

INFLUENCE OF SILVICULTURE AND ENVIRONMENT ON CORK+WOOD GROWTH BASED  
ON BAND DENDROMETER DATA

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## ABSTRACT

The objective of this study is to analyse the influence of environment and silviculture (inter-tree competition, stripping intensity, tree size) on cork oak stem growth, measured by band dendrometers. Two experimental field plots were installed in 2003 in two contrasting sites for the species: Hinojos (Huelva, Spain) and Cortes de la Frontera (Málaga, Spain). In 100 trees per plot, an aluminium band dendrometer was attached to the stem and monthly measurements of cork+wood circumference growth were collected since spring 2003. Measurements needed to calculate the stripping intensity (circunference and stripping length on the stem and branches) were collected. Inter-tree competition was taking into account calculating several distance dependent competition indexes. A model that takes into account the influence of tree size, cork thickness, stripping intensity, intraespecific competition, regional effect and tree type (stripped or not stripped cork oak) on wood+cork growth was developed. The circumference at breast height over cork, the competition index Area Overlap Index, the tree type, the year effect and the interaction circumference-region were the variables selected in the model.

Monthly growth patterns showed a winter rest period from November to February in Hinojos and from November to April in Cortes, with high interannual variability. Maximum growth rates occurs in spring and starting of summer with maximum values in June (Hinojos) and July (Cortes de la Frontera). Drought leads to a rest growth period at the end of summer in Hinojos site.

*Keywords:* circumference growth, environment, silviculture, competition, band dendrometer, *Quercus suber*.

## INTRODUCTION

Cork oak (*Quercus suber* L.) is one of the most important forest species in the Iberian peninsula, covering 713.000 ha in Portugal (D.G.F, 2001) and around 500.000 ha in Spain (DGCONA, 1998). It has a high socio-economic and ecological importance that make them highly appreciated by the society (Montero *et al.*, 1994). As the economic importance is mainly based on cork production for wine stoppers cork oak forests have been traditionally managed with the main objective of cork extraction. Hence most of the models that have been developed for management purposes have been focused on the estimation of cork production (Ferreira and Oliveira, 1991; Ribeiro and Tomé, 2002; Vázquez and Pereira, 2005) and little attention have been paid to growth models or on the influence of silviculture and environmental factors on growth of the species.

A more detailed knowledge of growth and silvicultural and environmental factors that are affecting it is of major importance for the use of technical criteria to define the management of this important species. In this work we analyze the influence of environment and silviculture (inter-tree competition, stripping intensity, tree size) on cork oak stem growth, measured by band dendrometers.

## MATERIAL AND METHODS

### *Study sites*

Two ecologically contrasted sites were selected for the study: Hinojos (Huelva) and Cortes de la Frontera (Málaga). Hinojos is a 1,89 ha plot situated in a flat area at 100 m.a.s.l. with arenosol and planosol soil types, while Cortes de la Frontera is a 0,67 ha plot at 850 m.a.s.l. in an eastern slope with cambisol soil type. Marked differences can be found also in climatic conditions (see contrasting climodiagrams in Figure 1), with less severe summer drought and lower temperatures in Cortes de la Frontera, and in stand density, with lower density in Hinojos (8,9 m<sup>2</sup> ha<sup>-1</sup>, 99,6 trees ha<sup>-1</sup>) than in Cortes de la Frontera (24,9 m<sup>2</sup> ha<sup>-1</sup>, 345 trees ha<sup>-1</sup>).

### *Material*

Each tree inside the plots was positioned with a topographical total station and the variables indicated in Table 1 were measured with the objective to analyse the influence of intra-specific competition, tree size and stripping pressure on tree growth. For the growth measurement, an aluminium band dendrometer was placed on each tree (107 in Hinojos, 110 in Cortes de la Frontera) in April 2003 and monthly measurements were carried out with a caliper, placing it between two close holes of a diameter of 3 mm that were made in the aluminium. Band dendrometers were own made with 2 cm wide aluminium strips.

