other regional weather stations, creating a continuous regional record from 1944 to 2005. Tree-ring-width index (solid line) was significantly but weakly linked to precipitation.

Fig. 2. Stand of mature, uneven-aged *P. nigra* on site W, Sierra Turmell.

by aspect: NE (average aspect 49°), W (average aspect 270°), and SW (average aspect 226°). Slopes averaged 49% at the NE site, 51% at the W site, and 53% at the SW site.

We selected three stands and installed five variable-radius plots on a grid in each stand, with four gridpoints forming a square with 60-m sides and the fifth point in the center. Stand structure, species composition, and tree age were measured on each plot using a $2.3\ m^2\ ha^{-1}$ BAF prism at each site to reconstruct stand dynamics and the extent of stand-replacing disturbances in the past. Tree measurements included species, condition (living or snag), diameter at breast height (dbh), height, crown base height, crown scorch, and bole char. Tree regeneration (trees < 130 cm in height) and shrubs were measured on a fixed 0.00405 ha plot (3.6 m radius) at each plot center. Forest floor depth (litter [Oi] and duff [Oe and Oa]) and woody debris (by diameter and decay classes) were measured using a 15.24 m planar transect (Brown, 1974) in a random direction from each plot center. Increment cores were collected from the first four trees (starting from north) on each plot plus all trees with dbh ≥ 45 cm.

Each site was searched thoroughly for the fire-scarred trees with the apparently longest and most complete record of fire scars. Although many trees had large and old scarred "catfaces", the majority of these had been cut with axes at some point in the past, perhaps to remove resinous wood for kindling. The axe cuts were old, as evidenced by large healing curls around wounds. Additional tree-tending actions were observed in the form of cutting one of the two stems of the majority of twinned trees on the sites. These cuts also appeared to be old. We collected 10 partial cross-sections from fire-scarred trees at each site, for a total of 30 samples. Twenty-six samples were collected from living trees, three from snags, and one from a cut stump.

2.2. Laboratory methods

Aboveground tree biomass was calculated using allometric equations in the Gotilwa+ model (Gracia et al., 1999). Biomass of woody debris was calculated from the planar transect data using the method of Brown (1974), which requires parameter values of average length, diameter, and specific gravity of wood particles of various sizes. These values have not been developed for *P. nigra*, so we substituted the parameters for the North American species *Pinus ponderosa* (Sackett, 1980), which has a similar growth form and specific gravity: *P. nigra*, 0.36–0.39 (Amarasekara and Denne, 2002), *P. ponderosa*, 0.42 (Simpson and TenWolde, 1999). The absolute values of woody debris biomass are uncertain because of the substituted parameters, but relative differences among sites should be reliable. We compared forest structure at Sierra Turmell with data from the Spanish national forest inventory for *P. nigra* across north-eastern Spain (Catalunya) (Gracia et al., 2004). The forest inventory data were collected only from trees with diameter ≥ 7.5 cm, whereas our sampling methods included all trees that reached breast height, so the comparison overestimates the relative density and biomass of small-diameter trees at Sierra Turmell. We calculated annual aboveground biomass increment from radial increment data for Catalunya (Gracia et al., 2004) and from measured ring-width data at Sierra Turmell. Carbon content of *P. nigra* was calculated as an average of 51% of biomass (Nicodemus and Williams, 2004).

Partial cross-sections and increment cores from fire history and tree age sampling were returned to the lab, sanded, and crossdated (Stokes and Smiley, 1968) with a local *P. nigra* chronology. The chronology consisted of 23 tree cores from 10 trees covering 213 years (1789–2001) with a series intercorrelation of 0.655 and average sensitivity of 0.349. Tree rings of the fire-scarred samples were measured and dating accuracy was checked with the Cofecha program (Holmes, 1983). Twenty-seven of the 30 fire-scarred samples were successfully dated. The season of fire occurrence was estimated based on the relative position of fire injuries within each annual ring (Baisan and Swetnam, 1990). The relationship between climatic fluctuations and fire occurrence was evaluated with superposed epoch analysis (SEA), using software developed by Grissino-Mayer (2001). The locally developed tree-ring chronology served as a proxy for climate. In the SEA, the climate values in all fire years were averaged and compared to the average climate values in a window of 5 preceding and 4 succeeding years. Bootstrapped distributions of climate data in 1000 random windows were used to create confidence intervals. Tree age distributions were created by adding the complete sampling of trees ≥ 45 cm to the systematic subsample (first four live trees per plot), corrected to represent the measured tree density.

