Environmental conditions and oak barrels timber quality: Which is the influence in the *Quercus petraea* Matts. Liebl. forests in the Iberian Peninsula?

PABLO VILA-LAMEIRO, P.; IGNACIO J. DÍAZ-MAROTO
Department of Agroforestry Engeneering
High Polytechnic School, University of Santiago de Compostela
Universitary Campus n/n E-27002 Lugo
SPAIN
pablo.vila.lameiro@usc.es

Abstract: - The autoecology of the oak *Quercus petraea* in the northwest Iberian Peninsula was investigated in the present study by applying the methodology developed in previous studies of other species of the genus Quercus. For this, the distribution of the species was firstly determined so that a minimum number of representative species could be selected. A total of 52 plots were chosen and in each one, 41 biotype parameters were established (6 physiographic, 17 climatic and 18 edaphic), along with 19 dendrometric and silvicultural parameters. The study of the variability of these parameters allowed description of both central and marginal physiographic-climatic and edaphic habitats of the sessile oak (*Q. petraea*) in the northwest Iberian Peninsula and an assessment of the effect of environmental factors on its present silvicultural status.
The species is indifferent to the type of substrate, tolerates and even prefers lime soils. Within the area of study, sessile oak forests occur at altitudes of between 540 to 1400 m, a range that corresponds to a difference in mean annual temperature of more than 6ºC; however, the main climatic feature that defines the stands under study is the abundance of precipitations, with a annual mean precipitation of 1589.8 mm and a summer mean precipitation of 303.6 mm. The species is less resistant to low temperatures than the pedunculate oak (*Q. robur*) and generally shows a longer growth period.

Key-Words: - Environmental / Quercus petraea / site / ecological limit / Iberian Peninsula / timber

1. Introduction: The problem

The area of distribution of *Quercus petraea* is very specific and less widespread than *Quercus robur*, being restricted to between latitudes of 37º and 62ºN and longitudes of 10º W and 50º E [1, 2, 3], i.e. the easternmost part of Europe [1, 4]. Its distribution is very disperse within the Iberian Peninsula, although wider than that of the pedunculate oak [1, 5, 6], and it is mainly concentrated in the northern mountainous area between Galicia and Cataluña, with notable ocurrences in the Cantabrian mountains, the Basque Country and Navarra [4]. In the northwest Iberian Peninsula, it often mixes and hybridizes with *Quercus robur* (*Quercus x rosacea* Bechst) and *Quercus pyrenaica* (*Quercus x andegavensis* Hy), which makes accurate identification difficult [7, 8, 9].

From a phytosociological point of view, the forests under study are situated in the Eurosiberian Region, Orocantabrian Province, Ubiñense-Picoeuropean and Laciano-Ancarense sectors, coinciding with the following phytosociological associations [10, 11, 12]: *Linario triornithophorae-Quercetum petraea* (Rivas-Martínez, Izco & Costa ex. F. Navarro 1974) F. Prieto & Vázquez 1987 and *Luzulo henriquessi-Quercetum petraea* (F. Prieto & Vázquez 1987) Díaz & F. Prieto 1994.

The locations where sessile oak forests occur are characterized by abundant precipitation, i.e. more than 600 mm of annual precipitation, of which at least 150 mm falls in the summer [1, 3].

However, the requirements are less stringent than those of *Quercus robur*, allowing the species to colonize drier and wilder sites [13, 14]. The species is not very demanding as regards temperature, tolerating a minimum temperature in the coldest month of around -3ºC, and between 15 and 25ºC in the hottest one [1, 3]. climatic ranges that are found in Atlantic sites small continental influence [2, 4]. In the northwest Iberian Peninsula, the forests receive an annual precipitation of more than 1100 mm, which may sometimes reach as high as 2000 mm. The summer precipitation is more than 200 mm and in many areas, more than 300 mm [3, 6]. The temperature variations within the study area are low and correspond to a cold temperate climate [15].

The lithologies present in the stands under study are diverse, and develop on both limestone and slates, in soils of high or low fertility, preferentially in loose soils, although they tolerate stony and even rocky soils when the moisture content is high [1, 2, 3]. It's frugalier with soils than *Quercus robur*, and grow mainly on Regosols and Umbrisols [3, 6, 16].

