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# Intro

* The vegetation response to water deficit was assessed using remote sensing information and dendrocronologial data.

### Sequías

Although summer drought is a characteristic feature of the Mediterranean climate (Lionello 2012), an increase in the frequency and severity of drought events have been recorded for the Mediterranean region (Hoerling et al. 2012), particularly for southern Europe (Vicente-Serrano et al. 2014, Spinoni et al. 2015, Stagge et al. 2017) where a trend towards drier summers has been reported for the last three decades (Spinoni et al. 2017a). Además las proyecciones apuntan a que este incremento en la frecuencia continuará (Spinoni et al. 2017b).

In the Iberian Peninsula, major drought episodies were recorded in 1981, 1995, 2000 and 2005 (Vicente-Serrano et al. 2014). The 2004/2005 and 2011/2012 hydrological years are considered two of the worst drought periods recorded in the Iberian Peninsula, particularly in the southern sector (García-Herrera et al. 2007, Trigo et al. 2013, Gouveia et al. 2015). These events were extreme in both its magnitude and spatial extent (Gouveia and Trigo 2014).

notas sequia

* the drought events have been longest and most severe in the period 1991-2010 for mediterranean are of Southern Europe
* Seasonally, drought frequency is projected to increase everywhere in Europe for both scenarios in spring and summer, especially over southern Europe, and less intensely in autumn (Spinoni et al. 2017b) Aumento de la frecuencia de sequías en spring and summer desde 1950 hasta 2014 (Spinoni et al. 2017a) Both for frequency and severity, the evolution towards drier conditions is more relevant in the last three decades over Mediterranean area in summer, an increase in the drought severity in the Iberian Peninsula has been observed in the last decades (Vicente-Serrano et al. 2014).

Althought several works have reported these two years as some of the worst drought events, we characterised the drought at several spatio-temporal scales in the study area. From a long-term perspective, we compare the accumulated monthly precipitation at a meteorological station (Granada, Base Aérea) during the hydrological years 2004-2005 and 2011-2012 with the average of accumulated monthly precipitation for the period 1950-2015.

### Extreme sequias y ecologia

* ojo hablar de que la sequía es un proceso natural, pero que se está viendo aumentado en los últimos años:

Drought is a natural phenomenon that occurs when water availability is significantly below normal levels over a long period and the supply cannot meet the existing demand.

ver intro Ecosphere: Drought affects ecological systems across every climatic zone worldwide and is exacerbated by climate change and increasing anthropogenic water demands (Mishra and Singh 2010). Characterized by below-normal precipitation (Dai 2011), meteorological drought results from complex interactions between the atmosphere and hydrologic processes within the biosphere. Unlike aridity, which is a permanent feature of climate (Wilhite 1992), drought is a temporary extreme event (Palmer 1965, Mishra and Singh 2010) that can persist for extended time periods (months to years; Mishra and Singh 2010). Drought can cause significant changes in ecosystem productivity and water dynamics, and it is one of the most economically and ecologically disruptive extreme events affecting millions of people globally (Dai 2011).

Extreme climate events (e.g. droughts) severely affect forests and grasslands throuhg changes in plant physiology, phenology and carbon allocation (Ummenhofer and Meehl 2017) (incluir citas para los efectos de la sequía sobre la vegetación).

No solo efectos aislados, sino también en conjunción con otros factores, sobre todo en el mediterráneo donde convergen muchos de los factores que pueden interaccionar:

* La sequía es un factor crucial a tener en cuenta, ya que es además de los efectos que puede tener de forma aislada, se ha visto que además presenta muchas interacciones con otros factores, siendo por tanto un factor crucial ($IMPROVE$ ver (Doblas-Miranda et al. 2017)):
* Some interactions alter the effects of a single factor, as drought enhances or decreases the effects of atmospheric components on plant ecophysiology
* Drought and land use changes, among others, alter water resources and lead to land degradation, vegetation regeneration decline, and expansion of forest diseases.
* Climate change, and especially drought, emerges as a crucial factor in most of the reviewed interactions and therefore it should be considered when it comes to designing and applying international management policies
* Drought should be considered when designing and applying management policies.

Además la sequía se espera que tengan …Droughts are most likely to have the largest and most long-lasting impacts globally due to large indirect and lagged impacts and long recovery especially for forest ecosystems (ver 18 en Ummenhofer and Meehl (2017)). Así por ejemplo se ha visto que todos los biomas presentan una vulnerabilidad similar … En una revision sobre la vulnerabilidad del sistema de trasnporte en plantas al embolismo inducido por sequía, ha mostrado que una convergencia de la vulnerabilidad de los bosques a la sequía, mostrando que todos los biomas son igualmente vulnerables a los fallos hidráulicos independientemente del régimen de precipitación (Choat et al. 2012, <doi:10.1038/nature11688>)

– Existen evidencias que sugieren que muchos bosques son vulnerables a eventos climáticos extremos … (Zhang) y esto puede ser especialmente relevante para especies situadas en el rear edge (completar)

Una vez dicho esto…

* Como la dendro ayuda a evaluar las sequías (ver Gazol 2017)
* Remote sensing:
  + Uso de Remote sensing para estudiar la sequía –> Leer Zhang et al. (2013) y escribir algo. Drought monitoring using remote-sensing approach was originally applied to agriculture. Several remote-sensing derived indices have been used to study the drought effects on vegetation …
  + Leer también a AghaKouchak et al. (2015)

Climate change projections indicate that extreme events will become more common in the future (IPCC 2013), making it important that we understand how ecosystems respond to these events and the potential feedbacks to radiative forcing.

### 

Uso de NDVI como estimador de la NPP:

* The NDVI properties have allowed the use of this information for estimating the Net Primary Production (NPP) (Goward and Dye, 1987; Running et al., 2004; Hasenauer et al., 2012). Different studies have already found a strong relationship between NPP and radial growth (e.g., Granier et al., 2008; Babst et al., 2013, 2014a, 2014b; Vicente-Serrano et al., 2015), albeit with significant differences, particularly those related to species, sites and environmental conditions.
* Ver Gilaber et al. 2017 <http://www.mdpi.com/2072-4292/9/3/193>

$NOTA$: NDVI sirve para estimar la producción primaria neta. Existen diferentes estudio que han evaluado el efecto de la sequía sobre la producción primaria neta utilizando NDVI.