3. Results

3.1. Forest structure

Trees were relatively large and old in the three study sites (Table 1, Fig. 3). Ninety-nine percent of the trees encountered on the plots were *P. nigra*. Mean forest density ranged from 483 (±45) to 766 (±480) trees ha^{-1}. The W site, with the highest density, had a high number of small-diameter trees. Basal area was lowest in the dense site W (19.3 ± 2.7 m^2 ha^{-1}), reflecting the dominance of small-diameter trees, and higher in sites NE and SW (27.1 ± 4.1 m^2 ha^{-1} and 31.2 ± 4.6 m^2 ha^{-1}, respectively). Multi-aged distributions were encountered at all three sites. Two of the three sites had trees predating the 18th century and the oldest tree encountered was 362 years old (center date 1642, site NE). Diameter and age were significantly correlated ($r = 0.71$, $p < .001$).

Table 1

Comparison of average forest attributes in the old forest at Sierra Turmell with all *Pinus nigra* forests in northeastern Spain

Variable	Units	Sierra Turmell	Northeastern Spain[a]
Density	trees ha^{-1}	592	690
Basal area	m^2 ha^{-1}	25.7	11.7
Average diameter	cm	23.5	14.7
Aboveground biomass	Mg ha^{-1}	101.8	39.1
Aboveground carbon storage	Mg ha^{-1}	51.9	19.9
Aboveground carbon sequestration	Mg ha^{-1} year^{-1}	1.86	0.30
Average age	years	158	53
Maximum age	years	362	215

[a] Data for northeastern Spain (Catalunya) are for trees ≥ 7.5 cm. Palahí et al. (2006) presented a similar analysis but restricted to plots with ≥5 *P. nigra* trees; their density and basal area values were within ±7% of the values reported here.

