PEDUNCULATE OR COMMON OAK (*QUERCUS ROBUR* L.) SILVICULTURE IN NATURAL STANDS OF GALICIA (NW SPAIN): ENVIRONMENTAL RESTRICTIONS

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The silviculture applied in the *Quercus robur* L. forests is well developed in countries where the species has economic importance. The situation in NW Spain is different, as there is little knowledge about the silviculture to apply. Coppice forest predominates and requires continual management otherwise the stands will age and stagnate. Many of these forests have been intensively exploited, and in many cases inappropriate treatments have been used. Recently, as a result of rural depopulation, there has been a change from overexploitation to a lack of intervention. Their management must now be carried out in accordance with silvicultural criteria and environmental restrictions. Our hypothesis is that the environmental conditions do not preclude the application of an alternative silviculture to obtain more gainful outputs rather than with the traditional. To obtain the mosaics which *Q. robur* is present the Forest Map of Spain was asked, and the sampling zones were selected. Representative oak stands were chosen to dispose the resulted 39 plots. Once were replanted, a floristic inventory was carried out and abiotic-biotic data were recorded. The results show that with lower values of the altitude, slope and distance to the sea, the density is greater, and the best sites for *Q. robur* correspond to thalweg or intermediate slope with an oceanic influence. In these zones, the climatic characteristics combine optimally higher minimum temperature, lower thermal amplitude and higher precipitation. Alternative treatments must be proposed, which will range from a conversion to high forest to recovery of the stands by reforestation.

Keywords: forest management, high forest, coppice, *Quercus robur*, NW Spain.
Parole chiave: gestione forestale, foresta, cedui, *Quercus robur*, NO Spagna.

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1. Introduction

Forest management has a considerable influence on the stability and sustainability of forest ecosystems (Johnson *et al*., 2002; Decocq *et al*., 2004). In the case of oak trees, the silvicultural practices applied form part of forestry mythology (Bouchon and Trencia, 1990).
The silviculture utilized to pedunculate or common oak (*Quercus robur* L.) are well developed and up to date in countries where the species is of great economic importance, such as France, where thousands of hectares of oak forest have been managed for centuries (Bary-Lenger and Nebout, 1993; Timbal and Aussenac, 1996; Harmer and Morgan, 2007). However, the situation in the study area is awfully different from that in the above-mentioned country, as there is minor knowledge about the silvicultural treatments that should be applied to autochthonous broadleaf forests, in general. Galician oaks present a varied range of ages and qualities, as a result of the different uses and status of conservation (Díaz-Maroto *et al*., 2005). Coppice forest predominates and it requires continual management otherwise the stands will age and stagnate and may disappear (Díaz-Maroto *et al*., 2006; Van Calster *et al*., 2007).
Many of these forests have been intensively exploited (i.e. for the wood and firewood extractions for domestic and industrial uses or for the naval industry) (Manuel and Gil, 2001), and in many cases inappropriate silvicultural practices have been applied (pollarding and felling of the best trees) (Díaz-Maroto *et al*., 2005).
The shipbuilding was stimulated by the Spanish maritime expeditions, the commerce with Europe and the Indies, and the fishing activity. Due to transportation difficulties, the naval industry needed closer forests to fulfill their necessities. The wood proportion by ship was about 30-50% conifers, and 70-50% broadleaves, mainly oaks. The employed trees had to have specific dimensions and they were of the best quality and after their extraction, the rest was generally used for firewood or for vegetable coal, which contributed to the devastation of many forests (Manuel and Gil, 2001).
Most recently, as a result of rural depopulation, technological developments and social requests, there has been a change during the past century from overexploitation of many of these forests to a total lack of exploitation (Rodá *et al*., 1999; Reque and Bravo, 2007). The status of these stands has changed recently and there is now a high social demand for their conservation and recovery (Díaz-Maroto *et al.*, 2005).
As outlined in Council Directive 92/43/EC, these forests comprise a habitat of interest to the community and should be conserved; therefore a better understanding of their ecological requirements is needed. Common oak forests, pure stands of *Quercus robur* or mixed with

