Multilevel ^{13}C-late-wood signatures from seasonal-drought-induced stress on *Pinus pinaster* during last 35 years

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Abstract

Keywords:

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1. Introduction

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This is the introduction

2. Materials and Methods

2.1. Study area

We developed our study in two areas in north and east-center of the Iberian Peninsula (Fig. 1). The areas belong to the most vast native provenance region of maritime pine (*Pinus pinaster* Ait.), growing on sandy soils and forming large continuous populations at moderate densities (average of 500 - 1000 trees per hectarea). Average altitude for this region ranges from 900 m to 1000 m above sea level. Mean annual temperature is about 11 °C and mean annual precipitation is aprox. 562 mm. Forest ecosystems of the area are associated with oaks (*Quercus ilex* L., *Q. faginea* Lam., and *Q. pyrenaica* Willd.), beeches (*Fagus silvatica* L.), and other pine species (*Pinus sylvestris* L., *P. nigra* Arn. and *P. halepensis* Mill)

2.2. Core sampling

Dominant trees in ten sites on the maritime pine forests where core sampled (5 mm diameter) at chest height (1.3 m). The sample trees were located in five sites on northern study-site edge and other five sites on the center-east edge. Two dominant trees were sampled by site, and two core samples were extracted by tree. The core samples were air dried, sanded, and scanned (1000:1600 ppi). The tree-ring widhts in the scanned images where measured with R-package: `measuRing` (Lara et al., 2015), and statistically controlled with `dplR` package (Bunn, 2010).

A master chronology of *P. pinaster* with strong common signal (EPS $>$ 0.95, SNR $>$ 22), developed with core samples of 150 trees on ten sites of study area (Bogino and Bravo, 2008), was used to develop statistical control of the measured rings. The cross-dating process was developed on four common regions, defined after clustering tree-dimensional coordinates of the sites, with each of the clusters having sites at most 80 km of closeness (Figure 2).

2.3. climatic data

We processed a high-resolution gridded dataset (0.11° resol.) of monthly mean temperatures for peninsular Spain: Spain02, (Herrera et al., 2015) to compute Standardized Precipitation Indexes (SPI) across Ebro basin (1971 - 2010). Proyection of UTM coordinates of the sample plots to coordinate system in climate algorithm was developed with R-package `rgdal` (Bivand et al., 2015). The SPIs were modeled from the extracted spatial precipitations with R-packages: `raster`(Hijmans, 2015) and `spi` (Neves, 2012).

2.4. ^{13}C-late-wood signatures

One core per site was used for isotopic analysis on late wood of the dated rings. Each latewood portion of rings was carefully separated from earlywood with a microtome. Only rings formed after 1974 were analysed. Whole wood was milled, an aliquot of 100 mg was packed in porous bags and used for cellulose extraction. The samples were washed in 5 percent NaOH solution twice for 2 h at 60 °C in order to remove fats, oils, resins and hemicellulose. In a second step the lignin was removed with NaClO 2.7% After each treatment the samples were washed with distilled water and then finally dried overnight at 60 °C.

The δ^{13}C was determined using an elemental analyser linked to an isotopic ratio mass spectrometer via a variable open split interface (Max Plank Institute for Biogeochemistry, Germany). The results of laboratory were presented in the δ notation:

$$\delta = [(R_{sample}/R_{standard}) - 1] \times 10^3 \quad (1)$$

relative to the internationsl VPDB standard for cabon; where R_{sample} and $R_{standard}$ is the fractions of ^{13}C/^{12}C for the sample and the standard, respectively. The standard deviation for the repeated analysis (commercial cellulose) was better than 0.1. was better than 0.1 percent. The calibration versus VPDB was done by measuring IAEA USGS-24(graphite) and IAEA-CH7 (polyethylene).

2.5. Multilevel detrending

We detrended δ^{13}C series and the extracted SPI with the R-package `BIOdry` (Lara and Bravo, 2015; Lara et al., 2013). Such a package processes multilevel data frames (MDFs) containing serial records in initial columns, followed by recorded times (i.e., moths, years, relative times, etc.), and ended with factor-column levels, with factors being ordered from lower levels (usually a core-sample replicate, or an annual set of monthly meteorological records) to higher levels in sampling hierarchy (i.e., plots, sites, or other spatial units).

The package holds several functions but we implemented only two of them to develop the detrending process: `modelFrame` and `muleMan`. The former function was implemented to normalize both: δ^{13}C in late wood of the core samples and the SPI. This package normalizes the series by fitting linear mixed-effects models with function `ringLme`, implementing methods in R-package `nlme`.