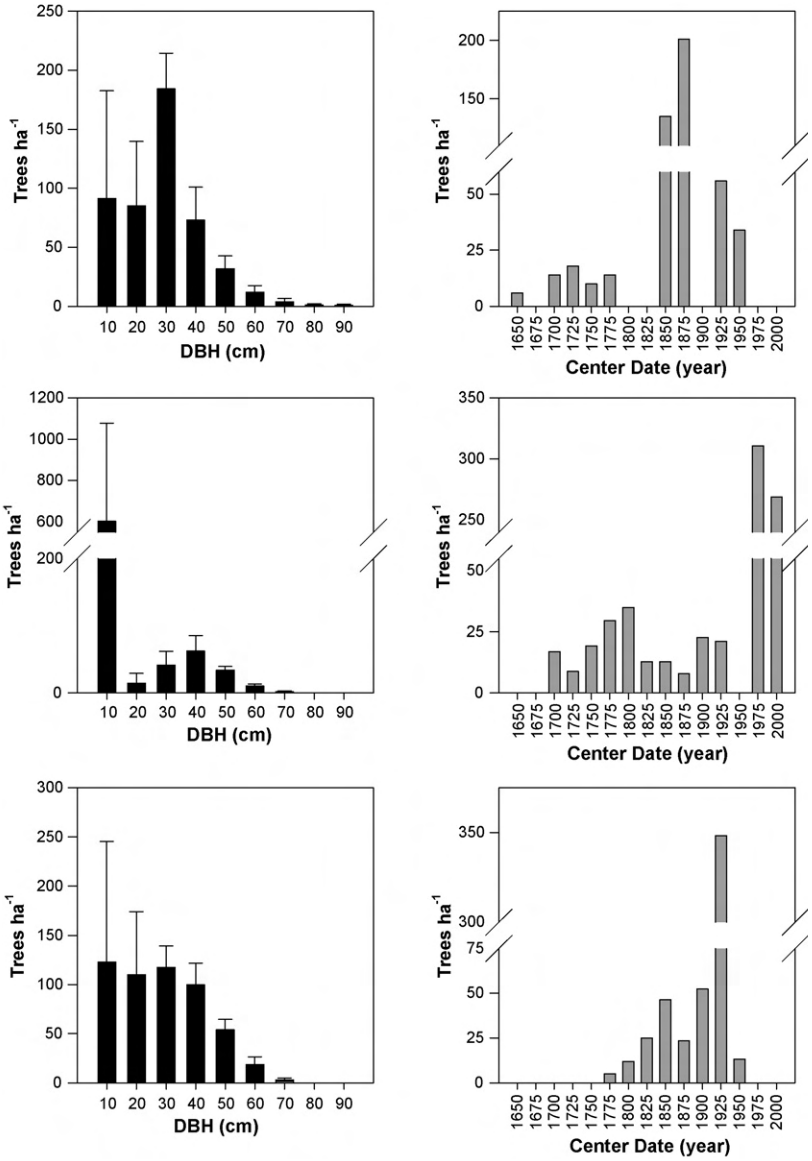

Fig. 3. Diameter and center date distributions (top site NE, middle site W, bottom site SW, error bars are standard errors). X-axis values are the endpoints of the DBH or date class.

Heights of the measured trees averaged 9.5 m (±1.1 m). Height was significantly correlated with dbh ($r = 0.47$, $p < .001$). Crown base height averaged 4.0 m (±0.15 m) and was also significantly correlated with total tree height ($r = 0.56$, $p < .001$). However, although crown base height tended to increase with tree diameter, variability was high and the relationship was not significant.

Tree regeneration consisted entirely of *Quercus ilex* shoots at sites W and SW, averaging 9603 stems ha^{-1}; all of the stems were ≤30 cm tall. At site NE, we found no *Q. ilex* but an average of 589 *P. nigra* stems ha^{-1} and 295 *Juniperus* spp. stems ha^{-1}. Two-thirds of the pines and junipers were well established, taller than 30 cm. Regeneration was very patchy throughout all three sites. *Q. ilex* was observed off-plots at site NE and pine and juniper regeneration was observed at the other sites.

Forest floors were shallow, with litter averaging 1.7 cm and duff only 0.9 cm (Fig. 4). The estimated biomass of woody debris varied moderately among sites, from a low of 1.9 Mg ha^{-1} at site SW to a high of 2.8 Mg ha^{-1} at site W. Sound woody debris in the diameter class >7.62 cm was encountered at only one site (W). No rotten woody debris was encountered at all.

To describe the differences between the structure of the old forest versus that of contemporary forests, we compared the average diameter distribution and aboveground biomass at Sierra Turmell with the averages for *P. nigra* in northeastern Spain (Catalunya; Fig. 5). The northeastern Spanish forests were dominated by smaller diameter trees, as opposed to the larger trees at Sierra Turmell. The difference between the forests became more exaggerated in the biomass comparison because of the exponentially increasing contribution of larger