other broadleaves, occupy an area of 246,445 ha in Galicia, i.e. approximately 18% of the total forest area (MAGRAMA, 2011). Within the region, *Q. robur* behaves as a robust, light-demanding species, which does not tolerate shade at early stages of development and the seedlings of which languish quickly under cover. The largest oak stands are found on steep slopes, where they have survived largely because felling would be complicated owing to the topography (Ruiz de la Torre, 1991). The starting hypothesis is that the environmental conditions do not preclude the application of an alternative silviculture to obtain more profitable outputs rather than with the traditional methods.

2. Material and methods

2.1 Study area

The study area comprises the Autonomous Community of Galicia which is located in the north-west of the Iberian Peninsula and covers an area of ~ 3 million hectares. The mean altitude in the region is 508 m and slopes of more than 20% occur in half of the region.

The lithological composition of the substrate is wide and includes granite, schist, slates and quartzite; the climate is very varied, although generally classified as Humid Oceanic, with a certain Mediterranean influence in some zones. Annual precipitation varies between 600 to more than 3000 mm (Díaz-Maroto *et al*., 2005).

2.2 Description of sampling, data recording and parameters measured

Initial stratification of the study area was not advisable because of the wide dispersal and heterogeneity of the oak stands throughout the region (Rubio *et al*., 1997); therefore, we considered the study area as a single unit when selecting the areas for sampling and posterior data recording. The area was firstly delimited, avoiding certain areas where the presence of *Quercus robur* was unlikely because the forest site characteristics (physiographic, climatic and edaphic) are not appropriate for these species (Timbal and Aussenac, 1996). The sampling zones were then selected, taking care to include a sufficiently representative number of oak stands, on the basis of the data included in the Forest Map of Spain (Ruiz de la Torre, 1991), obtaining the existing vegetation mosaics where *Q. robur* is present, and the sampling zones were selected from within these, with the help of information provided by forestry administration personnel and data reported in previous studies. Representative oak stands by each zone were chosen to replant the inventory plots. The minimum area of the stands considered ranged between 0.5 and 1 ha, which avoided problems associated with the edge effect. The resulting network of 39 rectangular plots, of variable dimension (depending on the number of trees), contained at least 50 inventoriable trees (Ø > 5 cm) (Hummel *et al*., 1959). Once the plots were established, physiographic, dendrometric and edaphic profile data were recorded. The climatic data were obtained from the network of stations of the National Meteorological Institute during 1960-2000, and they were interpolated to the sampling points according to the methodology of Carballeira *et al*. (1983). All these data along with the results of the edaphological analysis were used to elaborate a set of parameters, in each plot, that best describe the forest site and the present management status (Rubio *et al*., 1997; Lebourgeois *et al*., 2004; Bravo-Oviedo and Montero, 2005).

A total of 39 parameters were measured: 28 ecological (5 physiographic, 5 climatic and 16 edaphic) and 14 stand parameters (Tab. 1). The physiographic parameters used to describe the orography of each of the zones studied were altitude and mean slope, soil depth to parent material and closest distance from the sea (Rubio *et al*., 1997; Díaz-Maroto *et al*., 2005, 2006).

The climate was described by the following parameters: total annual and summer precipitation, annual mean temperature and annual mean of absolute maximum and minimum temperature (Carballeira *et al*., 1983). Within the ecological parameters, 16 edaphic parameters were also considered for evaluating the chemical properties and the soil fertility (Gallardo *et al*., 1995; Covelo and Gallardo, 2002; Marcos and Lancho, 2002; Bravo-Oviedo and Montero, 2005), including pH (H_2O), organic matter, total nitrogen, carbon/nitrogen ratio (C/N ratio), available phosphorus and exchangeable potassium, calcium and magnesium.

