

Differential effect of drought on *Pinus nigra* Arn. radial growth in mesic and xeric sites from southeastern Spain

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Introduction

Different water regimes are of great importance in ecosystems under Mediterranean climate, where drought is the most important factor limiting tree growth and productivity (Specht 1981). Climate change models for south-eastern Mediterranean Spain predict a decrease of annual mean precipitation between 6% and 14% (Sumner et al. 2003). Therefore, the frequency of extreme droughts may increase in the future, which could lead to a reduction of forest productivity and changes in species composition. A necessary pre-requisite for the appropriate management of forest is to understand their growth dynamics, including their response to drought.

Pinus nigra Arn. (black pine) is very widely distributed and is one of the most commonly used pines in large plantations all over the Mediterranean region and other parts of Europe. This makes it very susceptible to the increase in temperature and decrease in precipitation already observed in western Mediterranean (Rodrigo et al. 1999) and predicted by climate change models (Sumner et al. 2003).

Our study, thus, explores the response to drought of black pine trees growing in sites differing in water availability, slope and location. In xeric sites, water is supposed to be less abundant and more dependent on current year rainfall than in mesic sites. In the later, water accumulation from runoff as well as possible water table likely assures a more constant water supply for trees.

Material and Methods

Study sites

The study sites are located in the Cazorla Mountain Range in southeastern Spain (Fig. 1). Forests made up of Mediterranean pines (*P. nigra*, *P. halepensis* Mill., and *P. pinaster* Ait.) cover most of the area. Altitude ranges from 600 m to 2107 m a.s.l. The main soil types in the region are based on a dolomite and calcareous bedrock (Sanchez-Palomares et al. 1990). Soils are leptosols (rendzinas) on higher slopes, and luvisols on flat terrain with alluvial and colluvial deposits (Sanchez-Palomares et al. 1990; FAO 2006).



Figure 1: Distrubution of *Pinus nigra* in the Iberian Peninsula and location of study sites in southeastern Spain (circle).

Tree stands were selected from the network of permanent research plots (PRP) that was established by INIA (Spanish National Institute of Agricultural Research) in 1964, and inventoried 8 times afterwards (1964-2006). In order to represent different conditions of water availability, we selected two sites of high slope near the top of ridges and distant from any water current ('xeric') and two in flat terrain in valleys ('mesic'). All plots were even aged and located in well stocked stands where trees originated from natural regeneration.

Sampling and standard dendrochronological methods.

In June 2006, 15 -16 dominant trees were sampled from each plot. Dominant trees were defined as those within each plot that had had the largest DBH during the eight inventories (1964-2006). For each tree, two cores were taken from the upper slope side at a 120° angle from each other, to avoid reaction wood.

Applying a standard procedure, cores were mounted to grooved boards and sanded with three different grits (80-400). Widths of three tree-ring sections (i.e. total ring (TR), earlywood (EW) and latewood (LW)) were measured to the nearest 0.01 mm with a measuring table and registered using TSAP (Rinn 1996). Qualitative visual aspects (darkening and tracheid size) were used to define transition from EW to LW.

Raw ring-width series were visually and statistically cross-dated in TSAP. Then, ring-width index were developed in ARSTAN using the Huggershoff equation (Cook and Holmes 1994). This equation is a combination of a polynomial and a negative exponential. Since it only has one turning point with increasing age, it allows for increasing growth during the juvenile phase of the tree and a curvilinear decline as the tree ages (Warren 1980, Bräker 1996).

Climate data, correlation analysis and response function

Mean monthly temperatures (°C) and precipitation (mm) were collected from the meteorological station at Santiago de la Espada (Jaén) (38°06' N, 02°33' W, 1340 m a.s.l.), approximately 25 km from sampling sites. For the period considered (1940-2005) mean annual temperature was 12.9° C. Absolute maximum and minimum temperatures were 40 °C and -22 °C, and frost was possible from November to April. Precipitation (annual mean of 730 mm) showed a winter maximum and summer drought in the area lasted three-four months (June-September). Mean monthly temperature and total monthly precipitation (predictor variables) were regressed against ring-width indexes to assess climate-growth relationships (Fritts 1976). Correlation and response function were calculated with DENDROCLIM2002 (Biondi and Waikul 2004).