### Aims

$IMPROVE$

In this study we combined remote sensing information and dendroecological methods to evaluate the drought impacts in both greenees and growth of *Q. pyrenaica* forests in Sierra Nevada. Specifically,

The aims of this work were:

* To quantify how two extreme drought events influenced the greenness and radial growth of *Q. pyreancia* forests in their rear edge,
* to analyze the resilience of these forests to successive extreme drought events,
* and to explore differences in the resilience metrics between populations located in contrasting slopes within the rear edge of the distribution of this species.

Do northern and southern populations of Pyrenean oak forests differ in their resistance, resilience or recovery to extreme drought events?

## References

# Materials and methods

## Species and study site

The Pyrenean oak (*Quercus pyrenaica* Willd.) forests extend through south-western France and the Iberian Peninsula (Franco 1990) reaching its southern limit in north of Morocco. In the Iberian Peninsula these forests live under meso-supramediterranean and mesotemperate areas and subhumid, humid and hyperhumid ombroclimate (Rivas-Martínez et al. 2002) living on siliceous soils, or soils poor in basic ions (Vilches de la Serna 2014). *Q. pyrenaica* requires between 650 and 1200 mm of annual precipitation and a summer minimal precipitation between 100 and 200 mm (Martínez-Parras and Molero-Mesa 1982, García and Jiménez 2009), with summer rainfall being a key factor in the distribution of the species (Gavilan et al. 2007, Río et al. 2007).

This species reaches its southernmost European limit at Sierra Nevada, a high-mountain range located in southern Spain (37°N, 3°W) with elevations of between 860 m and 3482 m *a.s.l.*. The climate is Mediterranean, characterized by cold winters and hot summers, with pronounced summer drought (July-August). There are eight oak patches (2400 Has) identified (**Figure 1**) in this mountain range, ranging between 1100 and 2000 m *a.s.l.* and generally associated to major river valleys. Sierra Nevada is considered a glacial refugia for deciduous *Quercus* species during glaciation [Brewer et al. (2002); Olalde et al. (2002); RodriguezSanchez2010] and these populations are considered as a rear edge of the habitat distribution, which is important in determining habitat responses to expected climate change (Hampe and Petit 2005).

The populations of Pyrenean oak forests at Sierra Nevada are considered relict forests (Melendo and Valle 2000, Vivero et al. (2000)), undergoing intensive anthropic use in the last few decades (Camacho-Olmedo et al. 2002, Valbuena-Carabaña et al. 2010, Valbuena-Carabaña and Gil 2017). In fact, the status of conservation of this species for southern Spain is “Vulnerable” (Vivero et al. 2000). The relict presence of this species in Sierra Nevada is related both to its genetic resilience as well as to its high intraspecific genetic diversity (Valbuena-Carabaña et al. 2010). However, they are also expected to suffer the impact of climate change, due to their climate requirements (wet summers). Thus, simulations of the climate change effects on this habitat forecast a reduction in suitable habitats for Sierra Nevada (Benito et al. 2011).

## Drought episodes

* :red\_circle: Meter aquí algunos datos de sequia, similar a lo planteado por Gazol

:red\_circle: duda aqui Varias referencias hablan de los años 2005 y 2012 como extremadamente secos. Pero habría que hacer alguna referencia y/o análisis. Tengo dudas de si hemos de analizar (e incluir) que efectivamente los años 2005 y 2012 fueron caracterizados por un extrema sequía, por lo que habría que incluyendo referencia a apéndice

* O quizá un apartado llamado Drought episodes (similar a esto <https://www.nature.com/articles/srep28269>)

## Greenness data

To characterize the vegetation greenness of *Q. pyrenaica* we used the *Enhanced Vegetation Index* (EVI) derived from MOD13Q1 product obtained by the *Moderate Resolution Imaging Spectroradiometer* (MODIS) sensor (Didan 2015). EVI and NDVI (*Normalized Difference Vegetation Index*) are the most common greenness vegetation indices. We used EVI instead of NDVI because EVI is more sensitive to changes in high-biomass areas (a serious shortcoming of NDVI); EVI reduces the influence of atmospheric conditions on vegetation index values, and EVI corrects for canopy background signals (Huete et al. 2002, Cabello et al. 2012, Krapivin et al. 2015).

MODIS EVI Data from Collection 6 were obtanied using Google Earth Engine platform for the period 2000 - 2016. EVI data consits of 16-day maximun value composite images (23 per year) of the EVI value with a spatial resolution of 250 m x 250 m. We selected the pixels covering the distribution of *Q. pyrenaica* forests in Sierra Nevada (*n* = 928 pixels). A data filtering was applied to select EVI valid values. The filtering was done using quality flags and VI Usefulness Indices accompanying the EVI data. We filter out those values affected by high content of aerosols, clouds, snow and shadows, following the filtering recomendations of EVI data for mountain regions (Reyes-Díez et al. 2015).

After the filter out process, we built the annual EVI profile for each pixel and then computed the EVI’s annual mean values and the EVI anomaly for each pixel for the period 2000 - 2016. EVI mean was chosen since it is highly stable under the use of any filter (Reyes-Díez et al. 2015) and because it showed high significant correlations with annual (r = 0.81) and seasonal EVI values ( = 0.76 and = 0.88).

To explore the effect of drought events on greenness we calculated the EVI standardized anomaly () pixel-by-pixel, since it minimizes biases in the evaluation of anomalies, providing more information about the magnitude of the anomalies (Samanta et al. 2012, Gao et al. 2016). For each pixel we annually averaged all the EVI valid values, and then the standardized anomaly was computed as:

where is the EVI standardized anomaly for the year ; the annual mean value of EVI for the year ; the average of the annual EVI values for the period of reference (all except year), and the standard deviation for the reference period. Each pixel was categorized according the EVI standardized anomalies as “greening” (EVI standardized anomalies greater than + 1), “browning” (EVI standardized anomalies less than - 1) or “no changes” (EVI standardized anomalies between − 1 and + 1) (Samanta et al. 2010, 2012).