Two kind of model formulas ara available in the package to assist the detrending process: 'lmeForm' and 'tdForm', these characters implement functions with same names (see manual of R-package `BIOdry`). We used 'tdForm' to normalize the isotopes, and 'lmeForm' to center the SPI. The second function, `muleMan`, was used to compute the the signatures between normalized δ^{13}C of *P. pinaster* late-wood and precipitation indexes via Multilevel correlograms: Mantel correlograms are computed from distance matrices of normalized series, and permutation tests (Goslee and Urban, 2007).

3. Results

Intra-annual ^{13}C-late-wood signatures (1974-2010) were signifficant during Junes (Figure 5) and Augusts (Figure 6) of last 35 years. The resting simulated months were no signifficant and ommited from the analysis.

4. References

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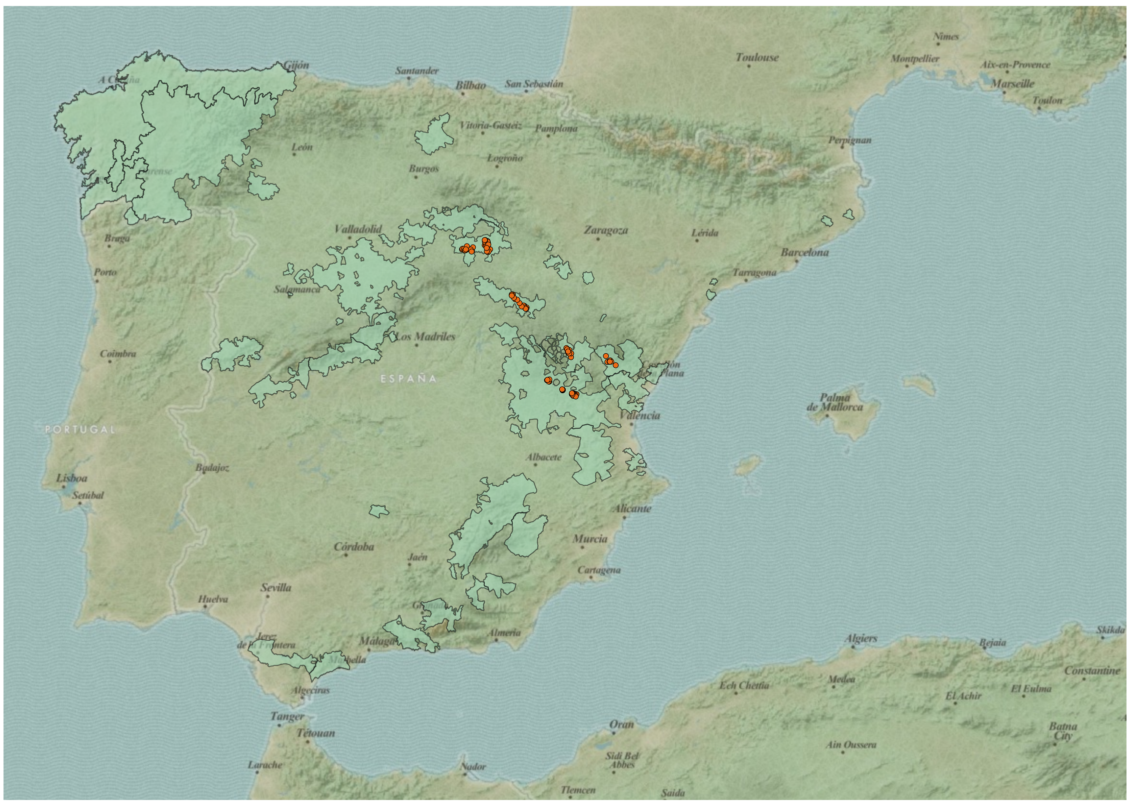