Superposed epoch analysis (SEA)

The nonparametric technique of superposed epoch analysis (SEA) was used to assess the relationship between extreme climatic events (drought) and the strength of the response in the corresponding year (tree growth indices) (Haurwitz and Brier 1981). Centered in the year of the drought, five years before and five years after were taken as background years for comparison. For this study, drought was defined as an extraordinary departure from mean cool season (October to May) precipitation, lower than the mean by one standard deviation for the period 1940-2005. The ten selected drought years were 1942, 1943, 1945, 1950, 1953, 1967, 1968, 1981, 1995, and 1999. Although the year 2005 was the driest for the period, it was not considered for the SEA because there were not five post-drought years to compare it with. The differences between the ring-width index (RWI) of the three tree-ring sections of each core and their means were calculated and later averaged for event years and background years (Orwig and Abrams 1997). The *T* statistic as described by Haurwitz and Brier (1981) and modified by Prager and Hoenig (1989) was used to test whether the RWI of the drought years differed significantly from pre- and post-drought years. These departures from the mean did not meet the general assumptions for normality so

Monte Carlo randomizations were run in SAS (SAS Institute Inc. 2004) to select 10 000 sets of 11 years to compute confidence intervals for T .

Raw ring width values during drought years were compared to the years before and after the drought to quantitatively analyze growth decreases and recoveries (Fekedulegn et al. 2003). Percent growth changes were calculated as follows:

- drought vs prior year: $[(D_0 - D_{-1}) / D_{-1}] \cdot 100$
- post-drought year vs pre-drought year: $[(D_{+1} - D_{-1}) / D_{-1}] \cdot 100$
- drought year vs five years pre-drought : $[(D_0 - D_{-5}) / D_{-5}] \cdot 100$
- five years post-drought vs drought year: $[(D_{+5} - D_0) / D_0] \cdot 100$
- five years post-drought vs five years pre-drought: $[(D_{+5} - D_{-5}) / D_{-5}] \cdot 100$

where D_0 is the raw ring width (RW) for any of the tree-ring sections the year of drought, D_{-1} is RW for the year prior to drought, D_{+1} is RW for the year after drought, D_{-5} is the average of RW for the five years prior to drought, and D_{+5} is the average of RW for the five years after drought. Analysis of variance for multiple comparisons was carried out using proc GLM in SAS (SAS Institute Inc 2004).

Table 1: Chronology statistics in dominant trees of xeric and mesic sites for each ring section calculated in raw ring-width data before detrending.

Plot	Altitude (m)	No. of trees	Chronology time-span (years)	TRW			EW			LW		
				Rbar	MS	AC	Rbar	MS	AC	Rbar	MS	AC
Xeric sites												
J03	1440	15	1806-2005 (200)	0.64	0.28	0.76	0.66	0.28	0.77	0.44	0.42	0.54
J04	1475	16	1910-2005 (96)	0.60	0.31	0.70	0.59	0.33	0.68	0.47	0.46	0.49
Mesic sites												
J02	1100	15	1830-2005 (176)	0.47	0.27	0.80	0.50	0.28	0.79	0.33	0.38	0.63
J18	1295	15	1910-2005 (96)	0.41	0.24	0.71	0.54	0.27	0.69	0.24	0.32	0.59

TRW, total ring; EW, earlywood; LW, latewood

Rbar, mean interseries autocorrelation; MS, mean sensitivity; AC, first-order serial autocorrelation coefficient.

Results and Discussion

As expected, xeric sites showed higher mean sensitivities (MS) than in mesic sites, particularly in the latewood (LW) (Tab. 1). Lower water availability caused LW widths to be less correlated with previous year growth as shown by autocorrelation coefficients (AC). This is further supported by results shown in figure 2. In xeric sites there is a higher abundance of years with narrow LW (curve is more left-skewed) and earlywood (EW) tends to be wider (less left-skewed) than mesic sites. In these later sites, EW and LW curves are more balanced and more similar to each other.

These results seem to indicate that mesic sites are growing more evenly every year and for a longer period (wider LW), whereas in xeric sites growth differs more from year to year, especially at the end of the season (narrower LW). However, the fact that there is a higher proportion of wide EW in xeric than in mesic sites (Fig. 2) shows that trees in xeric sites might have similar or wider diameter growth than trees in more mesic sites. Irrigation has been shown to increase LW production in *Pinus sylvestris* L. (Rigling et al. 2003) in a similar way that trees in mesic sites produced wider LW.