## Field sampling and dendrochronological methods

### Tree sampling

Sampling was carried during autumn of 2016. Trees were sampled at two locations in contrasting slopes of Sierra Nevada: San Juan (SJ; northern aspect) and Cáñar (CA; southern aspect) (Figure 1; Table 1). For the southern site two elevations were sampled: CA-Low and CA-High. All the sites were oak monospecific and representatives of two of the three population clusters identified for the species in this mountain range (Pérez-Luque et al. 2015). In each site between 15 and 20 dominant trees were randomly selected. Two cores of 5 mm of diameter were taken from each tree at breast heigth (1.3 m) using an increment borer. Diameter at breast height (DBH) and total height were measured using a girth tape and a Vertex IV ultrasonic hypsometer (Haglöf, Sweden) respectively. We assessed stand competition of target trees by recording distance, azimuth, dbh, species and total height of all neighboring living trees with dbh > 7.5 cm in a circular plot of 10 m radius. We computed two distance independent indices: density in , and basal area (BA) in ; and one distance dependent indices: size ratio proportional to distance (*srd*) as . We used non-parametric Kruskal-Wallis rank sum tests (Sokal and Rohlf 1995) for search differences between sites for height, DBH and competence indices. When significant differences were observed, we run multiple comparisons using the Dunn’s-test (Dunn 1964) with Bonferroni adjustment to correct significance values. These analysis were performed uisng the PMCMR package (Pohlert 2014).

### Dendroecological analyses

Tree cores were air dried, glued onto wooden mounts and sanded. Annual radial growth (ring width, RW) was measured with a LINTAB measuring device (Rinntech, Heidelberg, Germany) coupled to a stereomicroscope, with an accuracy of 0.001 mm. Individual ring series were first visually and statistically cross-dated with TSAP software (Rinntech, Heidelberg, Germany), using the statistics Gleichläufigkeit (GLK), t-value and the crossdating index (CDI). Validation of the cross-dating was done using COFECHA software (Holmes 1983).

The growth trends were analyzed at different time scales. To study the response of growth to the inter-annual variability of climate (short-term response) we used pre-whitened residual chronologies (RWI) calculated from ratios between raw growth measurements and individual cubic splines with a 50 % frequency cutoff at 30 years (Fritts 1976). Tree-ring width series were standardized and detrended using the dplR (Bunn 2008, 2010) package. Residual site chronologies were obtained computing the biweight robust mean of all prewhitened growth indices for the trees of the same site (Cook and Kairukstis 1990). The statistical quality of each chronology was checked via the expressed population signal (Wigley et al. 1984). A threshold value of EPS > 0.85 was used to determine the cutoff year of the time span that could be considered reliable.

The long-term growth response was analyzed using basal area increment (hereafter BAI, ). BAI represents a more accurate indicator of growth than ring-width, since it removes variation in growth attributable to increasing stem circumference after 30-40 years of juvenile increasing growth (Biondi and Qeadan 2008). We used measured dbh and raw ring-widths to compute BAI by subtracting twice the annual ring width from the annual diameter, starting from the measured diameter outside the bark (Piovesa et al. 2008). We used the following equation:

where is the radius of the tree and is the year of tree-ring formation. We calculated a mean BAI serie for each individual tree. Mean site BAI chronologies were obtained by averaging individual tree BAI time series.

Both RWI and BAI chronologies were compared to different climatic indices to analyse the tree low and the high-frequency response to climate. Statistical descriptive parameters (Fritts 1976) including the mean, standard deviation, first-order autocorrelation of raw series, the mean sensitivity (a measure of the year-to-year variability) and the mean correlation between individual series of residual ring-width indices, were also calculated for each site chronology.

### Climate and growth

Climate data were obtained from the European Daily High-Resolution Observational Gridded Dataset (E-OBS v16) (Haylock et al. 2008). Monthly precipitation and minimum and maximum temperatures were obtained at a 0.25 x 0.25 º resolution for the 1950-2016 period. We selected grid cells covering each sampled sites. Data were downloaded and preprocessed using the climate4R bundle (<http://www.meteo.unican.es/en/climate4R>) (Cofiño et al. 2018, Frías et al. 2018). We also used the Standardized Precipitation-Evapotranspiration Index (SPEI), a multiscalar drought index that incorporates both precipitation and temperature (Vicente-Serrano et al. 2010, Beguería et al. 2014). SPEI values for the period 1961-2014 were obtained with a spatial resolution of 1.1 km from the Drought indices dataset for Spain database (<http://monitordesequia.csic.es/>), a high resolution database of drought indices for Spain (Vicente-Serrano et al. 2017). We selected a temporal scale for the SPEI of 6 months.

The relationships between residual site chronologies and the climatic variables were assessed by a bootstrapped Pearson’s correlation estimate using the treeclim package (Zang and Biondi 2015). The bootstrapped confidence intervals were used to estimate the significance (p < 0.05) of the correlation coefficients.

### Disturbance analyses

Disturbance chronologies were built using tree-ring width to identify abrupt and sustained increases (release events from competition) or decreases (supressions) in radial growth (Nowacki and Abrams 1997) as indirect estimates of possible disturbance events (e.g. logging) in the past. By using a temporal window of reasonable length this method is intended to filter out the response to short-term changes in temperature and precipitation and minimizes the long-term growth trends (Nowacki and Abrams 1997, Fraver and White 2005).

Growth changes (GC) were calculated for the individual tree-ring series using a 10-year running window as either positive (PGC) or negative (NGC) growth changes:

where is preceding 10-year median and is subsequent 10-year median. We used medians since they are more robust estimator of central tendency than means (Rubino and McCarthy 2004, Camarero et al. 2011). Site disturbance chronologies were constructed by averaging the individual disturbances series annually. To separate growth peaks produced by disturbance events and expressing stand-wise disturbances from those by climate, we considered a threshold of 50 % (DUDA) of GC and more than 50% of the individual trees displaying the same growth changes was considered a stand-wise disturbance.

## Resilience

To evaluate the effects of drougth events on greeennes and tree growth (BAI) we used three resilience indices proposed by Lloret et al. (2011): resilience (*Rs*), resistance (*Rt*), and recovery (*Rc*). The resistance index (*Rt*) quantifies the severity of the impact of the disturbance in the year it occurred. It is estimated as the ratio between the performance during and before the disturbance (drought) event:

Resistance (*Rt*) = Drought / Predrought

The Recovery index (*Rc*) is the ability to recover from disturbance relative to its severity, and it is estimated as the ratio between performance after and during disturbance:

Recovery (*Rc*) = Postdrought / Drought

The Resilience index (*Rs*) is the capacity to reach pre-disturbance performance levels, and it is estimated as the ratio between the performance after and before disturbance:

Resilience (*Rs*) = Postdrought / Predrought

We computed the values of these indices for tree growth (BAI) and greenness during each drought event. We considered 2005 and 2012 as singles drought events. The predrought and postdrought values of each target variable (*i.e.*: BAI or EVI) were computed as the mean value during a period of three years before and after the drougth event respectively. A period of three years was chosen because we found similar results comparing periods of two, three and four years (Figure S3) and this length was used in other studies (Gazol et al. 2017).