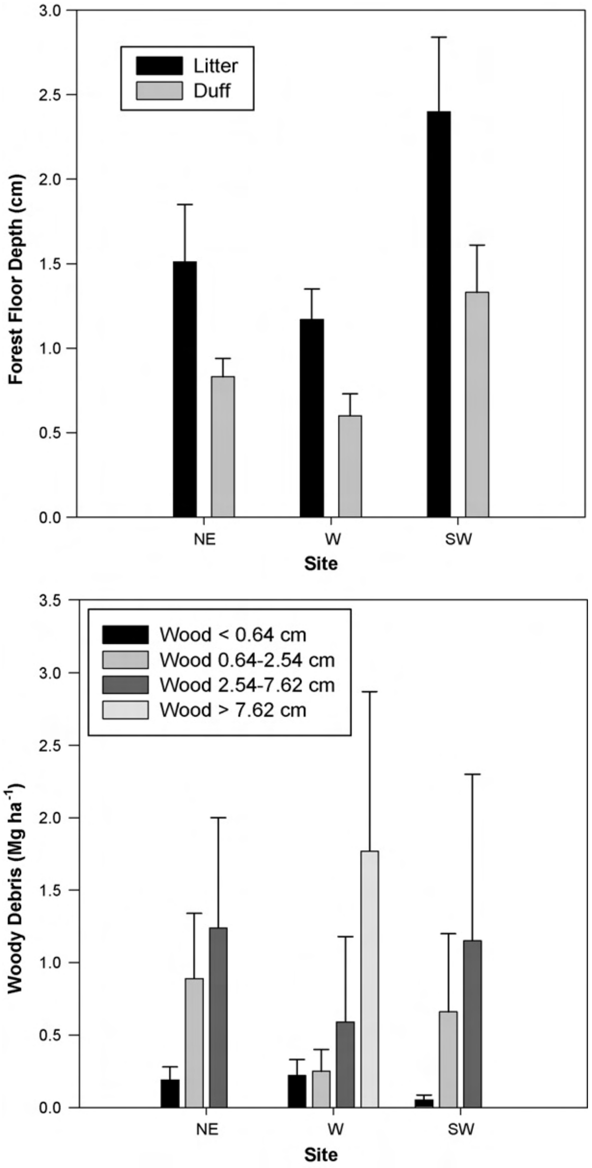

Fig. 4. Depth of forest floor (litter [Oi] and duff [Oe and Oa]) (top panel). Estimated biomass of dead woody debris divided by diameter size classes (bottom panel).

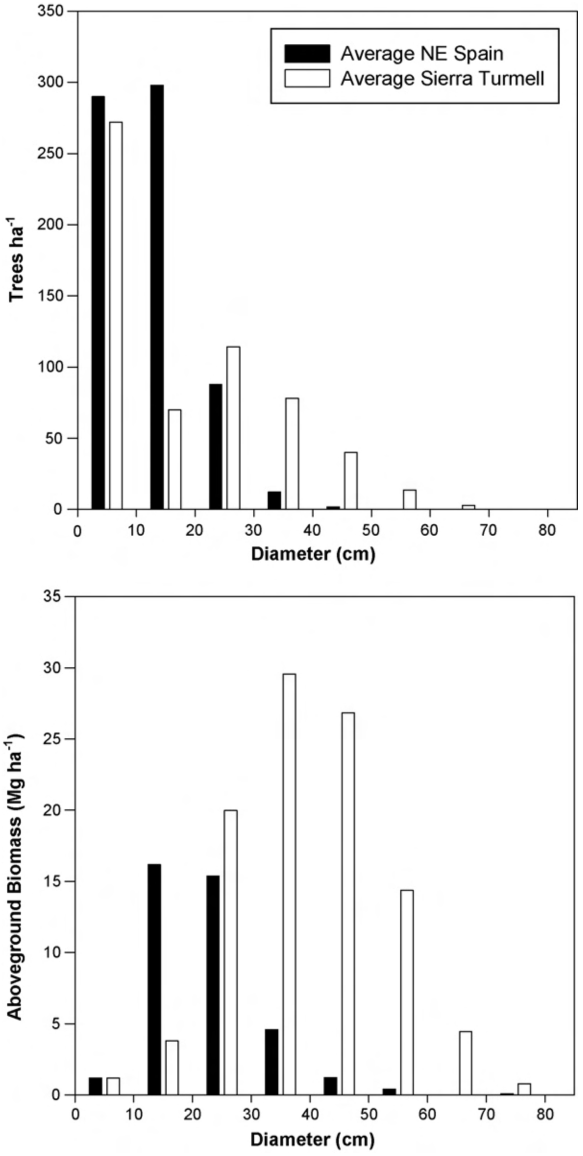

Fig. 5. Comparison of distributions of diameter (top panel) and aboveground biomass (bottom panel) of the average *P. nigra* forest in northeastern Spain and the average of the three sites at Sierra Turmell.

trees. On a per-hectare basis, the Sierra Turmell forest supported over twice the basal area and over 2.5 times the biomass of the northeastern Spanish forests (Table 1), with a comparable advantage in terms of carbon storage. Aboveground carbon sequestration, on the other hand, was over six times higher in the younger northeastern Spanish forests. Trees in the Sierra Turmell forest averaged almost three times older and the oldest tree at Sierra Turmell, 362 years, was over a century and a half older than the oldest *P. nigra* tree encountered on any of the inventory plots in northeastern Spain (Table 1).

