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SHORT COMMUNICATION

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Many missing rings in old Canary pines can be related with age, fires and traditional uses

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Abstract

Aim and area of study: In the present paper we estimated the age of four monumental *Pinus canariensis* of Gran Canaria (Canary Islands, Spain) by means of tree-ring analysis. Many tree-ring series have been accurately studied and many missing rings have been determined.

Material and methods: The trees were dead and the samples analysed were big disks. We measured numerous radii and crossdated the individual tree-ring series, paying particular attention to the existence and location of missing rings. We have distinguished between missing outer rings (MORs) and missing inner rings (MIRs) and analysed the possible causes of both.

Main results: We determined an average of 8.8% total missing rings (MRs) for these long-lived trees, with a maximum of 96 MRs in a series of over 500. We have tried to establish a tree-ring chronology on Gran Canaria Island, also having the tree-ring series from Inagua site, but the long individual tree-ring series analysed do not crossdate between them

Research highlights: We consider the Canary pine a species hard to conducting dendroecological studies, especially if the samples come from managed old trees, in which a large amount of known and potentially unknown missing rings can hampered dating. Even knowing the difficulties involved in dendrochronological analyses of *P. canariensis*, we can confirm that it is a long-lived species, which can grow to over 500 years, and some of whose growth changes could be associated with certain historical and ecological events.

Additional keywords: dendrochronology; Canary Islands; Spain; growth changes.

Abbreviations used: GA (Pino de Gáldar); LA (Pino de la Lajilla); MIR (missing ring located anywhere in the inner part of the trunk), MOR (missing ring located in the outer part of the trunk); MR (the whole of missing rings); PI (Pino de Pilancones); SE (Pino Seco)

Authors´ contributions: Designed the general plan of the paper, writing and revising the texts; revised the initial data and integrated the tables and figures: MG. Measured and synchronized most of the dendrochronological sequences produced in the Canary Islands and made a highly significant contribution by providing historical information: CS. Measured and synchronized the samples of several monumental *Pinus canariensis* trees: BM.

Supplementary material (Table S1 and Fig. S1) accompanies the paper on FS's website

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Introduction

Pinus canariensis C. Smith is found in the western Canary Islands (Spain) and is the largest pine species native to Eurasia and Africa. The biggest tree is located in Vilaflor (SW Tenerife Island), reaching a height of 60 m and a perimeter of 835 cm (265 com of diameter at breast height, or DBH) (Domínguez & Martínez, 2005); it is an example of the few survivors of the enormous trees which were common in these islands in the past and have disappeared due to clear-cutting or fires (González Navarro, 2005).

Monumental trees are highly symbolic, their age is one of their greatest values, although this issue is often controversial. Furthermore, long-lived trees provide extensive records of information in their tree-rings series, which can be very useful because their annual resolution can enable reconstruction of past events. Therefore, in the present paper we attempted to estimate the age and to establish long chronologies of four monumental Canary pines that had survived until recent times. We were able to take the opportunity to analyse some disks of the trunks, which provide a large amount of tree-ring data. However, this task was hampered due to the fact that a large number of rings were missing. We therefore studied and established the type and frequency of the missing rings, linking these growth anomalies with high age or traditional uses and fires events.

Material and methods

The samples analysed are disks taken from four dead monumental trees on the island of Gran Canaria (Table 1). Three of these trees grew in the Pilancones Nature Reserve and died following a devastating fire that occurred from 27 July to 2 August 2007. One of these trees, known as the Pino de Pilancones (PI), was considered to be one of the most emblematic in the Canary Islands and even in Spain (Domínguez & Martínez, 2005; Génova & Santana, 2006). A lesser known tree, also huge, was the Pino de la Lajilla (LA). Two of these trees (PI and the Pino Seco or SE) had been hollowed out for extraction of inner heartwood, which in *P. canariensis* contains an extraordinary amount of resins (Climent *et al*., 1998). The extraction of these very duraminized splinters of lightwood, which in Spanish is called *tea*, constituted a traditional use in old trees. It was used to light bonfires and also to manufacture torches before the electric light was installed. The 2007 fire likely increased the size of these hollows, thus reducing the trees' resistance to the wind (Fig. S1-a,b,d [suppl]), which led to the trunk breaking, which caused the death of the trees several months later. LA also fell some months after the fire, although no serious wounds were observed on the trunk. The fourth pine studied (Pino de Gáldar or GA) grew in the NW of the island and also died, although in this case at the end of the 20th century, due to unknown causes.

The Cabildo of Gran Canaria decided to cut these dead trees and use some disks for the purposes of scientific studies and divulgation. One of the challenges posed by the present research involved the transport of the available disks from this Island to the Universidad P.litécnica de Madrid, as well as measuring them, due to their huge size. P.ior to the measurement, all the disks were highly polished by mechanical and manual means with the use of different-grain sandpapers. We subsequently selected the most suitable number of measurement radii (Table 1, Fig. 1), according to the eccentricity and heterogeneity observed in each disk. We measured the rings (with an accuracy of 1/100 mm) by means of the Lintab measuring system and associated Tsap software (Rinn, 2003). Regarding PI, two discs were available: an incomplete one, which was cut into sections, and another one, which was complete but could not be cut into sections; we therefore resorted to measuring the eight radii selected by means of digital photography (Fig. S1-e [suppl]).