We considered both the total value for the entire edaphic profile, calculating the weighted mean for the whole profile by the method of Russell and Moore (1968), as well as the surface value, using the data for the upper 20 cm, except where this corresponded to more than one horizon, when a weighted mean was calculated.

Finally, to evaluate the structure and the silviculture of these forests, the following stand parameters were calculated: number of trees and basal area per hectare, mean arithmetic and quadratic diameters, dominant diameter (mean diameter of 100 thickest d.b.h. trees per hectare), mean arithmetic and quadratic heights, Assmann's dominant height (Assmann, 1970), standard deviation and coefficient of variation of the diameter and height distributions, Hart's index (HAI) (which estimates the distribution of trees in relation to dominant height trees) and Czarnowski's index (trees number in a squared plot of side equal to the arithmetic mean height) (Timbal and Aussenac, 1996; Claessens *et al*., 1999).

2.3 Statistical analysis

Measurement of the set of parameters allowed establishment of a database of information on the biotopes and the silvicultural characteristics of *Quercus robur* stands in Galicia. The application of univariate analysis (Walpole *et al*., 1999) allowed calculation of a series of characteristic values for the habitat of the species. To identify the most important parameters, discriminant analysis of the plots was carried out, following the methodology proposed by Hill (1979) and using the TWINSPAN program (Pisces Conservation LTD, 2004). To explain which of these parameters best characterize the silvicultural treatments and present situation of Galician oak forests, as well as to study the possible relationship with the biotope, two types of bivariate analysis were carried out. The first compared the stand parameters with the rest, and the second

compared the stand parameters with the environmental descriptors obtained by discriminant analysis (Fernández-Aláez *et al*., 2005), which allowed principal components analysis (PCA) to be applied (SAS Institute Inc., 2004). This in turn allowed us to identify how the most closely related stand and ecological parameters explain the variability in the *Quercus robur* forests in Galicia (Timbal and Aussenac, 1996; Collins and Carson, 2004).
On the basis of the results, the silvicultural status of the stands was modelled using stepwise multivariate linear regression analysis (SAS Institute Inc., 2004).

3. Results

From the data obtained in the stand inventories and, later, from the parameters calculated, we obtained the information necessary to characterize the habitat of *Quercus robur* on a regional scale in Galicia.
The descriptive statistics for the 39 parameters considered are shown in Table 1. The stands are located in areas with slopes of between 0 and 72% and of altitudes of between 60 and 1300 m, the latter which is reached in the mountainous zone in the east of Galicia (Os Ancares and O Courel); the distance from sea ranges from 1 to 135 km.
The climate is characterized by high precipitation, with values higher than 700 in all stands, and close to 2000 mm in some. The summer precipitation is usually higher than 120 mm; those oak stands in which such high values are not reached are compensated by horizontal precipitation in the form of mist. The mean annual temperature is 11.5 ºC, the maximum value of the absolute maximum mean temperatures is 32.6 ºC, with a maximum temperature of 38.5 ºC, whereas the absolute minimum value of the mTAB is −4.2 ºC, with a minimum temperature of −11.5 ºC (Tab. 2). In the PCA of all discretely defined stand parameters (tree density, BA, coefficient of variation of the diameter and height distribution, ADH, HAI and CZI, an optimal result was obtained, with a value of the Kaiser-Meyer-Olkin (KMO) coefficient > 0.8, and a single vector that explained more than 98% of the variability in the silvicultural data (Tab. 3).
With regard to the discriminant analysis, the worst result from all of the groups of data analyzed corresponded to the physiographic parameters (altitude, slope, soil depth and distance from the sea). As regards the climatic data, the discriminant analysis differentiated two groups of variables. On one hand the pluviometric variables and, on the other hand, the thermal variables.
The variability of the edaphic parameters was highly significant, especially that for pH, and to a lesser extent, organic matter, nitrogen and phosphorus. The CCA of the silvicultural variables defined by the PCA were very significant, with values of between 0.70 and 0.90, and it was possible to explain 93% of the edaphic variability.
In the bivariate correlation analysis, all of these were significantly related to the same silvicultural variable, the BA. The total number of species inventories was approximately 200. The discriminant analysis of the vegetation provided good results, as 95% of the variability in the *Quercus robur* stands was explained by only two vectors. Both vectors showed a canonical correlation of more than 0.9, i.e. a highly significant value. The species included in the first vector were: *Castanea sativa* Mill., *Anthoxanthum odoratum* L., *Vaccinium myrtillus* L., *Agrostis capillaris* L., *Ruscus aculeatus* L., *Stellaria holostea* L., *Ilex aquifolium* L. and, to a lesser extent, *Hedera helix* L., *Melampyrum pratense* L., *Holcus mollis* L. and *Pyrus cordata* Desv. Regarding the second vector, the species included were: *Lonicera periclymenum* L., *Pteridium aquilinum* (L.) Kuhn, *Teucrium scorodonia* L., *Rubus* spp. and *Betula celtiberica* L. had a noteworthy influence. The five most abundant species in addition to *Quercus robur* (*Rubus* spp., *P. aquilinum*, *H. helix*, *L. periclymenum* and *T. scorodonia*) therefore showed a certain, although not very high, degree of discriminatory capacity.
Despite the results obtained with these two vectors in the previous statistical analyses, both show few significant correlations with the silvicultural variables, with the only noteworthy relationships those between the first vector and the BA, and between the second vector and the coefficient of variation for the diameter distribution.