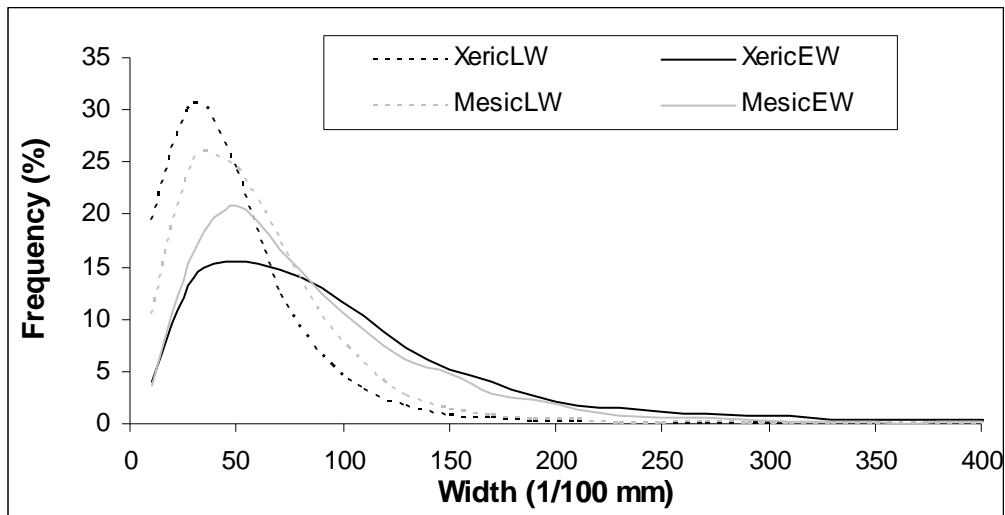


Figure 2: Relative frequency (%) of early- (EW) and latewood (LW) widths in mesic and xeric sites.

Radial growth of trees was positively influenced by moist and warm previous-year autumn, and cool and wet current-year spring (Tab. 2). Current-year late summer temperature positively affected trees in mesic sites, most likely showing that a higher water content in the soil allows these trees to grow after summer temperature decreases. However, the significance of September temperature on EW could also be a statistical artifact.

Table 2: Tree growth response to temperature and precipitation (response functions). O, significant coefficients at 95%. Shaded areas show negative coefficients.

		TEMPERATURE													
		Previous year				Current year									
		SEP	OCT	NOV	DEC	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
TRW	mesic				O			O							O
	Xeric	O			O						O				
EW	mesic				O						O				O
	Xeric	O			O						O				
LW	mesic										O				
	Xeric										O	O			

		PRECIPITATION													
		Previous year				Current year									
		SEP	OCT	NOV	DEC	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
TRW	mesic				O										
	Xeric				O					O					
EW	mesic														
	Xeric									O					
LW	mesic				O										
	Xeric				O					O					

Spring precipitation was only significantly correlated with growth in xeric sites, suggesting that in these sites water is more a limiting factor, than in mesic sites. Thus, the higher relative abundance of wider latewood in tree-rings from mesic sites (Fig. 2). This is also supported by the negative influence of temperatures in previous-year summers and current-year springs in xeric sites (Tab. 2) that might decrease the availability of water in the soil through evapotranspiration. High

temperatures in July reduced growth of LW in xeric sites only, probably showing a longer period of water stress.

During drought periods, all tree-ring sections showed reduced growth as compared with five years previous and after the drought (Fig. 3). LW was the most affected ring section (Fig. 3; Tab. 3), and EW the least. This suggests that water stress at the beginning of the growing season might not greatly differ from dry to normal years since soil water reservoir is charged during the wet-cool season (October-May). These differences increase later in the spring or summer.

Trees growing in xeric sites experienced greater tree-ring reductions during droughts than those in mesic sites (Fig. 3, Tab. 3), which is in accordance with findings on *Pinus ponderosa* Dougl. Ex. Laws (Adams & Kolb 2005) but contrasts with those on *Pinus virginiana* Mill. (Orwig & Abrams 1997.) All these results point toward a species specific site-drought response for the mentioned pines species. In xeric sites, LW formed during dry years was on average 25% narrower than those of five years pre- and post-drought. This difference was 14% in mesic sites (Tab. 3). One year after drought, trees in mesic stands recovered or exceeded normal growth by 14%. On the second year, trees achieved a growth greater than that before the drought and trees in xeric sites grew faster compared to mesic sites (Fig. 3). Prolonged post-drought reductions in black pine were not observed, in accordance with similar results in *P. virginiana* (Orwig & Abrams 1997.)