Figure 1: Study site

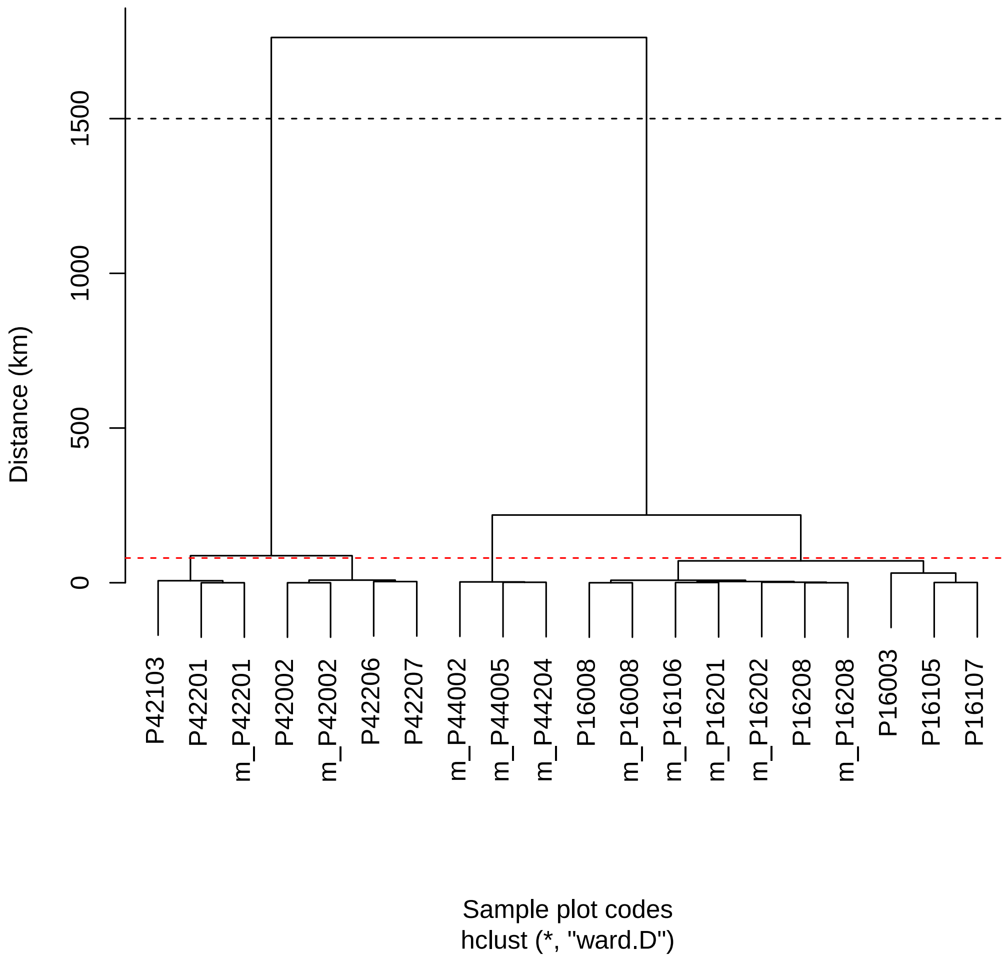

Figure 2: Relative geographic closeness between sample plots. Plots with master series are indicated with m_. Codes of sample plots begin with initial letter of the species (*P. pinaster*); following with two digits in code indicating the province code: 42 corresponding to *Soria* on Northern protion of *Ebro* river basin, and 16 being *Cuenca* on Southern region of such a basin; last three digits in codes indicate individual number of the sample plot. Sample plots of master series have been indicated with the letter m_. Black dashed line splits distance dendrogram in the two geographical portions of the river basin: North and South (distances $>$ 1500 km); and the red dashed line defines four groups used to statistically control (cross-dating) dendrochronological series (distances $<$ 80 km).