## Statistical analysis

We used robust two-way ANOVAs to test for differences between drought events (2005 and 2012) and oak population (northern and southern slopes) for each of the three resilience indices studied. These test were used beacuse original and log-transformed data both did not match the assumptions of normality and homogeneity of variance (Wilcox 2012). Robust measures of central tendency (M-estimator based on Huber’s Psi) were used since they were close to the mean value in all cases (Wilcox 2012). When running the robust ANOVA test, data were boostrapped 3000 times and trimmed automatically to control the potential influence of outliers (Field et al. 2012, Wilcox 2012). Post-hoc differences were assessed pairwise using a similar boostrap test. All the robust ANOVA and post-hoc tests were carried out using the WRS2 (Mair et al. 2017) and rcompanion (Mangiafico 2017) R packages. The level of significance was set to 0.05 and adjusted for multiple comparisons. All analyses were carried out in R software (R Core Team 2017) using several packages (see Supplementary S?)

# Results

## Vegetation Greenness

Trends analysis showed that 78.9 % of the pixels of *Quercus pyrenaica* forests experienced an EVI positive trend for the 2000-2016 period, of which 31.67 % were significant trends. The strongest trends were observed in southwestern populations (Figure S1). Vegetation greenness of *Q. pyrenaica* forests were lower during both the 2005 and 2012 years than the greenness observed for the reference period (Figure 2a). The lowest values for EVI standardized anomalies were recorded in 2005 being singnificantly lower (-2.285 ± 0.029) than 2012 (-0.418 ± 0.029) (LSMEANS, t.ratio = -45.358; p\_value < 0.0001), particularly for northern populations (Figure 2b). Reduction in annual EVI mean was considerably higher in northern populations than in southern ones during the 2005 drought (Figure 2b).

According to the standardized anomalies, *Q. pyrenaica* forests suffered a browning during 2005 drought event (99.36 % and 79.37 % of the pixels for northern and southern populations respectively), however no changes were observed for the 2012 drought (Figure S2).

## Responses to drougth: greenness

*Q. pyrenaica* forest showed significantly lower resistance to 2005 drought event than to 2012 one (Table 3; Figure 3a). The 2005 drought reduced the greenness of oak to 85.8 % while the 2012 reduced 94.3 % (Table S1). Southern populations showed significantly higher values of resistance to drought than northern ones (Table 3), except for 2012 where non-significant differences were recorded (Table S1. Figures 3a, 4a).

The oak forests recovered their greenness significantly more rapidly after the 2005 drought than after 2012 (Tables 3, S1). In the period after 2005 drought, greeness achieved was 112 % (Rc = 1.12) and after 2012 was 105.7 % (Rc = 1.057) (Table S1). A similar recovery after the 2005 and 2012 drought event was observed for southern populations (p = 0.2453; Figure 4a), whilst the northern populations showed a significantly greater recovery after the 2005 drought than after the 2012 drought (Figure 4a).

Resilience values were significantly higher for the 2012 drought event than for 2005 (Tables 3, S1), although both values were close to 1 indicating that greenness level was rather similar after each disturbance event (Table S1). The southern populations showed higher resilience values than the northern ones, although they were not significantly different for 2005 drought (p = 0.036; Figures 3a, 4a).

## Responses to drougth: tree-growth (BAI)

Although no significant differences were observed in the resistance of the oak growth to both drought events (Table 3; Figure 3b), the 2005 drought reduced growth more than 2012 did (Rt = 0.721 and 0.819 respectively) (Table S2). Northern population showed resistance values lower than southern ones, especially for 2005 drought event where the growth was reduced to 44.5 % of the preceding period (Figures 3b, 4b).

Oak forests recovered their growth more rapidly after 2012 than after 2005 staying at levels of Rc < 1 (Table S2). Norhtern populations showed signigicantly higher values of recovery than southern ones (Tables 3, S2), which even not reach recovery values of Rc = 1 (Figure 3b, 4b).

Significantly higher values of resilience of growth were observerd for the 2012 drought event than for the 2005 one (Table S2; Figure 4b). We found no differences of resilience values for growth between northern and southern populations (Table 3). For 2005 drought event the resilience of northern population was lower than southern ones, but opposite pattern was found for the 2012 drought event, with northern population showing values greater than unity (Figure 3b).

# Chronology

The trees of the southern population were older and larger than northern ones, particularly for the high elevation site (Ca-High) which had bigger and taller trees than the other sites (Tables 1, 2). Competence indices were similar among sites (Table 1). The basal area increment (BAI) were different between sites (Figure 5). El sitio mas elevado (Ca-High) mostró mayores valores de BAI que los otros sitios, mostrando además una tendencia positiva a partir de 1970. Se observan diferencias en cuanto al crecimiento entre los sitios de las poblaciones del sur. Ca\_Low se parece en crecimiento mas a SJ que a Ca\_High.

Los tres sitios mostraron una reducción en los valores de BAI durante las sequías de 1995 y 2005, y menos evidente para el año 2012 (Figure 5). La población del norte (SJ) mostró una gran liberación en torno a 1945 fruto quizá de cortas asociadas a la actividad minera de la zona. Asimismo, esta población mostró un marcado descenso en BAI durante el periodo 1986 - 1999.

and higher values of tree-growth (Table 2).

El sitio caH mostró además los mayores valores de AR(1) y de MS

El sitio del norte, mostró mayores valores de MS (Table 2). ¿esto sugiere que este sitio tiene una alta limitación climática?

Different growth trends were observed for each site (Figure 5). Ca-High (the highest elevation site) had higher values of tree growth than the other sites.

# Climate and tree

Tree-growth exhibited a significant response to water availability more than to the temperatures. Cumulative precipitation of the hydrological year (September of the previous year to August of the growth year) influenced positively the tree-growth for the both northern and southern populations (FIG ). Precipitation of previous december was also positively correlated with tree growth in the northern population and in the highest location of the southern population. Hydrological, Spring and Summer SPEI showed a strong positive correlation with tree-growth, specially for northern population. Spring Maximum temperature was the most significant limitation of the tree-growth for the southern population while maximum temperatures of the previous August did for the northern one. Conversely, mean, minimum and maximum temperatures of current September positively influenced the tree-growth in the northern population.