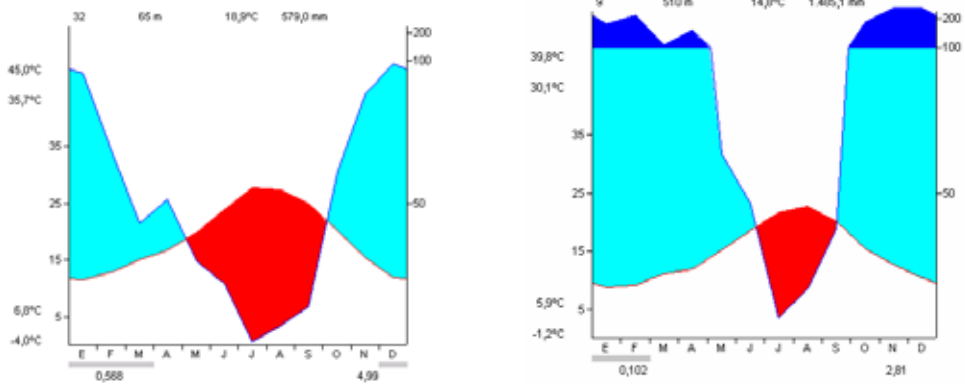


Figure 1. Climodiagrams of the study sites of Hinojos (left) and Cortes de la Frontera (right)

Variable	Definition and description	Unit
COC	Circumference at breast height over cork	m
CUC	Circumference at breast height under cork	m
R <sub>i</sub>	Crown radius at azimuth i., with i = 0°, 90°, 180° and 270°	m
SH	Stem height	m
SHS	Stripped height in the stem	m
PMIC	Stem perimeter inside cork measured at the middle of the stem stripped height	m
NB	Number of stripped main boughs	-
SLS <sub>i</sub>	Stripped length of main bough i measured from the insertion into the stem	m
SLB <sub>j</sub>	Stripped length of bough j measured from the insertion into other bough	m
PB <sub>j</sub>	Perimeter at breast height of bough j under cork measured at the middle of the bough stripped length	m
BAIC	Basal area under cork. $BAIC = CUC^2/4\pi$	m <sup>2</sup>
CB	Cork thickness	mm
SLMAX	Maximum stripping length. $SLMAX = SHS + \max(SLS_i)$	m
SLMEAN	Mean stripped length. $SLMEAN = SHS + \frac{\sum_{i=1}^{NB} SLS_i}{NB}$	m
SLTOT	Total stripped length. $SLTOT = SHS + \sum_{i=1}^{NB} SLS_i$	m
SCMAX	Maximum stripping coefficient. $SCMAX = SLMAX/COC$	-
SCMEAN	Mean stripping coefficient. $SCMEAN = SLMEAN/COC$	-
SCTOT	Total stripping coefficient. $SCTOT = SLTOT/COC$	-
SS	Stripped surface. $SS = SHS \cdot PMIC + \sum SLB_j \cdot PB_j$	m <sup>2</sup>
SIN	Stripping intensity. $SIN = SS/BAIC$	-
CCS	Circular crown surface. $CCS = \pi \cdot (\sum R_i / 4)^2$	m <sup>2</sup>
ECS	Elliptical crown surface.	m <sup>2</sup>
X	X Coordinate	m
Y	Y Coordinate	m

Table 1. Variables measured and calculated on each tree

*Model*

A model that takes into account the influence of tree size, cork thickness, stripping intensity, intraspecific competition, regional effect and tree type (stripped or not stripped cork oak) on wood+cork growth has been developed. Three growing periods were considered (2003, 2004 and 2005). The structure of the model is:

$$y_{ijkl} = \beta_0 + \sum_{s=1}^h \beta_{sij} x_{ijls} + \alpha_i + \tau_j + \omega_k + \alpha\tau_{ij} + \alpha\omega_{ik} + \tau\omega_{jk} + e_{ijkl}$$

$y_{ijkl}$ , Circumference growth in the k growing period of the l tree of type j in the i region

$\beta_0$ , intercept

$x_{ijls}$ , value of the sth selected covariate in tree l of type j in the i region. Includes covariates related with tree size, stripping pressure and intraspecific competition

$\beta_{sij}$ , sth coefficient of the h selected covariates

$\alpha_i$ , fixed regional effect

$\tau_j$ , fixed tree type effect

$\omega_k$ , fixed effect of the k growing period

$e_{ijkl}$ , residual error

The assessment of the intraspecific competition was made with the calculation of 20 varieties of distance dependent competition indexes, including:

- Crown overlap index:  $ISC_i = \frac{1}{SC_i} \sum_{j=1}^n SCInt_{ij}$

where,

$ISC_i$ : crown area of subject tree i  
 $SCInt_{ij}$ : crown area intersection of subject tree i and competitor j

- Area Overlap Index:  $AO_{mski} = \frac{1}{AI_{mi}} \sum_{j=1}^n \left( \frac{ao_{mij}}{AI_{mi}} \right) \left( R_{sij} \right)^k$

where,

$R_{sij} = D_j / D_i$ , where  $D_j$ : diameter of competitor tree j and  $D_i$ : diameter of subject tree i  
 $ao_{mij}$ : overlap area between subject tree i and competitor j using some definition m of radius of influence

$AI_{mi}$ : area of influence of tree i using m as definition of radius of influence

Values tested: Radius of influence (Rm): b= 0,10; 0,15; 0,20.

k: 0, 1, 2.