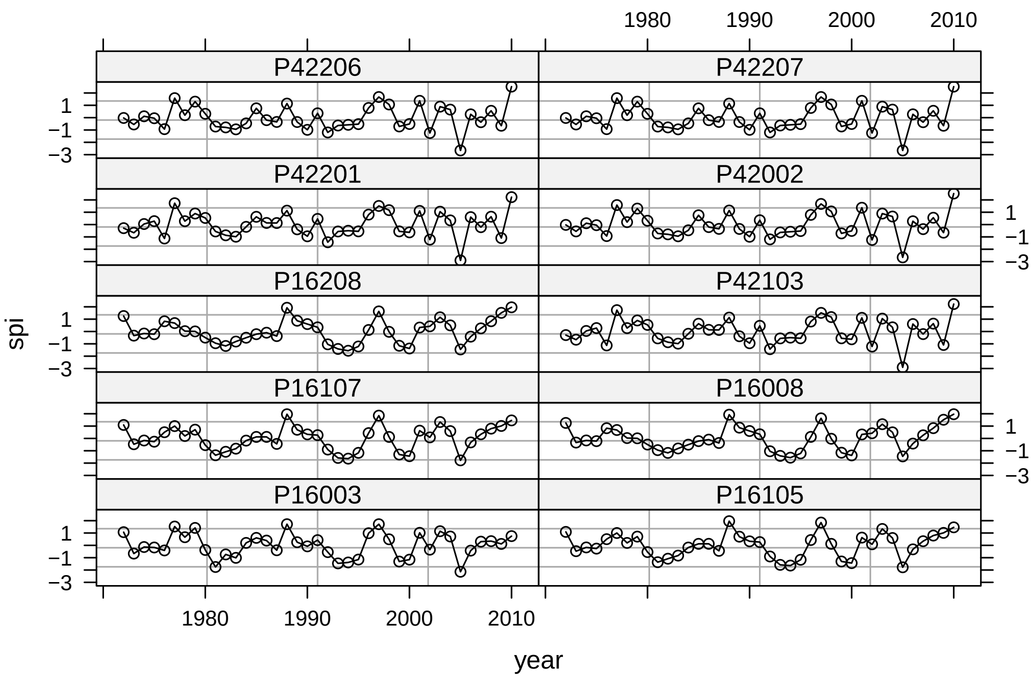

Figure 3: Series of standardized precipitation indexes (spi) on ten sample plots of *P. pinaster* located on Northern protion of *Ebro* river basin (42: *Soria*) and on Southern region of such a basin (16: *Cuenca*). Panels are ordered from plots with lower spi values (lower-left panel) to plots with higher spi extremes (higher-right panel).See legend in Figure 2 for further explanation of both: codes and plot locations.

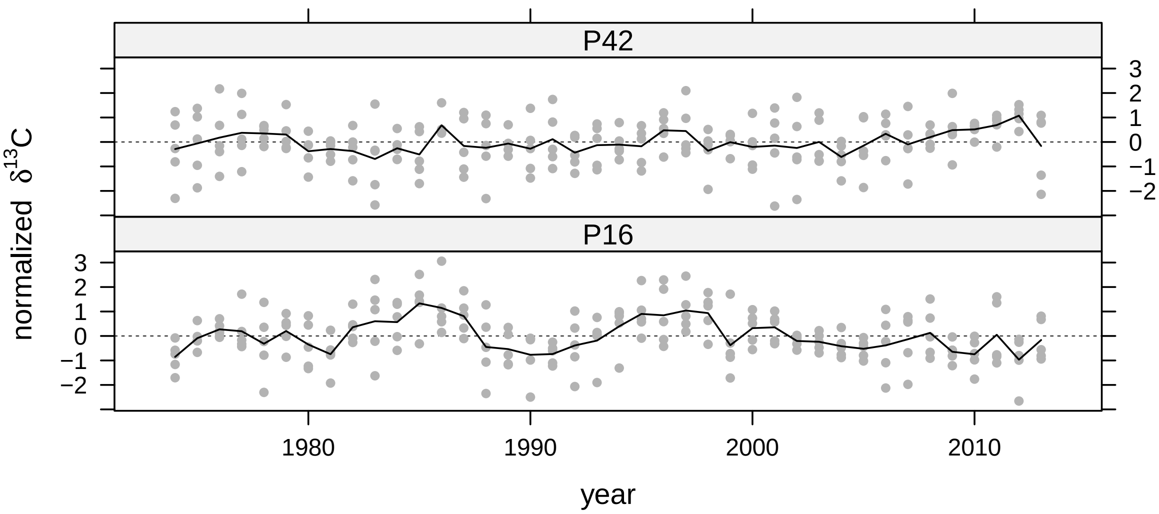

Figure 4: Normalized δ^{13}C of *P. pinaster* late-wood in trees growing on Northern Ebro basin (P42) and Southern portion of the basin (P16), Spain

