Growth trends and sensitivity to climate of declining Mediterranean open woodlands exhibiting widespread mortality in Southern Spain

NATALINI, Fabio[1]; ALEJANO, Reyes[1] [@]; VÁZQUEZ-PIQUÉ, Francisco Javier[1]; CAÑELLAS, Isabel[2]; GEA-IZQUIERDO, Guillermo[2]

[1] Departamento de Ciencias Agroforestales, Universidad de Huelva (Spain); [@] ralejan@dcaf.uhu.es

[2] INIA-CIFOR, Madrid

INTRODUCTION and OBJECTIVES

Holm oak (*Quercus ilex* L.) is the most widespread *Quercus* species in Spain and constitutes with *Quercus suber* the Spanish open woodland forest agroecosystem called "dehesa". Widespread decline and mortality events are occurring in the dehesas of SW Spain. We discuss the implication of climate in this phenomenon.

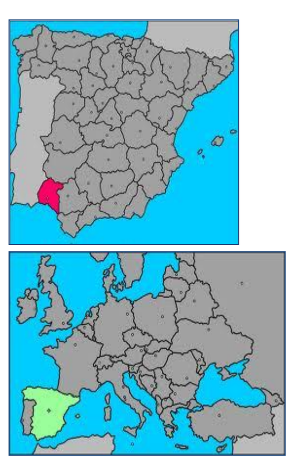
Our objectives were:
- •Establishing the changes of climate in this region over the last decades;
- •Exploring the variability of basal area increment in two stands affected by decline and mortality to different extents;
- •Assessing the driving climatic factors for tree growth and exploring the interdecadal changes in these relationships.

MATERIALS and METHODS

STUDY SITES, SAMPLES and CLIMATE

TABLE 1. Main features of the plots

	QCA	QHR
Location	Province of Huelva (SW Spain)	
Species	*Q. ilex* ssp. *ballota*	
Climate	Mediterranean (FIG.1, "Huelva" station, 1920-2010)	
Altitude (m a.s.l.)	165	200
Tree density (trees/ha)	35	73



Trees weakening happened to different extents in our plots and in different times within the 2000s (TABLE 2). Mortality has been expanding in the last years, becoming a large-scale phenomenon.

Heavily affected trees were logged in 2007 (QCA) and 2011 (QHR). Twelve basal stem sections from QHR and nineteen from QCA were selected for ring measurement.

FIGURE 1.

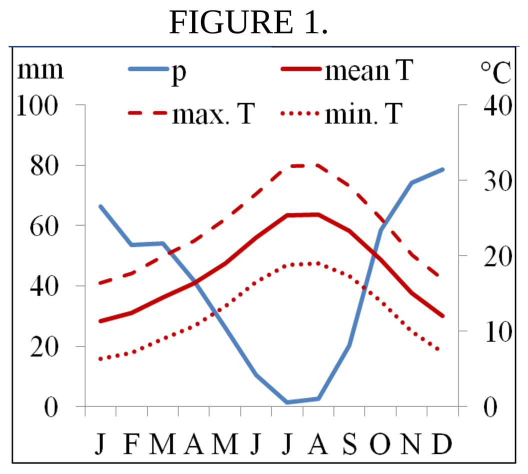


TABLE 2

	QCA		QHR
	2001	2006	2010
def.	90%	95%	26%
def.>50	55%	78%	6%

Defoliation (observed on different surveys); "def." is total % of trees presenting defoliation (loss of leaves, shoots and side branches); "def.>50" is % of trees presenting heavy defoliation (loss of more than 50% of leaves, shoots and side branches).

DENDROCHRONOLOGICAL ANALYSES

Tree-ring widths were measured using LINTAB™ and TSAP-Win™ software (Rinntech®). The raw ring width curves were cross-dated using COFECHA(Grissino-Mayer, 2001). The master chronologies were verified by crossdating them with a close *Pinus pinea* stand chronology we had established previously, using *Gleichläufigkeit* (>60), t-value (>3) and Cross Date Index (>10) as parameters (and thresholds). The individual series were standardized by applying a 32y smoothing spline, the autocorrelation was removed and the dimensionless ring width indexes (Gi) were obtained. Ring widths and cross section diameters were used to compute the basal area increments (BAI). The whole procedure was carried out in R software using library dplR

RESULTS

CHRONOLOGIES

TABLE 3. Statistics of the chronologies

	QHR			QCA		
Time span	1862-2011 (150 years)			1892-2007 (116 years)		
Common interval to all trees	1927-2008 (82 years)			1923-2006 (84)		
Trees vs. Master chronology Pearson correlation	0.65			0.70		
Expressed Population Signal	0.90			0.95		
Crossdating with *P. pinea*	Glk	T-value	CDI	Glk	T-value	CDI
	0.62 (p<0.05)	11	41	0.67 (p<0.01)	10.6	47

Discontinuous rings (i.e. rings incompletely formed along the circumference) appeared mostly from the 1970s and were more frequent in the 1990s.