# Disturbance

En las poblaciones del norte osbervamos dos eventos de PGC por encima del 25 e incluso el 50 %. El primero de ellos desde 1940 hasta 1950, mientras que el segundo entre 1994 y 2001. Estos periodos se alternan con periodos de NGC: previo 1940, 1960 - 1991, y quizá aunque no lo vemos en al actualidad (?? duda. Esto es especular un poco). Esto responde creo que a:

1. actividad minera y tratamientos forestales. La actividad minera en la zona fue intensa (aunque a veces intermitente, entre 1890 y 1957 (cuando se clausuró); y previamente desde 1858 tras los trabajos de Amalio Maestre). Hay costancia de la existencia de hornos de fundición de mineral en alguna de las minas (La Probadora).
2. actividades forestales:

* Se conoce la existencia de un proyecto redactado en 1943 de repoblación forestal de la cabecera del río Genil (he pedido los mapas).
* Ver actividades forestales (bd proyectos de gestión)

En el trabajo de (Gea-Izquierdo and Cañellas 2014) se observa una liberación posterior a 1950 (QPUY9) (entre 1950 y 1960 aprox.) y luego una supresión hasta mediados de 1990. Esto coincide con lo que hemos observado en nuestra chrono.

Respecto a las poblaciones del sur, destaca en la caH una primera liberación en torno a 1829-1830 y 1837-1840; y luego predominan los eventos de supresión que se alternan con algunos de liberación (muy débiles) hastas 1950. Posteriormente se alternan liberaciones-supresiones débiles. Destaca una liberación en torno a 2000-2003 (relación con clima??? posterior a sequía 1999???)

En caL, observamos un periodod de limitación hasta 1885 aprox. Luego se alternan al igual que antes periodos de liberación con otos de supresión con señales más fuertes que en caL, y al igual que antes destaca con mas intensidad si cabe, una liberación entre 2000 y 2003 (antrópico o climática ??)

Duda: ocurre en los dos sitios caL y caH, entonces, es aumento de crecimiento debido a actuación forestal? o debido a clima??

(Gea-Izquierdo and Cañellas 2014) encontró un pico de disturbance en torno a 1860 en QUPY10 (cañar) sugiriendo que la baja densidad en esos sitios fue presumible el resultado de un thinning (aclareo). El patrón de supresión que observa para este sitio va en la linea de lo que nosotros encontramos (supresiones que alcanzan a veces el 25 % y otras no)

En cuanto a la señal a nivel de sitio, para el Norte, vemos que tanto las supresiones como las liberaciones se observan para mas del 50 % de los árboles. En el caso del sur, vemos que algunas supresiones se observan para mas del 50 % de los árboles, mientras que las liberaciones observadas en torno a los 2000 se observan para mas del 50 % de los árboles

notas para discusión

En ambos casos (evi y bai) la sequía de 2005 y de 2012 redujeron el greenness y el crecimiento. Además en ambos casos la sequía de 2005 redujo mas la variable, sin embargo, para el greenness si existen diferencias entre ambos eventos de sequía, mientras que para el crecimiento no. Por tanto podemos decir que se ha reducido el greennes pero para el crecimiento esto está mas amortiguado.

Al explorar la resistencia por sitio y drought se observa una curiosidad. La resistencia de los robledales de CaLow se mantiene casi igual. La de la cara norte (SJ) sufre mucho en 2005 y luego se recupera un poco. La de caH presenta menor resistencia en 2012 que en 2005 (y eso llama la atención)

## References

# Discussions notes

## Greenness

* Aproximadamete el x% de los robledales mostraron un incremento en los valores de productividad (greenees) … (relacionar con tendencias EVI y ontologias).
* tendencias ontologias
* Si analizamos el plot de trajectorias (evi medio anual), vemos como en 2005 y 2012 se observó un browning para los valores medios de EVI. En ambos casos, se observó un patrón homogéneo de browing, aunque en 2012 el browning fue mucho menor.

## Dos cronos en Cañar

* Gea-Izquierdo and Cañellas (2014) muestrea solo en CA-Low (QUPY10) y obtiene resultados similares a CA-Low.
* En tan poco espacio hay diferencias enormes entre las dos cronos
* *Las tendencias de BAI de Cáñar baja altitud son diferentes a las del norte, las cuales se parecen mucho a las que suelen encontrarse en la mayoría de sitios. Puedes mirar por ejemplo las tendencias de las líneas negras (de más de 100 años, sobre todo) en la Fig 2 del artículo de Ecosystems… fíjate que QUPY3 se parece más a QUPY10… y QUPY3 era la única dehesa (en parte) y uno de los sitios más secos (por otro lado, aunque frío). En fin, todo esto es algo especulativo, pero sirva como exploración de tus cronos, y para mostrar que me parece muy interesante la diferencia entre Cáñar alto y bajo (y nuevo).*

## Reducción crecimiento y sequías

Se observó una gran reducción de crecimiento en 1994-1995, 1999 y 2005 para Pinus nigra en el SE de Andalusia (Sánchez-Salguero et al. 2013) coincidiendo con años de sequía para esa zona. La máxima reducción en crecimiento fue observada para 2005, siendo significativamente mayor que para el resto de años (Sánchez-Salguero et al. 2013).

## Dendro

### Diferencias crecimiento entre sitios.

Mayor crecimiento en los robles situados en CaHigh. Sorprende que en el rear edge de la distribución de la especie, en la cara sur dentro de este rear edge, y en la parte mas alta (estas parcelas están en el treeline de la especie en SN) es donde encontramos mayores crecimientos. Parece que los robles estuvieran mejor en esta zona. Algunas reflexiones

* Quizá están creciendo donde les están dejando (menor impacto antrópico)
* ¿Menor estrés hídrico en zonas mas altas?
* ¿Diferencias entre suelos? (ver artículo (“Taxonomic and functional diversity of a quercus pyrenaica willd. rhizospheric microbiome in the mediterranean mountains” 2017) que compara suelos de Cáñar). En este estudio sobre microbiota del suelo, analizó tres sitios: por encima del treline (XZF), low altitudinal oak forest (LAF) and high altitudinal oak forest (HAF). LAF está mucho mas bajo, pero HAF está cerca de las parcelas caHigh y encontró lo siguiente:
* tipo de suelo: LAF es Sandy-loam, HAF es loam
* HAF tuvo los valores mayores de disponibilidad hídrica (% available water tabla s1 en (“Taxonomic and functional diversity of a quercus pyrenaica willd. rhizospheric microbiome in the mediterranean mountains” 2017))
* Los tres sitios eran pobres en materia orgánica, pero el HAF dobló los valores de los otros dos sitios
* No diferencias en contenido de N, C/N ratio similares en HAF, y LAF

Sorprende que en Cáñar haya diferencias tan grandes de crecimiento estándo tan cerca. ¿Puede estar relacionado con intensidad de uso antrópico? De hecho la Ca-Low tiene crecimientos similares a SJ.