Unilateral and Bilateral versions

Competition indexes have been calculated with INCO program (Vázquez *et al.*, 2001).

The selection of covariates was made with all possible regressions considering variables related with tree size, cork thickness, stripping intensity, competition and fixed effects, without interactions. In this phase, the estimation was made with Ordinary Least Squares and the selection of the best combination of covariates through statistical criteria: Adjusted R<sup>2</sup> (AdjR2), Mean

square error (MSE), Akaike information criterion (AIC), Schwarz Bayesian Criterion (SBC), PRESS, APRES, Variance Inflation Factors (VIF) and Condition Number (NCOND), combined in a punctuation algorithm with 0-1 range:

$$\begin{aligned}
 \text{PUNTI} = & \frac{3}{10} \left( \frac{1}{4} \left( \frac{\max(\text{MSE}) - \text{MSE}}{\text{rango}(\text{MSE})} + \frac{\text{AdjR}^2 - \min(\text{AdjR}^2)}{\text{rango}(\text{AdjR}^2)} + \frac{\text{abs}(\text{AIC} - \max(\text{AIC}))}{\text{rango}(\text{AIC})} + \frac{\text{abs}(\text{SBC} - \max(\text{SBC}))}{\text{rango}(\text{SBC})} \right) \right) + \\
 & + \frac{5}{10} \left( \frac{1}{2} \left( \frac{\max(\text{PRESS}) - \text{PRESS}}{\text{rango}(\text{PRES S})} + \frac{\max(\text{APRES}) - \text{APRES}}{\text{rango}(\text{APRE S})} \right) \right) + \frac{2}{10} \left( \frac{1}{2} \left( \frac{\max(\text{VIF}) - \text{VIF}}{\text{rango}(\text{VIF})} + \frac{\max(\text{NCOND}) - \text{NCOND}}{\text{rango}(\text{NCON D})} \right) \right)
 \end{aligned}$$

The final variance-covariance matrix was block diagonal with an autoregressive order 1 AR(1) structure for within-tree repeated observations. The estimation of the covariance parameters was made through Restricted Maximum Likelihood (REML) and the estimation of fixed effects with Generalised Least Squares.

### RESULTS

In Figure 2, monthly mean current growth at Hinojos and Cortes de la Frontera plot is shown for the 28 months of study. Two growth periods can be detected: spring, that accounts for most of the total growth of the year, and autumn. Minimum growth is detected in the winter rest period (from November to March in Hinojos, from November to April in Cortes de la Frontera) and at the end of summer mainly in Hinojos. High interannual variability can be observed. The severe drought in 2005 made that this year growth was markedly reduced in comparison to the same period of 2004. In Table 2, the mean growth values for the two regions and the three growing periods are presented. Growth is higher in Cortes de la Frontera due to a less severe summer drought, even if the winter rest period is longer. In Figure 3, a comparison between the two regions in a monthly basis is shown and a shift can be detected, due to the different phenology in the two regions.

Year	Region			
	Hinojos		Cortes de la Frontera	
	Mean (mm)	SD	Mean (mm)	SD
2003	11,14	5,33	15,88	6,96
2004	15,17	6,41	20,10	8,08
2005	0,73	1,99	5,96	2,95

Table 2. Mean growth values in mm and standard deviations (SD) for the two regions and the three growing periods.

The covariates selected in the final model were the circumference over cork (COC) and the competition index Area Overlap index (AOI) with  $k=0$   $b=0,1$  and unilateral. It was detected a significant tree type and growing period effect and a significant interaction circumference-region. In the covariance parameter estimates phase a significant within years AR(1) structure was detected with a correlation parameter = 0,45. The estimates of the fixed effects is shown in Table 3 and the plot of residuals vs. predicted values is shown in Figure 4.