CLIMATE and BASAL AREA INCREMENTS

In the recent decades, drought (PDSI - Palmer Drought Severity Index - FIG. 2) was severe. There were an upturn of spring and summer temperatures and a downturn of winter temperatures, and no trends in precipitation.

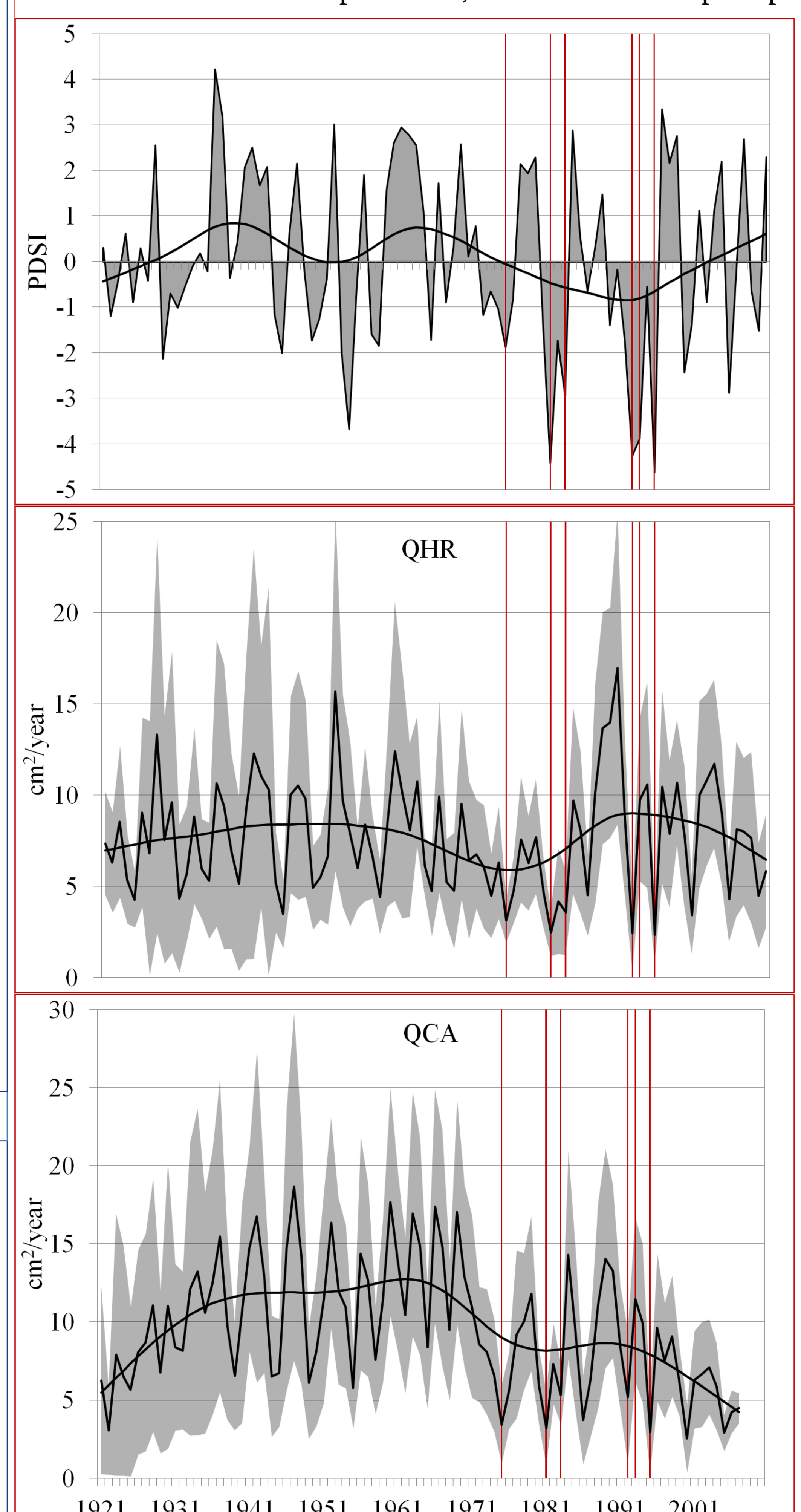


FIG. 2 Palmer Drought Severity Index (above) and mean basal area increments of the two stands (solid line). Grey areas in QHR and QCA are mean BAI ± standard deviation. Fitting curves are 30y splines. Vertical red bars are extreme climatic events (see text).