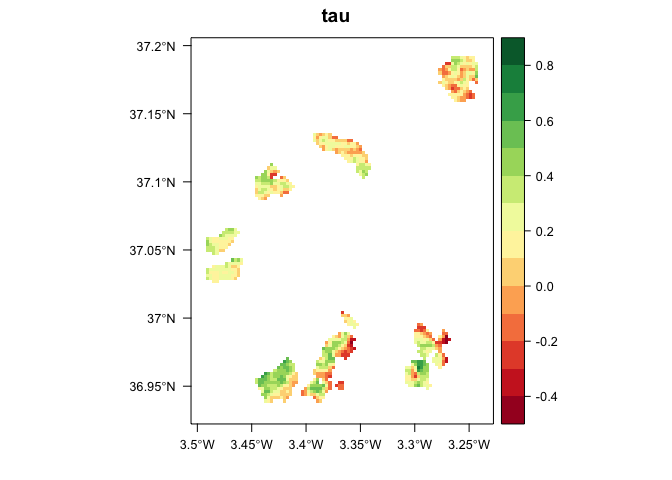
## Relaciones crecimiento-clima en otras especies

## References

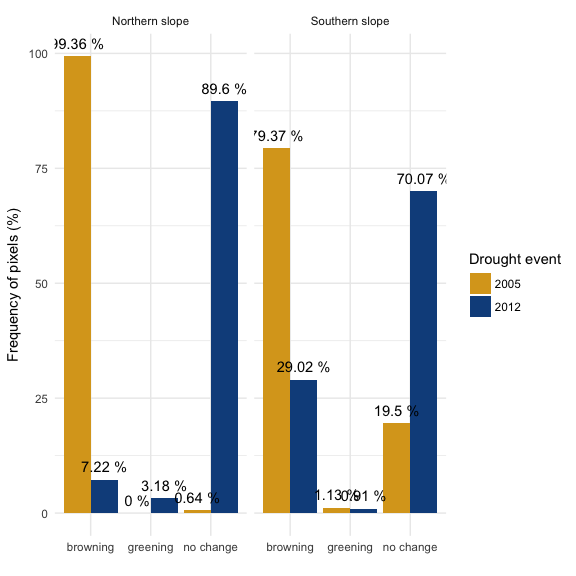
# Supplementary

## Figures

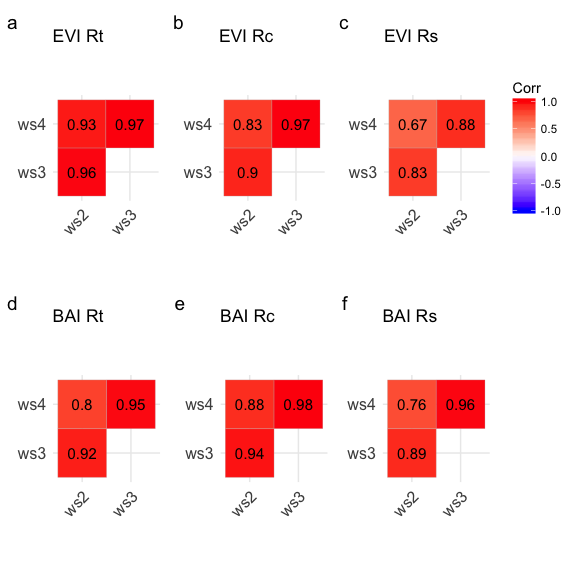
**Figure S1**. Spatial distribution of the EVI-annual trends () for the period 2000-2016. Negative values (*red* values) indicate negative trends and positive values (*green* values) indicate positive trends.



**Figure S2.** Percentage of pixels showing browning, greenning or no-changes during the 2005 and 2012 droguht events according to EVI standardized anomalies.



**Figure S3.** Correlation



AghaKouchak, A., A. Farahmand, F. S. Melton, J. Teixeira, M. C. Anderson, B. D. Wardlow, and C. R. Hain. 2015. Remote sensing of drought: Progress, challenges and opportunities. Reviews of Geophysics 53:452–480.

Beguería, S., S. M. Vicente-Serrano, F. Reig, and B. Latorre. 2014. Standardized precipitation evapotranspiration index (spei) revisited: Parameter fitting, evapotranspiration models, tools, datasets and drought monitoring. International Journal of Climatology 34:3001–3023.

Benito, B., J. Lorite, and J. Peñas. 2011. Simulating potential effects of climatic warming on altitudinal patterns of key species in mediterranean-alpine ecosystems. Climatic Change 108:471–483.

Biondi, F., and F. Qeadan. 2008. A theory-driven approach to tree-ring standardization: Defining the biological trend from expected basal area increment. Tree-Ring Research 64:81–96.

Brewer, S., R. Cheddadi, J. de Beaulieu, and M. Reille. 2002. The spread of deciduous quercus throughout europe since the last glacial period. Forest Ecology and Management 156:27–48.

Bunn, A. G. 2008. A dendrochronology program library in r (dplR). Dendrochronologia 26:115–124.

Bunn, A. G. 2010. Statistical and visual crossdating in r using the dplR library. Dendrochronologia 28:251–258.

Cabello, J., D. Alcaraz-Segura, R. Ferrero, A. Castro, and E. Liras. 2012. The role of vegetation and lithology in the spatial and inter-annual response of {evi} to climate in drylands of southeastern spain. Journal of Arid Environments 79:76–83.

Camacho-Olmedo, M., P. García-Martínez, Y. Jiménez-Olivencia, J. Menor-Toribio, and A. Paniza-Cabrera. 2002. Dinámica evolutiva del paisaje vegetal de la alta alpujarra granadina en la segunda mitad del s. xx. Cuadernos Geográficos 32:25–42.

Camarero, J. J., C. Bigler, J. C. Linares, and E. Gil-Pelegrín. 2011. Synergistic effects of past historical logging and drought on the decline of pyrenean silver fir forests. Forest Ecology and Management 262:759–769.

Cofiño, A., J. Bedia, M. Iturbide, M. Vega, S. Herrera, J. Fernández, M. Frías, R. Manzanas, and J. Gutiérrez. 2018. The ecoms user data gateway: Towards seasonal forecast data provision and research reproducibility in the era of climate services. Climate Services.

Cook, E., and L. Kairukstis. 1990. Methods of dendrochronology: Applications in the environmental sciences. Springer, Doredrecht.