3.2. Fire

Fire-scarred trees provided evidence of numerous surface fires in the past, but the practice of cutting into the catfaces with axes obliterated many of the oldest records (Fig. 6). We identified 11 scars as being definitely or most probably due to axe cutting, based on observation of the tree in the field and of the sample in the lab. Cross-sections were artificially flattened by axe cutting, in contrast to natural healing curls observed after fire scarring. The confirmed axe cut dates ranged from 1789 to 1904; the average date was 1868. An additional 4 scars were considered possibly due to axe cutting; these dates ranged from 1851 to 1876, averaging 1866.

The oldest confirmed fire date was 1834, in site NE. An additional five fire dates were determined in the 19th century. The 20th century fire record was most complete, probably both because less wood was lost to fire or decay and because the cutting practice ceased at the end of the 19th century. The first fire date recorded on more than one sample was in 1938, with scars on 5 of the 7 recording samples (those with open scars that facilitate recording of fires) in site W. In 1951, fire was recorded on one sample in each of sites W and SW. Fire in 1953 scarred many more samples in these two sites, 11 of the 14 recording samples. Fires in 1963 and 1981 were confined to sites W and SW, respectively. The Xert fire of 2001 crossed all three sites, scarring 16 of the 22 recording samples. The final fire, in 2003, scarred only a single sample tree in site SW.

We did not calculate fire frequency statistics such as the mean fire interval or fire rotation because it was clear that a substantial portion of the fire record had been erased from the catfaces by cutting. However, taking all three sites together, there were 11 fire dates in 172 years (1834–2005). In the 20th century, 3, 7, and 6 fire dates were recorded in sites NE, W, and SW, respectively. The minimum interval between 20th century fire dates within any site was 2 years (sites W and SW); the maximum was 57 years (site NE).

Fire and climate were not significantly linked in superposed epoch analysis (data not shown). The local tree-ring width index, used as the proxy variable for climate, was weakly but significantly correlated with total precipitation in the region for the overlapping period 1944–2001 (Fig. 1) ($r = 0.17, p < .001$). The lack of linkage between fire dates and precipitation was confirmed by inspecting the regional precipitation record during the 8 fires in the overlapping period. Regional precipitation was below average in only half of the fire years and no fires were recorded in the 15 driest years. Even fewer fire years (2 out of 8) were below average in summer (June–August) precipitation.

Seasonality of scarring could be determined on 40% of the fire scars. Seventy-six percent were formed while tree-ring growth was dormant, 7% in the early earlywood, 10% in the middle earlywood, and 7% in the late earlywood.