The stripping intensity, in the levels that is applied in the plots, is not affecting cork+wood growth and the introduction of competition index improves the performance of the model and

the sign has biological meaning (higher competition, less growth). The most important effect is the year effect due to: (1) 2003 and 2005 are not complete years, (2) the extreme drought in 2005 made that mean growth in Cortes de la Frontera was 13% of the previous year growth and 2% in Hinojos. The type of tree (stripped, not stripped) is significant because cork growth in not stripped trees is lower than in stripped trees

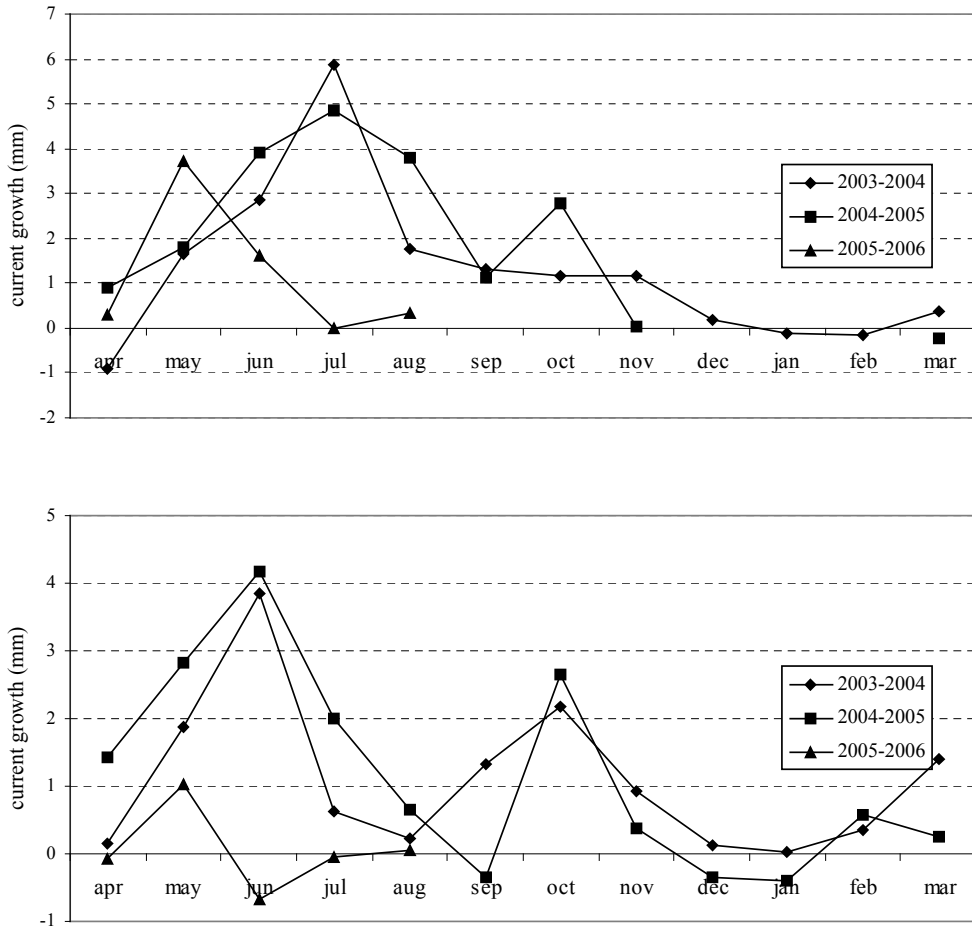


Figure 2. Current circumference growth (in mm) in Hinojos (above) and Cortes de la Frontera (below) for 28 months

The model gives biased estimations of negative growth (Figure 4) but negative values only occur in damaged trees, winter cold periods and severe droughts. For the continuous variables selected (competition index, circumference over cork) no specific trends are observed in the residuals (Figure 4).