4. Discussion

4.1 Univariate analysis of the ecological parameters

The pedunculate oak stands was most variable in terms of physiographic and climatic parameters, with coefficients of variation near or higher than 70% for parameters SLP and AmT; the rest of parameters presents coefficients of variation < 70% (Tab. 2). In the case of the slope, the data indicate that at present many oak stands in Galicia are located in steeply sloping areas, where they have remained because of the difficulty of harvesting (Ruiz de la Torre, 1991).
The high coefficient of variation for the annual mean of the absolute minimum temperatures parameter (AmT) was particularly noteworthy, in contrast to the other climatic parameters (Tab. 2). This pattern is due to the high thermal range, accentuated by the variation in altitude within the study area (Carballeira *et al*., 1983).
Analysis of the edaphic parameters shows above all, that many are highly variable.
This, however, is not unexpected given the wide range of lithological substrates on which these forests are established, mainly of silicaceous nature, which gives rise to acid soils (Covelo and Gallardo, 2002).

4.2 Silvicultural characteristics and relationship between stand parameters and biotope

The age and site quality of the oak stands were very varied, as a result of their different uses (Díaz-Maroto *et al*., 2005). More specifically, there was high variability in the parameters NT, BA and CZI, with a coefficient of variation higher than 50% (Tab. 2); in the other parameters related to normal diameter (AMD, QMD, SDD, CVD and DD) and especially to the total height (AMH, QMH, SDH, CVH, ADH and HAI), the variability was lower (Lévy *et al*., 1992; Díaz-Maroto *et al*., 2005).