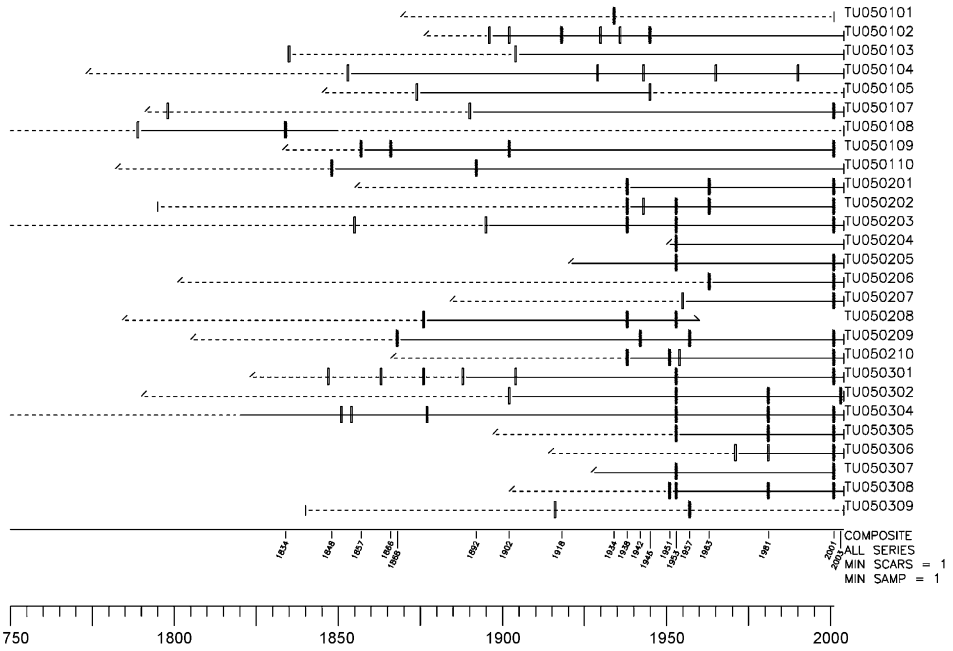

Fig. 6. Fire history chart for the three study sites. Filled vertical bars are fire dates, listed on the bottom axis; open bars are other injuries. Solid horizontal lines indicate recording periods; dashed horizontal lines are non-recording periods (e.g., before formation of first scar). Site NE trees numbered 101–110, site W trees numbered 201–210, site SW trees numbered 301–309.

4. Discussion

The relict forest at Sierra Turmell provides evidence of multi-aged forest structure persisting through numerous surface fires over several centuries. It is not possible to generalize from a single mountain to all the diverse environments where *P. nigra* grew in the past. However, the relict forest had many attributes that were consistent with a fire-resistant evolutionary strategy (Keeley and Zedler, 1998). Forest structure was relatively open with large trees and high crown bases, reducing vulnerability to crown fire behavior. Shallow forest floors and low woody debris loading, probably due to repeated fires, were also conducive to reduced fire severity. Only one of the three sites was dominated by small-diameter trees and even that site had a wide range of large and old (300+ years) trees. The multi-aged stand structure indicated that regeneration had been dominated by small-scale events for at least 350 years, with mature overstory trees surviving many surface fires. There were no consistent relationships between tree ages and fire events. Regeneration modes ranged over 100 years, from 1875 at site NE to 1975 at site W (Fig. 3). Site SW had minimal tree establishment after the early twentieth century, but the other two sites had substantial numbers of trees that established after the widespread fires of the 1930s and 1950s. These patterns support the hypothesis that repeated surface fires tended to thin young trees, but not eliminate them. Current pine regeneration (trees < 1.3 m in height) was quite patchy and we encountered no pine seedlings on the plots on two of the three sites, although there were some seedlings nearby. However, the overall average for pine regeneration was 196 *P. nigra* seedlings per hectare. Assuming a lifespan of 300 years, a rudimentary demographic analysis shows that maintaining the average forest density of 592 trees ha^{-1} would require successful recruitment of only 19.7 trees ha^{-1} decade^{-1}, suggesting that regeneration appears to be adequate for sustaining the forest. The dense regeneration of Quercus and additional regeneration of Juniperus, though currently limited to short plants, indicate a capacity for these species to expand if a stand-killing disturbance were to occur.

Fires recurred frequently on Sierra Turmell, even given our minimal ability to detect the complete inventory of fire dates due to the cutting of catfaces. The overall fire frequency of 11 fire dates in 172 years was similar to fire occurrence in *Pinus pinaster* in Málaga, 13 fire dates in 175 years (Vega-Hidalgo, 2000). Even at the smaller scale of the individual sites ($\sim$3 ha), the longest fire-free interval was 57 years, still falling within the range of the ‘‘predictable stand-thinning fire’’ regime (Keeley and Zedler, 1998).

The lack of linkage between fire occurrence and climate appears unusual, given the general relationship between drought and area burned in the eastern Iberian Peninsula (Piñol et al., 1998; Pausas, 2004) and in many other regions of the world. For example, fire-climate analyses with similar numbers of fire dates and time periods in semi-arid pine forests of southwestern North America showed strongly significantly dry conditions in fire years (Swetnam and Baisan, 2003; Fulé et al., 2005). A possible explanation for the difference could be the variation between the climate patterns at the peak of Sierra Turmell versus the climate of the relatively sheltered and sometimes distant communities where the weather stations were located. The fact that weather records were incomplete and had to be pieced together from different stations also may have introduced error.