A drop of the BAI occurred in the 1970-80s. A recovery was observed in both plots in the last 1980s, but QCA did not return to the earlier growth rates. In QHR mortality happened more abruptly. Remarkable drops of BAI values in recent decades were triggered by extreme climatic events (e.g. PDSI≤ -3; precipitations 50%-70% less than previous year). The partial recovery in the 1980s could be explained by epigenetic responses to severe climate (improved water conductivity, narrower vessels, stomatal closure control). The differences between the two stands can be related to local environmental factors that could have smoothed climate extremes in QHR, e.g. higher stand density (Gea-Izquierdo et al., 2009) or better soils.

CLIMATE-GROWTH CORRELATIONS

		previous year								current year											
		M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
QCA	P	+	+	-	-	-	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+
QHR	P	+	+	-	+	+	+	+	+	+	+	+	+	+	-	+	-	+	+	+	+
QHR	max T	+	-	-	-	+	-	-	-	-	-	-	-	-	+	+	+	+	-	-	-
QHR	min T	+	+	-	-	+	+	+	+	+	+	+	+	-	-	+	-	+	-	-	-
QCA	max T	n	-	-	-	+	-	-	-	-	-	-	-	-	-	+	+	+	-	-	
QCA	min T	n	-	-	-	+	+	+	+	+	+	+	+	-	-	+	-	-	-	-	-

TABLE 4. Pearson correlations between Gi and monthly climate. "max/min T" are average of maximum/minimum temperatures. Dark grey are p<0,01, light grey p<0,05.

Growth is mostly related (TABLE 4) to precipitations from previous autumn to spring and mild temperatures in winter. Relationships (FIG.3) with previous autumn and winter have increased since the 1970s. Negative effects of May temperature arose in the last decades. Multiple regression analysis (FIG.4) indicate negative relationships of growth with both winter and spring PDSI, more significant in QCA.

FIG. 3. 20yrs running window Gi-climate correlations (x-axis shows the mid-year of the window). Months of previous year are in caps. Horizontal dotted lines are critical values (α=0,01), solide lines are statistical critical values using Bonferroni correction (α=0,001).