Didan, K. 2015. MOD13Q1 MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V006. NASA EOSDIS Land Processes DAAC.

Doblas-Miranda, E., R. Alonso, X. Arnan, V. Bermejo, L. Brotons, J. de las Heras, M. Estiarte, J. Hódar, P. Llorens, F. Lloret, F. López-Serrano, J. Martínez-Vilalta, D. Moya, J. Peñuelas, J. Pino, A. Rodrigo, N. Roura-Pascual, F. Valladares, M. Vilà, R. Zamora, and J. Retana. 2017. A review of the combination among global change factors in forests, shrublands and pastures of the mediterranean region: Beyond drought effects. Global and Planetary Change 148:42–54.

Dunn, O. 1964. Multiple comparisons using rank sums. Technometrics 6:241–252.

Field, A., J. Miles, and Z. Field. 2012. Discovering statistics using r. Page 1426. SAGE.

Franco, A. 1990. Quercus l. Pages 15–36 *in* A. Castroviejo, M. Laínz, G. López-González, P. Montserrat, F. Muñoz-Garmendia, J. Paiva, and L. Villar, editors. Flora ibérica. Real Jardín Botánico, CSIC, Madrid.

Fraver, S., and A. S. White. 2005. Identifying growth releases in dendrochronological studies of forest disturbance. Canadian Journal of Forest Research 35:1648–1656.

Fritts, H. C. 1976. Tree rings and climate. Academic Press, London.

Frías, M., M. Iturbide, R. Manzanas, J. Bedia, J. Fernández, S. Herrera, A. Cofiño, and J. Gutiérrez. 2018. An r package to visualize and communicate uncertainty in seasonal climate prediction. Environmental Modelling & Software 99:101–110.

Gao, Q., W. Zhu, M. W. Schwartz, H. Ganjurjav, Y. Wan, X. Qin, X. Ma, M. A. Williamson, and Y. Li. 2016. Climatic change controls productivity variation in global grasslands. Scientific Reports:26958.

García, I., and P. Jiménez. 2009. 9230 robledales de quercus pyrenaica y robledales de quercus robur y quercus pyrenaica del noroeste ibérico. Pages 1–66 *in* VV.AA., editor. Bases ecológicas preliminares para la conservación de los tipos de hábitat de interés comunitario en españa. Ministerio de Medio Ambiente, y Medio Rural y Marino, Madrid.

García-Herrera, R., E. Hernández, D. Barriopedro, D. Paredes, R. M. Trigo, I. F. Trigo, and M. A. Mendes. 2007. The Outstanding 2004/05 Drought in the Iberian Peninsula: Associated Atmospheric Circulation. Journal of Hydrometeorology 8:483–498.

Gavilan, R. G., D. S. Mata, B. Vilches, and G. Entrocassi. 2007. Modeling current distribution of spanish quercus pyrenaica forests using climatic parameters. Phytocoenologia 37:561–581.

Gazol, A., J. J. Camarero, W. R. L. Anderegg, and S. M. Vicente-Serrano. 2017. Impacts of droughts on the growth resilience of northern hemisphere forests. Global Ecology and Biogeography 26:166–176.

Gea-Izquierdo, G., and I. Cañellas. 2014. Local climate forces instability in long-term productivity of a mediterranean oak along climatic gradients. Ecosystems 17:228–241.

Gouveia, C. M., and R. M. Trigo. 2014. The 2005 and 2012 major drought events in Iberia: monitoring vegetation dynamics and crop yields using satellite data. Page 15179 *in* EGU general assembly conference abstracts.

Gouveia, C. M., P. Ramos, A. Russo, and R. M. Trigo. 2015. Drought trends in the Iberian Peninsula over the last 112 years. Page 12680 *in* EGU general assembly conference abstracts.

Hampe, A., and R. J. Petit. 2005. Conserving biodiversity under climate change: The rear edge matters. Ecology Letters 8:461–467.

Haylock, M. R., N. Hofstra, A. M. G. Klein Tank, E. J. Klok, P. D. Jones, and M. New. 2008. A european daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006. Journal of Geophysical Research 113:D20119.

Hoerling, M., J. Eischeid, J. Perlwitz, X. Quan, T. Zhang, and P. Pegion. 2012. On the increased frequency of mediterranean drought. Journal of Climate 25:2146–2161.

Holmes, R. L. 1983. Computer-assisted quality control in tree-ring dating and measurement. Tree-Ring Bulletin 43:69–78.

Huete, A., K. Didan, T. Miura, E. Rodriguez, X. Gao, and L. Ferreira. 2002. Overview of the radiometric and biophysical performance of the {modis} vegetation indices. Remote Sensing of Environment 83:195–213.

Krapivin, V. F., C. A. Varotsos, and V. Y. Soldatov. 2015. Remote-sensing technologies and data processing algorithms. Pages 119–219 *in* New ecoinformatics tools in environmental science: Applications and decision-making. Springer International Publishing.

Lionello, P., editor. 2012. Page 502. Elsevier, Oxford.

Lloret, F., E. G. Keeling, and A. Sala. 2011. Components of tree resilience: Effects of successive low-growth episodes in old ponderosa pine forests. Oikos 120:1909–1920.

Mair, P., F. Schoenbrodt, and R. Wilcox. 2017. WRS2: Wilcox robust estimation and testing.

Mangiafico, S. 2017. Rcompanion: Functions to support extension education program evaluation.

Martínez-Parras, J. M., and J. Molero-Mesa. 1982. Ecología y fitosociología de quercus pyrenaica willd. en la provincia bética. los melojares béticos y sus etapas de sustitución. Lazaroa 4:91–104.

Melendo, M., and F. Valle. 2000. Estudio comparativo de los melojares nevadenses. Pages 463–479 *in* J. Chacón and J. Rosúa, editors. I conferencia internacional sierra nevada. Universidad de Granada, Granada.

Nowacki, G. J., and M. D. Abrams. 1997. Radial-growth averaging criteria for reconstructing disturbance histories from presettlement-origing oaks. Ecological Monographs 67:225–249.

Olalde, M., A. Herrán, S. Espinel, and P. G. Goicoechea. 2002. White oaks phylogeography in the iberian peninsula. Forest Ecology and Management 156:89–102.

Pérez-Luque, A. J., R. Zamora, F. J. Bonet, and R. Pérez-Pérez. 2015. Dataset of migrame project (global change, altitudinal range shift and colonization of degraded habitats in mediterranean mountains). PhytoKeys 56:61–81.