Another possible explanation of the poor relationship between drought and fires could be the source of the fires. Fire regimes in southwestern North America were influenced by people but there is substantial evidence that high lightning incidence and dry windy weather may have accounted for the great majority of past forest fires (Allen, 2002). In contrast, people have been considered the most important source of ignition for Mediterranean fire regimes (Grove and Rackham, 2001). Human-caused wildfires can be ignited by accident or as arson, but Grove and Rackham (2001) argue that ‘‘occupational’’ burning to improve pasture for sheep and goats was common throughout southern Europe. Frequent burning by sheepherders was also suggested by Vega-Hidalgo (2000) to explain the Málaga fire history.

Occupational burning by pastoralists could be an explanation for the pattern of burning during average or relatively wet years at Sierra Turmell, if the burning practitioners intentionally selected less hazardous conditions for fire. This hypothesis would be consistent with the other cultural activities observed on the site: cutting into catfaces and pruning of twinned stems. These activities, which appear to have taken place in the 19th century, seem to have been oriented toward conservation of trees. Cutting into the catfaces had undesirable effects in terms of our ability to reconstruct the fire history, but the cutting was relatively shallow and thus served as a way to harvest a useful resource—resinous wood—without killing the trees. Pruning twinned stems resulted in the retention of single-stemmed trees. Although a botanist in the late 18th century commented on the ‘‘unaltered’’ isolation of the forest at the crest of Sierra Turmell (Cavanilles, 1795), the development of terraced farmlands and the evidence of cutting and perhaps human-caused burning in the subsequent two centuries show that human influences had increased.

How can information from the old forest ecosystem be applied to modern management? We suggest two ways. First, the contrast between the Sierra Turmell forest and the average *P. nigra* forests of northeastern Spain shows important differences in stand structure that have implications for genetic variability, wildlife habitat, and many other forest attributes. Here we focus on the carbon and fire implications. Forest plantations worldwide and in northeastern Spain serve to sequester and store carbon, but this ecosystem service is of limited value if fire kills the trees and rapidly releases the carbon (Battle et al., 2000; Houghton et al., 2000). The average *P. nigra* forests are young, consisting mostly of planted trees, so carbon sequestration is rapid. The average *P. nigra* forests are dense with small trees, however, so the arrangement of fuels ensures that there is a high loss of forest to severe wildfire (Espelta et al., 2003). The remnant forest stores substantially more biomass and carbon per hectare, and it has proven to be resistant to several wildfires. To the extent that Mediterranean forests contribute to European carbon balance, it may be useful to consider managing some *P. nigra* forests for larger and older trees. Prescribed burning, perhaps following patterns of frequency and seasonality developed by pastoralists, might be useful for reducing the size and severity of wildfires (Piñol et al., 2005). Newer forests could mimic mature forests in their structure and disturbance regimes, especially in the low density of stands and the maintenance of traditional low-intensity fires.

The Sierra Turmell data provide a living example of old forest structure that has persisted for over 300 years. Relict sites and reconstructions of historical conditions are valuable for describing reference conditions of ecosystem structure, composition, and dynamics, providing guidance for ecological restoration of degraded areas (Society for Ecological Restoration 2002). In a broad sense, the 20th century reforestation of Spain and other Mediterranean countries was intended to restore the perceived benefits of forest cover, including timber production, and erosion control (Pausas et al., 2004). Unfortunately, the establishment of dense stands of flammable conifers may have had the unintended consequence of increasing fuel hazards (Grove and Rackham, 2001); these fuels appear to be particularly incompatible with warming climate trends (Piñol et al., 1998). Current approaches to ecological restoration in the region are focused on more sophisticated and realistic assessments of plant communities, human needs, and future climates (Pausas et al., 2004; Vallejo et al., 2006). In this context, the relict forest of Sierra Turmell may offer useful guidance for practical and attainable goals (Ehrenfeld, 2000) for restoring some sustainable *P. nigra* forests resistant to severe wildfire.

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