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Past growth suppressions as proxies of fire incidence in relict Mediterranean black pine forests

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ABSTRACT

Global warming and land use changes, contributing to landscape level fuel increments, could threaten Mediterranean pine forest resilience to wildfire disturbances. Reconstructions of historical fire regimes allow for the disentanglement of these two drivers by comparing the influence of climatic and anthropogenic variables on fire. Here we combine three sources of historical data: charcoal accumulation rates from a peat bog, detailed historical records of fire incidence and tree-ring width data from five relict black pine (*Pinus nigra*) forests with fire-scarred trees located in Sierra de Gredos (central Spain). We found growth suppression in 1893 and 1894 in all the sites which coincided with a peak of fire incidence in historical records and an increase in charcoal accumulation rates. The occurrence of these three synchronous events suggests increased wildfire incidence in the area which shaped the current stand structure of relict black pine forests. These late 19th century developments, we argue, can be mainly attributed to anthropogenic factors and contributing climatic drivers. We argue that the dissolution of the "Mesta", the biggest transhumance livestock organization in Europe lasting from the 13th to the 19th centuries, led to more extensive grazing and uncontrolled use of forests and grasslands which likely contributed to increased wildfire incidence. Additionally, 1893 was characterized by anomalously warm spring temperatures which may have facilitated vegetation flammability. Our approach couples human and climate systems as drivers of historical fire incidence in Mediterranean pine forests.

1. Introduction

Mediterranean pine forest ecosystems are known to be resilient to disturbances such as wildfire and drought (Naveh, 1974, Trabaud, 1987, Alfaro-Sánchez et al., 2015). However, two major global environmental changes may disrupt this resilience. First, climate warming is expected to increase the severity and frequency of heat waves and droughts which have been linked to increased wildfire risk (Piñol et al., 1998, Pausas, 2004, Cardil et al., 2014). Second, land-use changes driven by rural depopulation during the second half of the 20th century have increased the amount and homogeneity of landscape fuel beds leading to a greater frequency and size of fires in many Mediterranean countries since historical studies indicate that most fires were small and limited by fuel availability (Gil-Romera et al., 2010b, Pausas and Fernández-Muñoz, 2012, Molina-Terrén et al., 2016, Chergui et al., 2017). However, to understand if warming-amplified aridification, fuel build-up and human activities may be converging synergistically to trigger fire regime changes in Mediterranean pine forests we need long-term reconstructions of fire activity (Keeley et al., 2012). Applied historical fire ecology approaches are therefore needed for periods with abrupt land-use changes to discern the role played by humans on the fire regime (Swetnam et al., 1999; Abel-Schaad and López-Sáez, 2013, Sarris et al., 2014).

At millennial time scales, changing fire regimes have shaped Mediterranean pine forests throughout history as a function of climate-human feedbacks (Marlon et al., 2008, Gil-Romera et al., 2010a, Blanco-González et al., 2015, López-Sáez et al., 2017). Indeed, fire seems to have led to rapid structural and compositional changes in Mediterranean pine forests for at least the past 3000 years (Pyne, 2009, Carrión et al., 2010, Abel-Schaad et al., 2014, Leys et al., 2014). For instance, black pine (*Pinus nigra*) showed a long-term resilience to fire regimes characterized by frequent small fires and rare high-intensity fires, but recurrent anthropogenic crown fires linked to intensive land-use may have triggered their decline in the northern Iberian Plateau