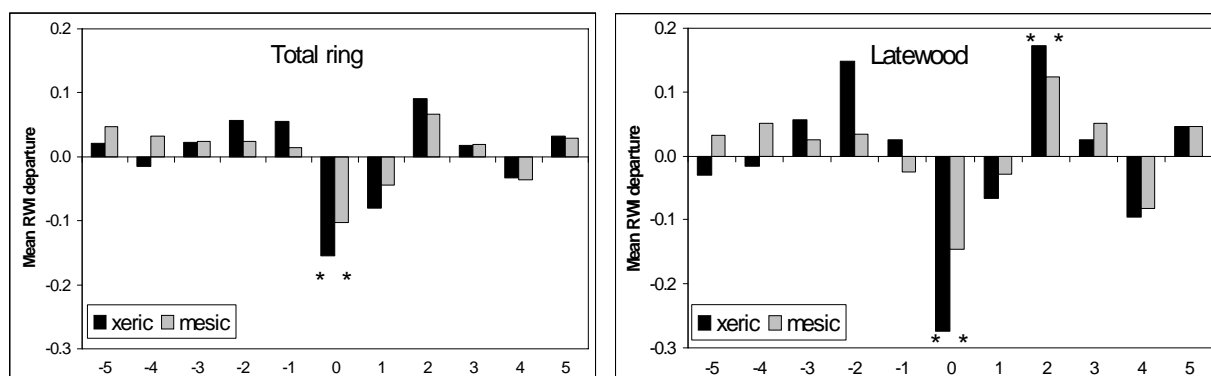


Figure 3: Mean RWI departures of TRW and LW in the SEA for the drought years and five years before and after drought. (*) denotes a departure greater than expected to occur by chance from 10,000 random simulations ($P < 0.005$).

Table 3: Means \pm SE and relative changes ($\% \pm$ SE) in raw ring width in xeric (X) and mesic (M) sites for each ring compartment. Departures are pooled from the ten drought episodes considered. Means in a column with the same letter are not significantly different at $P < 0.005$.

Ring compart.		Drought vs prior year (%)	Post- vs pre-drought (%)	Drought vs 5 year pre-drought (%)	5- year post-drought vs drought (%)	5 year post- vs 5 year pre-drought (%)
TRW	X	-7.0 \pm 2.7 a	-2.8 \pm 3.1 a	-17.0 \pm 1.4 b	21.0 \pm 1.9 b	6.4 \pm 1.5 a
	M	-7.1 \pm 2.1 a	-0.1 \pm 2.4 a	-11.5 \pm 1.3 ab	23.5 \pm 2.3 b	-0.9 \pm 1.5 bc
EW	X	-2.1 \pm 3.0 a	-0.8 \pm 3.8 a	-11.9 \pm 1.5 ab	15.1 \pm 1.9 b	6.2 \pm 1.5 a
	M	-5.9 \pm 2.0 a	-4.3 \pm 2.2 a	-9.1 \pm 1.3 a	16.0 \pm 2.2 b	1.8 \pm 1.4 ab
LW	X	-9.0 \pm 3.2 a	6.3 \pm 3.6 ab	-25.1 \pm 1.6 c	55.4 \pm 3.9 a	4.2 \pm 1.8 ab
	M	-2.9 \pm 3.17 a	14.1 \pm 4.0 b	-13.9 \pm 1.9 ab	55.1 \pm 4.8 a	-5.7 \pm 1.8 c

TRW, total-ring width; EW, earlywood; LW, latewood.

Conclusions

It was clearly shown that drought periods impose a higher than regular water stress for black pine growth regardless of the site type (mesic or xeric). Mesic sites have better developed soils with higher soil water capacity and higher amount of run-off water. Black pine trees in these sites seem to withstand drought better than trees in xeric sites and recover faster from growth-decrease after

drought. However, when soil water is not such a limiting factor, trees in xeric sites could have ring growth similar or wider than trees in more mesic sites.

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