From the set of stand parameters selected by bivariate analysis to describe the use and present status of the oak stands, the dominant height (ADH) must be eliminated, as well HAI, which depends on the former (Rondeux, 1993). This is because dominant height is affected by certain unsuitable silvicultural treatments to which the stands have been subjected, such as pollarding and felling of trees to provide firewood and food for livestock. Finally, only four stand parameters remained for pedunculate oak (AMD, QMD, AMH and QMH). All of these are closely related to the following biotope descriptors (Díaz-Maroto *et al*., 2005): mean altitude (ALT), soil depth to the parent rock (DPTH), mean annual temperature (MT) and annual mean of absolute minimum temperatures (AmT), even, as with AMD and QMD, at a level of significance of 99%. Therefore, these parameters are suitable for correctly defining the features of pedunculate oak stands in Galicia (Timbal and Aussenac, 1996; Rubio *et al*., 1997), and it can be established that the distribution of the stands are more closely related to the physiographic and climatic characteristics than to edaphic factors probably because the substrates' character on which the stands develop is similar (Díaz-Maroto *et al*., 2005, 2006). The results of the PCA showed that the highest possible variability can be explained with four new vectors (SAS Institute Inc., 2004); the first of these is a vector about stand structure, formed by diametric components (AMD, QMD, DD), height components (AMH, QMH, ADH) and NT.
The second vector can be defined as 'oceanity' (Díaz-Maroto *et al*., 2006), because of the importance of the parameters distance from the sea and altitude, both have the same weighting, but with a negative sign.
In the last two vectors, the climatic parameters, especially precipitation, and DPTH were particularly important. The statistical relationships between stand and ecological parameters revealed by multivariate regression analysis showed that, although it is possible to establish close correlations with climatic factors, it is the physiographic parameters, slope (SLP), distance from the sea (DS) and depth of soil (DPTH), that best define the present status of these forests (Díaz-Maroto *et al*., 2005, 2006).

5. Conclusions

The present location of many oak stands in steep areas indicates that they have remained in such areas from immemorial times because it was not feasible their harvesting and these stands are now very valuable in ecological and landscape terms. However, the results show that with lower values of the physiographic parameter, altitude, slope and distance from the sea, the stand density is greater and the spacing between trees is lower. Therefore the best sites for *Q. robur* in NW Spain correspond to thalweg zones or intermediate slopes with an important oceanic influence.
In these zones, the climatic characteristics combine optimally higher minimum temperature, lower thermal amplitude and higher precipitation.
This is related to the growth period of the species and guarantee adequate growth. As regards the floristic data, the results obtained indicate that the floristic composition of the undergrowth has little effect on the growth and production of pedunculate oak stands.
Given the present silvicultural status of these stands, alternative methods must be proposed for their management, which will range from a conversion to high forest to recovery of the most deteriorated stands by reforestation.

Table 1. Parameters measured in each plot.

Number	*Parameter (unit)*	*Code*
1	Mean altitude (m)	ALT
2	Mean slope (%)	SLP
3	Soil depth to the parent rock (cm)	DPTH
4	Closest distance from the sea (km)	DS
5	Annual precipitation (mm)	AP
6	Summer precipitation (mm) SP	SP
7	Mean annual temperature (°C)	MT
8	Annual mean of absolute maximum temperatures (°C)	AMT
9	Annual mean of absolute minimum temperatures (°C)	AmT
10	Total pH in H_2O	PH
11	Surface pH in H_2O	SPH
12	Total organic matter (%)	OM
13	Surface organic matter (%)	SOM
14	Total nitrogen (%)	N
15	Surface nitrogen (%)	SN
16	Total C/N ratio	C/N
17	Surface C/N ratio	SC/N
18	Total available phosphorus (ppm)	P
19	Surface available phosphorus (ppm)	SP
20	Total exchangeable potassium (ppm)	K
21	Surface exchangeable potassium (ppm)	SK
22	Total exchangeable calcium (ppm)	Ca

(*Table 1. Continued)*

23	Surface exchangeable calcium (ppm)	SCa
24	Total exchangeable magnesium (ppm)	Mg
25	Surface exchangeable magnesium (ppm)	SMg
26	Number of trees per hectare (N_0 ha^{-1})	NT
27	Basal area per hectare (m_2 ha^{-1})	BA
28	Arithmetic mean diameter (cm)	AMD
29	Quadratic mean diameter (cm)	QMD
30	Standard deviation of the diameter distribution (cm)	SDD
31	Coefficient of variation of the diameter distribution (%)	CVD
32	Dominant diameter (cm)	DD
33	Arithmetic mean height (m)	AMH
34	Quadratic mean height (m)	QMH
35	Standard deviation of the height distribution (m)	SDH
36	Coefficient of variation of the height distribution (%)	CVH
37	Assmann's dominant height (m)	ADH
38	Hart's index (%)	HAI
39	Czarnowski's index	CZI

Table 2. Descriptive statistics of the ecological parameters.