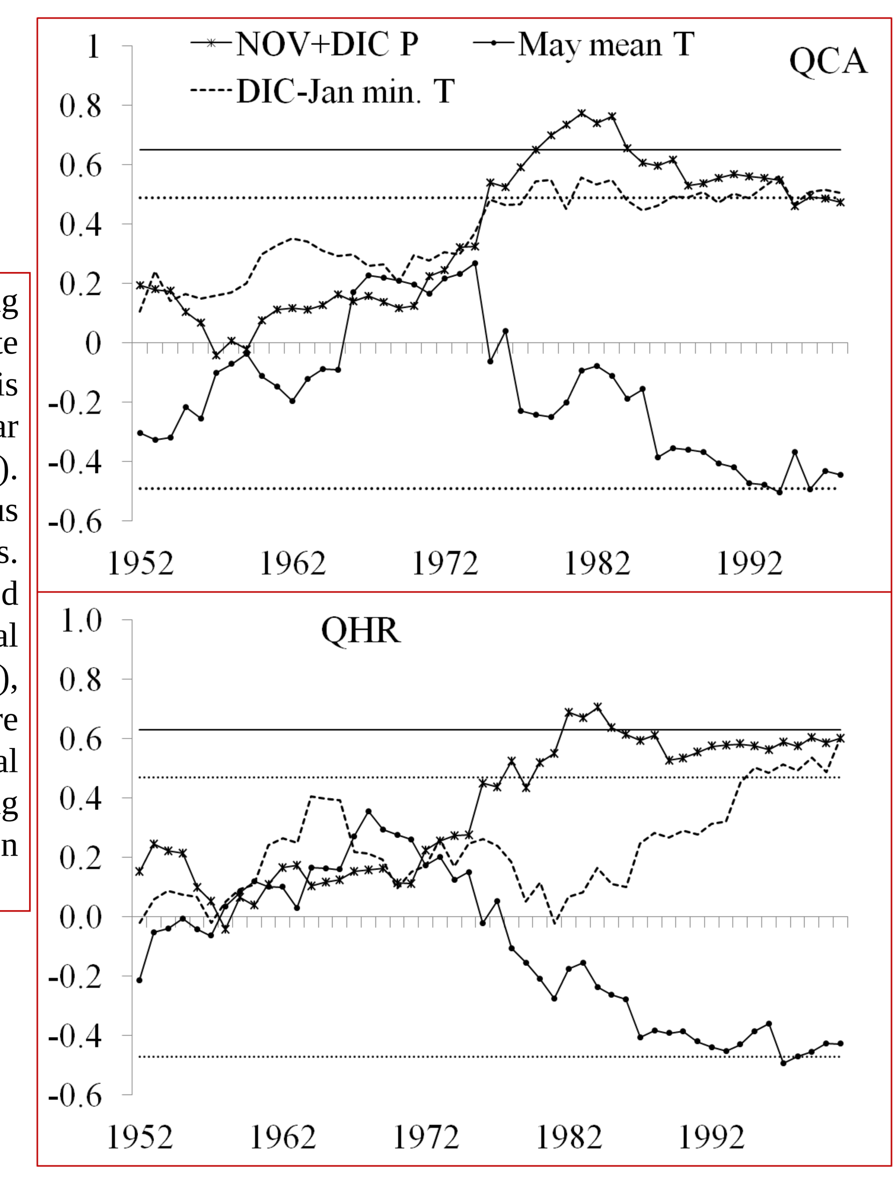
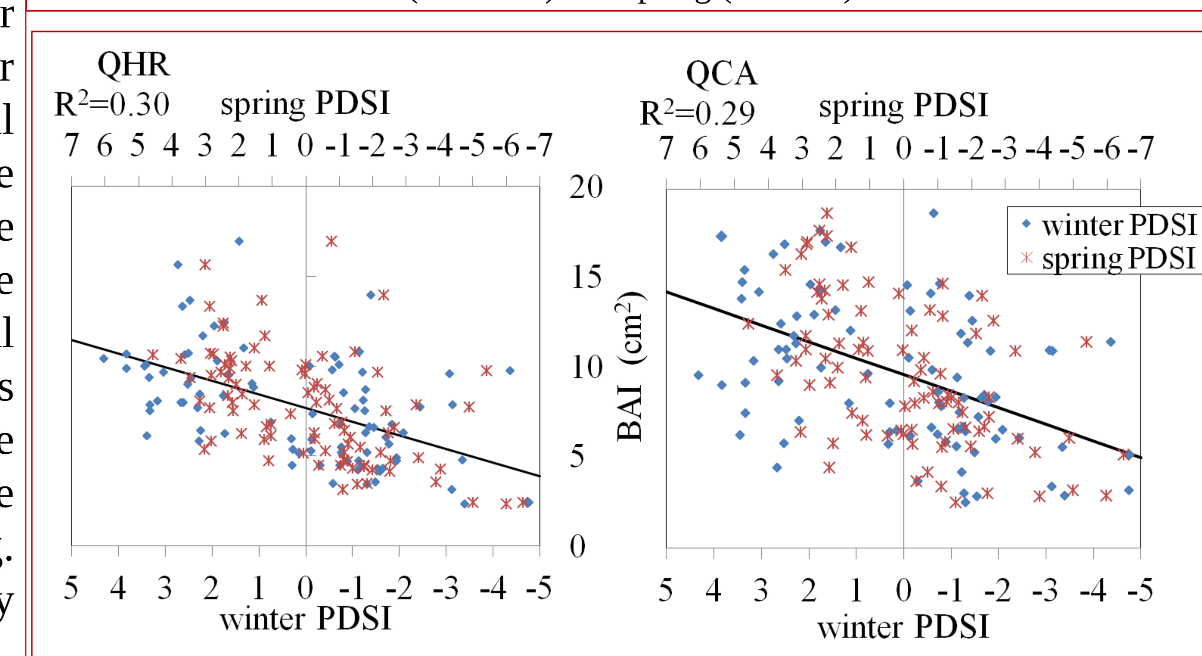


FIG. 4. Multiple regression between BAI and winter (blue dots) and spring (red dots) PDSI.



COLCLUSIONS

Growth decline started simultaneously with the increasing drought. After a partial and not uniform recovery in the 1980s, the heavy and prolonged drought of the mid 1990s and the increased climatic variability of the last years could have make adaptation more difficult.

Growth mostly relies on water availability from preceding months, as well as on mild winters that allow photosynthesis. These relationships have become particularly significant since the 1970-80s, suggesting modifications in phenology, i.e. cambial activity increases its dependency on pre-spring climatic conditions and avoids late-spring/summer, that have become drier in recent dedades.

Drought events in winter and spring can be serious constraints. Prolonged drought can amplify the risk of carbon starvation. In the last decades, the warming in spring/summer entails a higher transpiration pull and the downturn of winter temperatures induces a risk of frost-induced embolism.

Climate changes can be considered predisposing factors of mortality in these woodlands. Anthropogenic disturbances (low stand density, livestock pressure) and pathological agents are additional factors which limit their survival value.

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