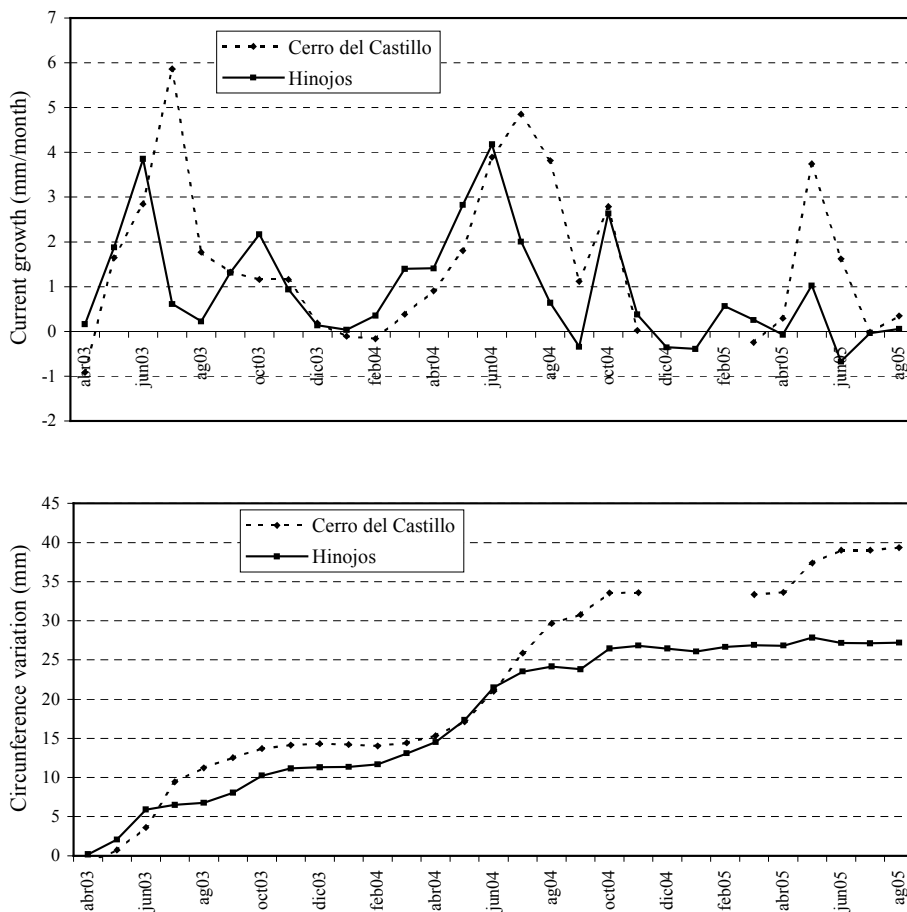


Figure 3. Comparison between current circumference growth (above) and accumulated circumference growth (below) in Hinojos and Cortes de la Frontera for the 28 months period

Effect	Level	Estimate	Prob>t
Intercept		-11,6	0,0001
COC		0,11	0,0001
AOI		-1,08	0,27
Region	Hinojos	2,12	0,34
	Cortes de la Frontera	0	
Tree type	Stripped tree	7,3	0,0001
	Not stripped tree		
Year	2003	10,16	0,0001
	2004	14,29	0,0001
	2005	0	0,0001
COC*Region	Hinojos	-0,07	0,0003
	Cortes de la Frontera	0	

Table 3. Estimation of fixed effects. COC: Circumference over cork; AOI: Area Overlap competition index

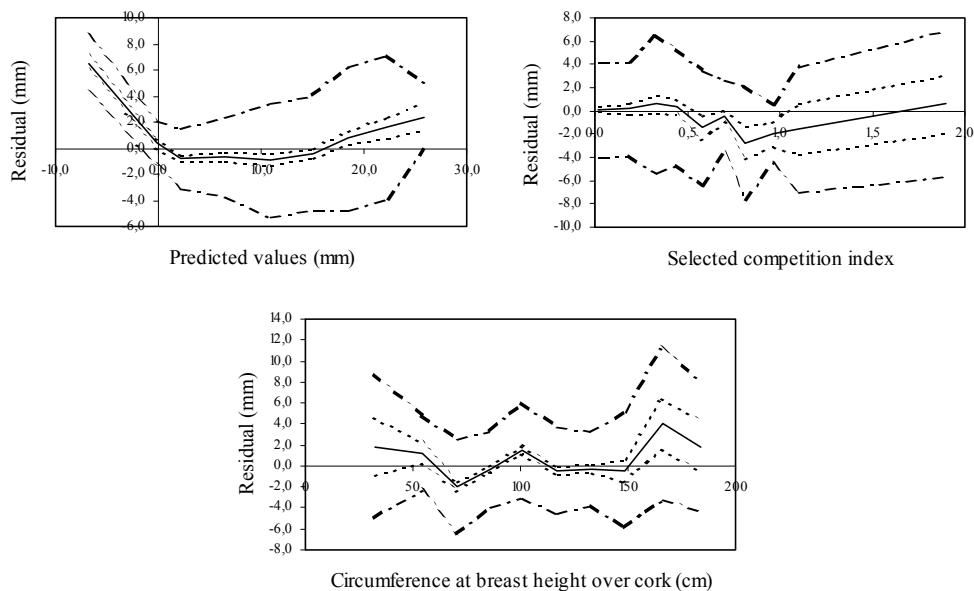


Figure 4. Predicted values, selected competition index and circumference at breast height vs. Residuals with indication of standard errors and the standard errors of the mean

## CONCLUSIONS

The circumference at breast height over cork, the competition index Area Overlap Index, the tree type, the year effect and the interaction circumference-region are variables that affect significantly cork+wood growth. The stripping intensity, in the levels that is applied in the plots, is not affecting cork+wood growth.

Minimum growth is detected in the winter rest period (from November to March in Hinojos, from November to April in Cortes de la Frontera) and at the end of summer mainly in Hinojos. Maximum growth rates occurs in spring and starting of summer with maximum values in June (Hinojos) and July (Cortes de la Frontera).

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