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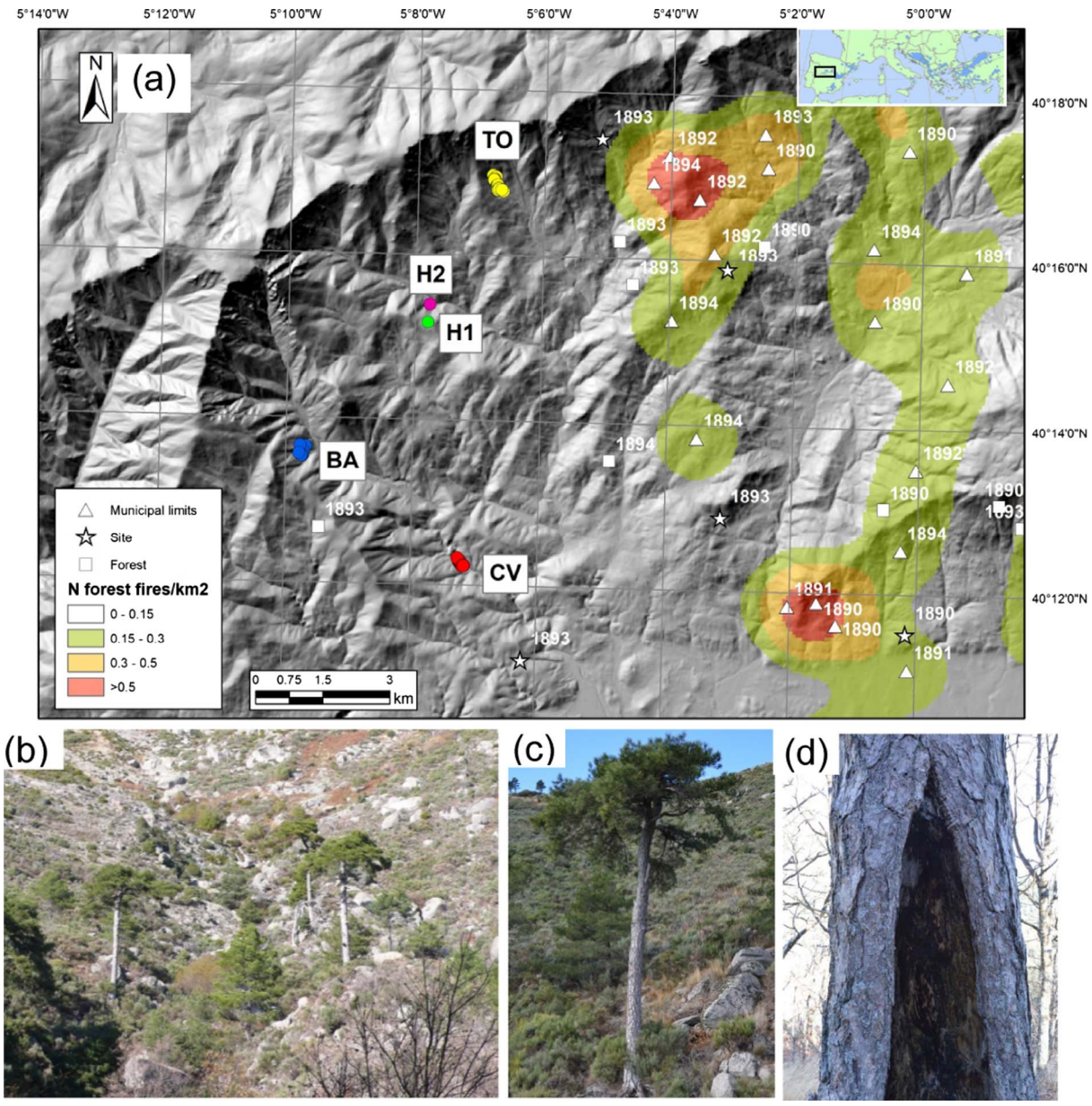

Fig. 1. Geographical situation (a) of the five black pine forests investigated in Sierra de Gredos (see Table 1; symbols show the locations of sampled trees and stands) and historical fire locations and estimated density of fire foci (color scale) during the 1890–1894 period when there was a peak in the number of forest fires recorded in the study area (Sierra de Gredos) based on documentary sources (three georeferenced historical fire levels are used: triangles, municipality; stars, sites without specified boundaries; and squares, forests or plots with precise limits of the property); views of an isolated relict stand (b), a sampled tree (c) and a living, fire-scarred tree (d) showing a cat face (triangular scar located at the base of the stem caused by fire damage). In the map the upper inset shows the distribution of black pine (*Pinus nigra*) in Europe and the location of the study area in central Spain (box). In the map of the study area (a), the shading represents the elevation gradient which ranges between low (700–900 m, down-right part) to high elevations areas (2000–2200 m, upper left part).

1400 years ago (Morales-Molino et al., 2017). Nowadays, this species forms relict populations in northern and central Spain, representing the south-western distribution limit of the species in Europe (Fig. 1), whereas it is abundantly distributed throughout eastern Spain (Barbéro et al., 1998).

Macrofossil evidence confirms that in central Spain, black pine was present from the mid-Holocene up to the present (Rubiales and Génova, 2015). The palynologic record has revealed that pine forests were more widespread in this area before the Middle Ages, when human pressure (fire, grazing) intensified leading to extensive deforestation from the 13th to the 15th centuries (López-Sáez et al., 2009, 2014, 2017; Robles-López et al., 2017). The beginning of this period coincides with the establishment of the "Mesta" transhumance grazing system, which was created in 1273 and was the major livestock organization in the Iberian peninsula until its dissolution in 1836 (Klein, 1920; Pascua-Echegaray, 2007). The end of "Mesta" activities in the 19th century represented a socio-economic shift with clearly negative impacts on forests because this organization regulated the controlled use and management of forests and pastures where sheep herds grazed (López-Sáez et al., 2017). It is therefore plausible that after the "Mesta's" dissolution unrestrained exploitation of mountain forests may have facilitated increased wildfire frequency (López-Merino et al., 2009, 2016a, 2016b).

Here we analyze the possible effects of the end of the "Mesta" on relict black pine forests in the Sierra de Gredos (central Spain) using dendrochronology to reconstruct growth patterns and past fire incidence. Previous dendroecological studies have provided long-term information on tree growth which is useful to preserve Mediterranean relict pine populations experiencing high human pressure (Todaro et al., 2007, Génova and Moya, 2012). For instance, it is necessary to characterize the climate-growth relationships in these relict stands so as