We measured numerous radii in each disk (Table 1, Fig. 1), in most cases from the bark to the pith, except in SE, because the disk did not present any central portion as a result of the wound caused by lightwood extraction (Fig. S1-a [suppl]), and in two of the PI radii that only reached the lightwood scar, with the aim of dating it (Fig. S1-e [suppl]). The tree-ring series measured were analysed and crossdated by means of TSAPWin (Rinn, 2003) and Cofecha (Grissino-Mayer, 2001) graphic and statistical tools. In this analysis we paid particular attention to the location of missing rings: incomplete, discontinuous or wedging rings. We distinguished between the missing rings located anywhere in the inner part of the trunk (MIRs), and the missing outer ones (MORs), which had not developed in the final growth periods. MIRs and MORs, together called MRs, are established by crossdating all the radii measured in each disk. We also checked and analysed once again the tree-ring series of 36 samples from 21 trees extracted with a Pressler borer in 1996 in the east of Gran Canaria (Inagua site, Génova & Santana, 2006); of these, one tree contains up to 350 rings and 9 display over 300 rings (Fig. 1). We estimated the age of each tree based on the number of rings in the average series (Table 1). We used different detrending methods such as the negative exponential curve, smoothing splines and a low-pass filter, to standardize the individual mean tree-ring series, subsequently attempting to crossdate these series. Finally, we checked these series with the long local chronologies established in the islands of La Palma and Tenerife (Génova & Santana, 2006).

Results and discussion

We elaborated a total of 34 tree-ring width series. The series from the same tree were successfully crossdated following a laborious process in which a large amount of discontinuous rings was found. Table 1 shows the number and the percentages of discontinuous rings located in these long-lived *P. canariensis*, with a maximum of up to 83 missing rings in a sequence of 328 years (25%).

The individual tree mean series established for these long-lived pines and those obtained from the Inagua site did not crossdate accurately and the exact dating therefore cannot be established, possibly due to non-synchronous disturbances which caused many complete missing rings. Our attempt to crossdate all these individual growth series with the local chronologies of La Palma and Tenerife (Génova & Santana, 2006) was also unsuccessful. Dendrochronological analysis of the Canary pine requires numerous tree-ring data replications within and between trees in order to suitably detect missing rings for reliable dating, and even then this it is not always possible, especially if the trees are old.

In any case, in our current study the estimated ages were closer to the actual ones comparing to the obtained ones in Génova & Santana (2006), because we availed of disk samples which in most cases presented pith and enabled us to better detect the missing rings. For example, the age of PI was estimated at 378 years by means of cores, whereas herein we estimated an age of 508 years through study of the disks (Table S1 [suppl]).

Among the different factors causing missing rings, the following have been indicated for *P. canariensis*: climate (Jonsson *et al*., 2002), severe crown fires (Rozas *et al*., 2011), volcanic eruptions (Miranda *et al*., 2013) and flood damage (Génova *et al*., 2015). We distinguished between MIRs and MORs, considering that in long-lived trees both types of missing rings result from different causes. We determined a higher frequency of MIRs close to the wounds and/or in periods with very narrow rings caused by intense stress episodes, while MORs are more frequent as the tree gets older (Table 1 and Fig. 1). Furthermore, the relationships between stem length and stem thickness and between stem size and root size, especially in damaged trees displaying wounds produced by lightwood extraction or by fires, which cause structural imbalances, might be complementary factors giving rise to MORs in these monumental Canary pines.

Figure 1 shows the tree-ring series analysed in this study, sorted out according to the year of tree death (table 1). Note that these pines exhibited low growth during the 17th century, contrasting with the following centuries. Subsequently, these high degree of tree competition in a dense forest most likely diminished as forest cutting intensified from the 18th century (González Navarro, 2005), and consequently the growth of the surviving trees increased; in parallel, correlative MIRs were becoming more frequent. We estimated the start of lightwood extraction wounds to be in the 18th century, coinciding with a high number of MIRs. Whereas the fire scar was dated in the middle of the 19th century, also coinciding with a high number of MIRs in three of the trees, indicating fire damages extended (Fig. 1).

In conclusion, after damage, reinitiation of activity of the vascular cambium in Canary pine can be retarded or highly irregular, with the resulting incomplete or complete missing rings. Some of these missing rings can be related with certain traditional uses and fire events, thus indicating the increase in anthropic impacts.