Piovesa, G., F. Biondi, A. D. Filippo, A. Alessandrini, and M. Maugeri. 2008. Drought-driven growth reduction in old beech (fagus sylvatica l.) forests of the central apennines, italy. Global Change Biology 14:1265–1281.

Pohlert, T. 2014. The pairwise multiple comparison of mean ranks package (pmcmr).

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reyes-Díez, A., D. Alcaraz-Segura, and J. Cabello-Piñar. 2015. Implicaciones del filtrado de calidad del índice de vegetación evi para el seguimiento funcional de ecosistemas. Revista de Teledeteccion 2015:11–29.

Rivas-Martínez, S., T. Díaz, F. Fernández-González, J. Izco, J. Loidi, and M. Lousã. 2002. Vascular plant communities of spain and portugal. addenda to the syntaxonomical checklist of 2001. part ii. Itinera Geobotanica 15:5–922.

Río, S. del, L. Herrero, and Á. Penas. 2007. Bioclimatic analysis of the quercus pyrenaica forests in spain. Phytocoenologia 37:541–560.

Rubino, D., and B. McCarthy. 2004. Comparative analysis of dendroecological methods used to assess disturbance events. Dendrochronologia 21:97–115.

Samanta, A., S. Ganguly, H. Hashimoto, S. Devadiga, E. Vermote, Y. Knyazikhin, R. R. Nemani, and R. B. Myneni. 2010. Amazon forests did not green-up during the 2005 drought. Geophysical Research Letters 37:L05401.

Samanta, A., S. Ganguly, E. Vermote, R. R. Nemani, and R. B. Myneni. 2012. Interpretation of variations in modis-measured greenness levels of amazon forests during 2000 to 2009. Environmental Research Letters 7:024018.

Sánchez-Salguero, R., J. J. Camarero, M. Dobbertin, Á. Fernández-Cancio, A. Vilà-Cabrera, R. D. Manzanedo, M. A. Zavala, and R. M. Navarro-Cerrillo. 2013. Contrasting vulnerability and resilience to drought-induced decline of densely planted vs. natural rear-edge pinus nigra forests. Forest Ecology and Management 310:956–967.

Sokal, R., and F. Rohlf. 1995. Biometry: The principles and practice of statistics in biological research. Page 887. Freeman, New York.

Spinoni, J., G. Naumann, and J. V. Vogt. 2017a. Pan-european seasonal trends and recent changes of drought frequency and severity. Global and Planetary Change 148:113–130.

Spinoni, J., G. Naumann, J. V. Vogt, and P. Barbosa. 2015. The biggest drought events in europe from 1950 to 2012. Journal of Hydrology: Regional Studies 3:509–524.

Spinoni, J., J. V. Vogt, G. Naumann, P. Barbosa, and A. Dosio. 2017b. Will drought events become more frequent and severe in europe? International Journal of Climatology.

Stagge, J. H., D. G. Kingston, L. M. Tallaksen, and D. M. Hannah. 2017. Observed drought indices show increasing divergence across Europe. Scientific Reports 7:14045.

Taxonomic and functional diversity of a quercus pyrenaica willd. rhizospheric microbiome in the mediterranean mountains. 2017. Forests 8:390.

Trigo, R. M., J. A. Añel, D. Barriopedro, R. García-Herrera, L. Gimeno, R. Castillo, M. R. Allen, and A. Massey. 2013. The record Winter drought of 2011-12 in the Iberian Peninsula [in "Explaining Extreme Events of 2012 from a Climate Perspective. [Peterson, T. C., M. P. Hoerling, P.A. Stott and S. Herring, Eds.] 94:S41–S45.

Ummenhofer, C. C., and G. A. Meehl. 2017. Extreme weather and climate events with ecological relevance: A review. Philosophical Transactions of the Royal Society of London B: Biological Sciences 372.

Valbuena-Carabaña, M., and L. Gil. 2017. Centenary coppicing maintains high levels of genetic diversity in a root resprouting oak (quercus pyrenaica willd.). Tree Genetics & Genomes 13:28.

Valbuena-Carabaña, M., U. L. de Heredia, P. Fuentes-Utrilla, I. González-Doncel, and L. Gil. 2010. Historical and recent changes in the spanish forests: A socio-economic process. Review of Palaeobotany and Palynology 162:492–506.

Vicente-Serrano, S. M., S. Beguería, and J. I. López-Moreno. 2010. A multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index. Journal of Climate 23:1696–1718.

Vicente-Serrano, S. M., J. I. López-Moreno, S. Beguería, J. Lorenzo-Lacruz, A. Sanchez-Lorenzo, J. M. García-Ruiz, C. Azorín-Molina, E. Morán-Tejeda, J. Revuelto, R. Trigo, F. Coelho, and F. Espejo. 2014. Evidence of increasing drought severity caused by temperature rise in southern Europe. Environmental Research Letters 9:044001.

Vicente-Serrano, S. M., M. Tomas-Burguera, S. Beguería, F. Reig, B. Latorre, M. Peña-Gallardo, M. Y. Luna, A. Morata, and J. C. González-Hidalgo. 2017. A high resolution dataset of drought indices for spain. Data 2.

Vilches de la Serna, B. 2014. Comprehensive study of “quercus pyrenaica” willd. forests at iberian peninsula: Indicator species, bioclimatic, and syntaxonomical characteristics. PhD thesis, Complutense University of Madrid, Madrid.

Vivero, J., J. Prados, and J. Hernández-Bermejo. 2000. Quercus pyrenaica willd. Pages 303–306 *in* G. Blanca, B. Cabezudo, J. Hernández-Bermejo, C. Herrera, J. Muñoz, and B. Valdés, editors. Libro rojo de la flora silvestre amenzada de andalucía. ii. especies vulnerables. Consejería de Medio Ambiente, Junta de Andalucía, Sevilla.

Wigley, T. M. L., K. R. Briffa, and P. D. Jones. 1984. On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. Journal of Climate and Applied Meteorology 23:201–213.

Wilcox, R. 2012. Introduction to robust estimation and hypothesis testing (third edition). Page 608. Third Edition. Academic Press.

Zang, C., and F. Biondi. 2015. Treeclim: An r package for the numerical calibration of proxy-climate relationships. Ecography 38:431–436.

Zhang, Y., C. Peng, W. Li, X. Fang, T. Zhang, Q. Zhu, H. Chen, and P. Zhao. 2013. Monitoring and estimating drought-induced impacts on forest structure, growth, function, and ecosystem services using remote-sensing data: Recent progress and future challenges. Environmental Reviews 21:103–115.