Parameter (unit)	*Minimum*	*Maximum*	*Mean*	*CV (%)*
ALT (m)	60	1300	539	48.2
SLP (%)	0	72	27	77.7
DPTH (cm)	46	150	94	27.6
DS (km)	1	135	42	66.6
AP (mm)	772	1947	1372	22.7
SP (mm)	61	283	164	31.3
MT (ºC)	7.3	14.6	11.5	13.0
AMT (ºC)	20.0	38.8	24.0	8.3
AmT (ºC)	−4.2	6.2	0.8	300.0
PH	3.92	6.15	4.85	9.3
SPH	3.82	6.53	4.71	10.7
OM (%)	1.04	23.31	8.64	60.0
SOM (%)	1.19	34.21	12.85	60.4
N (%)	0.042	0.793	0.307	58.0
SN (%)	0.050	1.019	0.442	52.5
C/N	6.9	29.6	31.9	31.0
SC/N	10.4	30.1	16.8	25.3
P (ppm)	0.4	117.2	21.8	133.6
SP (ppm)	0.4	119.5	19.8	147.5
K (ppm)	19	252	103	48.5
SK (ppm)	3	1297	120	180.0
Ca (ppm)	4	1704	170	167.6
SCa (ppm)	0	85	29	72.4
Mg (ppm)	0	143	265	77.5

Table 3. Results of PCA of the stand parameters.

	KMO test	*Variable*	*Variability explained (%)*	*Accumulated variability (%)*	*Explanatory parameters*
Stand parameters	0.840	1	98.4	98.4	NT, BA, HAI, and CZI
		2	1.2	99.6	CVD and CVH
		3	0.4	100.0	ADH, HAI, and CZI

KMO: Kaiser-Meyer-Olkin coefficient.

RIASSUNTO

Selvicoltura della Quercia peduncolata o Farnia (*Quercus robur* L.) in popolamenti naturali della Galizia (NO Spagna): Restrizioni ambientali

La selvicoltura utilizzata nelle foreste di *Quercus robur* L. è ben sviluppata nei paesi in cui la specie ha importanza economica. La situazione in NW Spagna è diverso, in quanto vi è poca conoscenza circa la silvicoltura da applicare. Il ceduo predomina e richiede continua gestione altrimenti gli stand invecchieranno. Molte di queste foreste sono state intensamente sfruttate, e in molti casi sono stati applicati trattamenti inadeguati. Recentemente, a seguito di esodo rurale, vi è stato un cambiamento da eccessivo sfruttamento ad un mancato intervento.
La loro gestione deve ora essere effettuata secondo criteri selvicolturali e vincoli ambientali. La nostra ipotesi è che le condizioni ambientali non ostano all'applicazione di una selvicoltura alternativa per ottenere risultati più lucrativi, piuttosto che con il tradizionale. Per ottenere i mosaici che *Q. robur* è presente la Foresta Mappa di Spagna è stato chiesto, e sono state selezionate le zone di campionamento. Querce rappresentative sono state scelte per smaltire i provocato 39 trame. Una volta sono stati ripiantati, un inventario floristico è stato effettuato e sono stati registrati dati abiotici-biotici. I risultati mostrano che, con i valori più bassi di altitudine, pendenza e distanza dal mare, la densità è maggiore, e le migliori siti per *Q. robur* corrispondono al fondovalle con un'influenza oceanica. In queste zone, le caratteristiche climatiche si combinano in modo ottimale temperatura minima più elevata, escursione termica inferiore e superiore delle precipitazioni. Trattamenti alternativi devono essere proposti, che vanno da una conversione a fustaia al recupero degli stand di riforestazione.

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