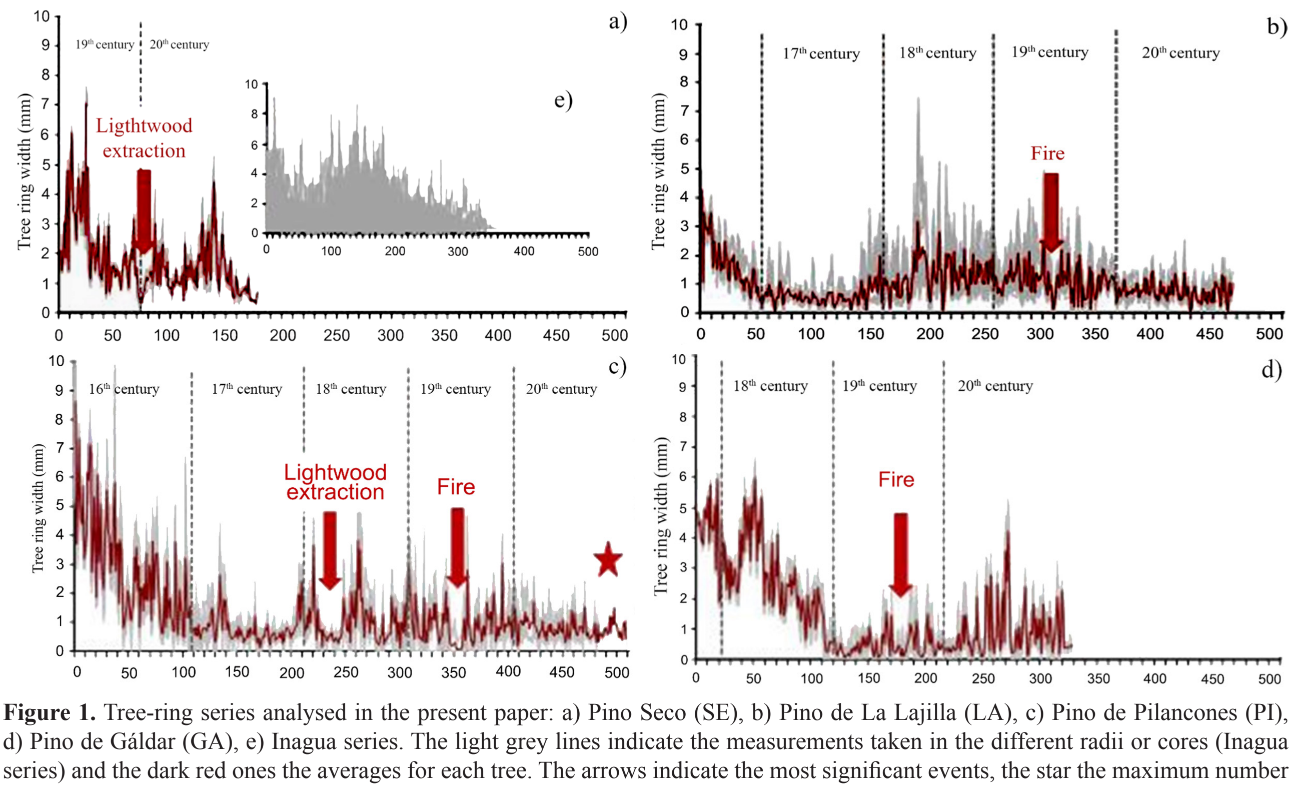

Figure 1. Tree-ring series analysed in the present paper: a) Pino Seco (SE), b) Pino de La Lajilla (LA), c) Pino de Pilancones (PI), d) Pino de Gáldar (GA), e) Inagua series. The light grey lines indicate the measurements taken in the different radii or cores (Inagua series) and the dark red ones the averages for each tree. The arrows indicate the most significant events, the star the maximum number of continuously MORs (56) and the dashed lines its approximate time range.

Table 1. The monumental trees studied along with their dendrochronological characteristics.

Characteristics[1]	SE	LA	PI	GA
Locality (Gran Canaria)	S. Bartolomé de Tirajana	S. Bartolomé de Tirajana	S. Bartolomé de Tirajana	Gáldar
Latitude (N)	27º 53´	27º 53´	27º 53´	28º 02´
Longitude (W)	15º 36´	15º 36´	15º 36´	15º 37´
Altitude (m)	1.150	1.120	800	1.500
Perimeter at breast height (cm)	220	480	525	300
Year of death	2008	2008	2008	1998
Nº radii measured	3	10	13	8
Max Nº missing rings per radii	9	40	96	83
% MIRs	0	3.6	6.6	12.8
% MORs	1.9	2.8	5.6	1.9
% MRs	1.9	6.4	12.2	13.7
Mean intercorrelation	0.868	0.742	0.715	0.759
Mean width (mm) ± SD	1.75 ± 1.2	1.02 ± 0.7	1.67 ± 1.4	1.50 ± 1.4
Estimated age (years)	178 (202)[2]	466	508	328

[1] MIR: missing inner rings. MOR: missing outer ring. MR: total missing ring. SD: standard deviation. [2] Number in parenthesis shows the estimated age calculated by adding the number of rings that would be missing to reach the pith, according to the mean width of the ten innermost rings. SE: Pino Seco. LA: Pino de la Lajilla. PI: Pino de Pilancones. GA: Pino de Gáldar.

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