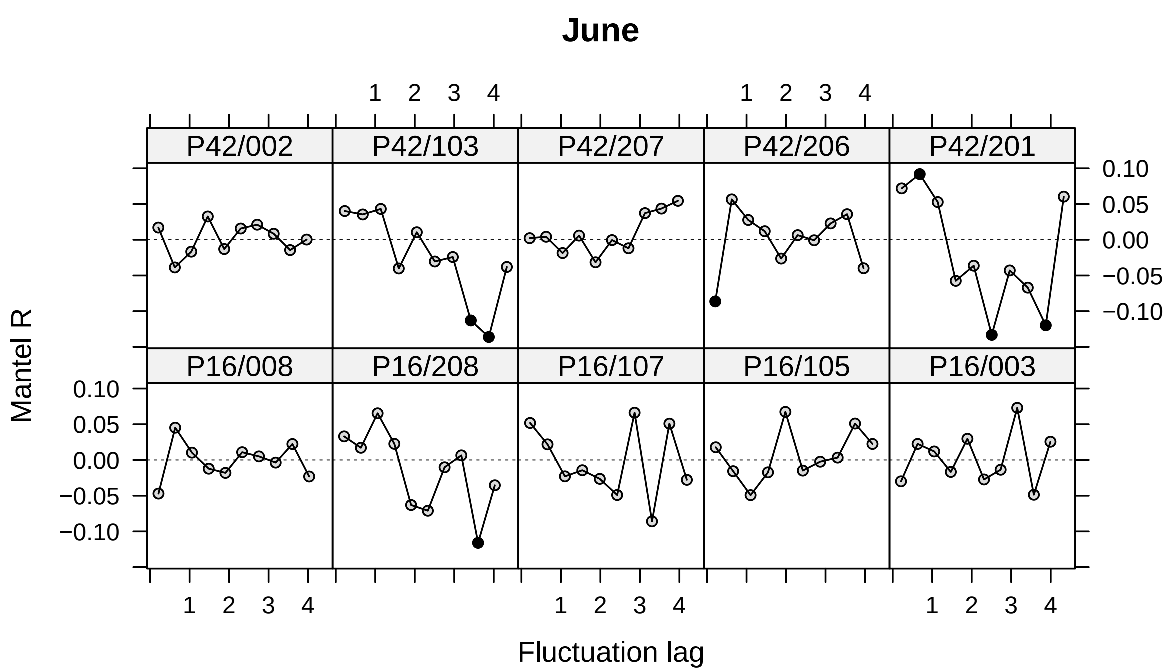

Figure 5: Signatures between normalized δ^{13}C of *P. pinaster* late-wood and precipitation indexes (June) from 1974 to 2010. Signatures where computed with Multilevel correlograms. The Fluctuation lags where computed with Sturdges' rule. 10^4 permutation texts where developed on compared fluctuation-distance matrices.

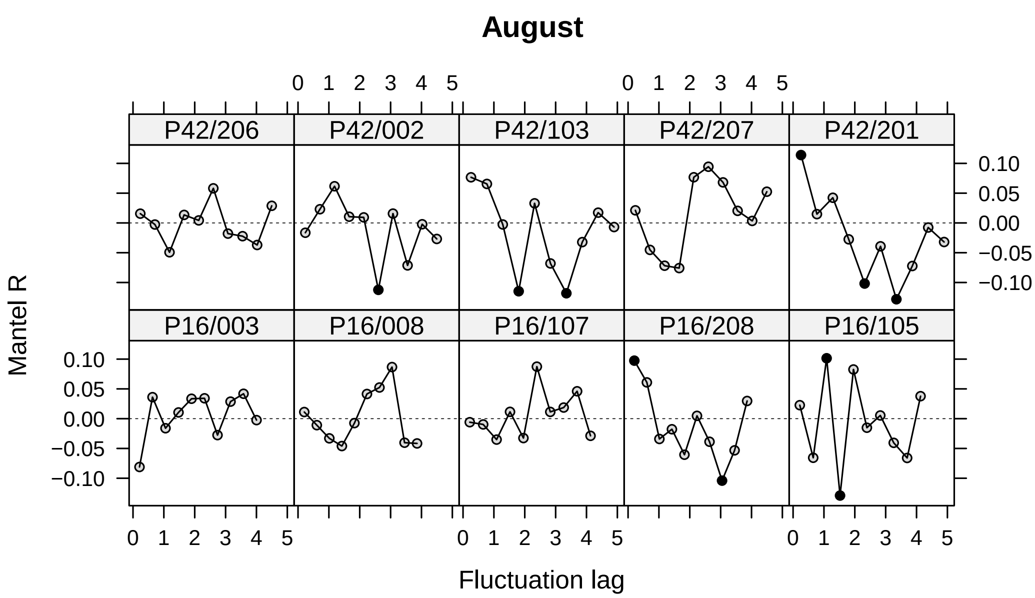

Figure 6: Signatures between normalized δ^{13}C of *P. pinaster* late-wood and precipitation indexes (August) from 1974 to 2010. Signatures where computed with Multilevel correlograms. The Fluctuation lags where computed with Sturdges' rule. 10^4 permutation texts where developed on compared fluctuation-distance matrices.