Within the study area *Quercus petraea* occurs in semi-shade and has a fairly robust character [3, 7]. The saplings can grow and develop under cover for several years, but for full development they should be free of cover after about 10 years [13, 17, 18, 19]. They grow slowly, partly because of the low fertility of the soils, at rates ranging between 1 and 5 $m^3 \cdot ha^{-1} \cdot year^{-1}$ in favourable seasons [3, 6]. Many of these natural forests have been harvested since inmemorial time, mainly for naval construction and railway sleepers [1, 3, 5]. In many cases inadequate silvicultural treatments were applied, such as thinning of the best specimens and the unauthorised felling of trees to obtain wood and charcoal [17, 20, 21]. However, because of the difficulties involved in extracting and transporting the wood in mountainous areas, the felling did not have an excessively negative impact, and the forest have suffered more severe deterioration recently, as a result of farming activities and cultivation of the land for agricultural crops [3, 5]. Despite the reduction in the surface area, some highly valuable autochthonous stands have survived, someones in protected sites under the Nature 2000 Network [22]. Another important aspect is the existence of a characteristic flora and fauna, as the sites are the home grounds of species that are in danger of extinction, such as the brown bear and the capercaille [10, 23], underlining the need to conserve and to try to increase the range of this oak species through sustainable development compatible with conservation.

Background information is provided by the numerous phytosociological studies carried out on these formations [8, 10, 12, 23]. Some authors [3, 4, 6, 7] provide ecological and dendrometric data about *Q. petraea*. The sessile oak is one of the most widely studied broaleaf species within Europe in terms of silviculture and wood quality [17, 19, 20, 24, 25, 26, 27, 28]. In this context, the study of its autoecology, involving analysis of the effect of environmental variables in the development of the species, is fundamental in evaluating the present situation [29, 30, 31]. The aims of the present study were therefore: 1) to characterize the species ecosystems in the northwest Iberian Peninsula, 2) to determine its physiographical-climatic and edaphic habitats, and 3) to relate the environmental variables to silvicultural variables, indicative of its conservation status.

2. Material and methods

2.1. Site description

The study area is located in the northwest Iberian Peninsula, and includes parts of Galicia, Asturias and León (Figure 1). More specifically, the forests under study are mainly located in eastern Galicia, the mountainous area in the south of Asturias and the Leonese side of the Cantabrian Mountain range [3]. comprising the easternmost area of the Orocantabrian Province [8, 11]. The surface area occupied by pure stands of *Quercus petraea* within this territory, estimated on the basis of the most recent data available [31, 32], is approximately 90,000 ha.

2.2. Description of sampling and data recording

Using information provided in the Forest Map of Spain [29] the existing vegetation mosaics in which *Quercus petraea* is present in the area of study were obtained, and the sampling areas were selected from within these, with the help of information provided by Forestry administration personell and data reported in previous studies [3, 6]. To avoid an edge effect, a minimum surface area of one hectare was considered [3, 22, 33]. Prior to the siting of each plot within the stand, the prevailing environmental conditions were established so that a representative site was selected [22]. A total of 52 permanent and rectangular plots (with surface areas of between

400 and 1200 m^2) were established on the basis of the stand density (Figure 1 and Table I), so that the number of trees of diameter greater than the minimum that could be inventoried (Ø normal ≥ 5 cm) was no less than 50 [34, 35]. The physiographic, dendrometric and soil profile data were then obtained, and along with the climatic data were fitted to the sampling points, according to the methodology of Carballeira et al. [36], and compared with the results of the edaphological analysis, allowing establishment of the biotype parameters in each plot that best define the suitability of the site as a forest site and the present silvicultural status [22, 30, 37].

2.3. Parameters established (see annex)

From a total of 60 parameters studied, 41 were ecological and related to the physiographical structure, climate and edaphology of the biotype and 19 were parameters that characterize *Quercus petraea* forests in terms of dendrometrics and silviculture.

a) Physiographic parameters [22, 30, 31, 38]: altitude and mean slope, orientation, sunshine (Gandullo, 1974), depth of soil to the parent rock and distance from the sea.

b) Climatic parameters [19, 38, 39, 40].- Precipitation: annual, winter, spring, summer and autumn mean values; Temperature: mean annual temperature, mean temperatures in the hottest and the coldest month, maximum and minimum absolute temperature, temperature range (difference between the maximum t^a and minimum annual) [36], annual evapotranspiration [41] and temperature index [11]; Hydric regime: sum of surpluses and deficits (positive and negative differences respectively, between monthly precipitation and evapotranspiration), hydric index [42] and duration of drought [43].

c) Edaphic parameters [22, 29, 30, 31, 44].- Chemical parameters: pH in H_2O, organic matter, nitrogen and ratio of C/N; Parameters that evaluate the soil fertility: available phosphorous, exchangeable potassium, calcium and magnesium. For all of these, the surface concentrations, corresponding to the upper 20 cm of the profile, were determined, except when there was more than one horizon at this depth, in which case the corresponding weighted mean [14, 22, 33] and the total value of the parameter in the profile were calculated, using the method of Russel and Moore [45] (Russell and Moore, 1968). The percentages of fine earth (Ø < 2 mm) and of total gravel (Ø > 2 mm) were also calculated .

d) Dendrometric/silvicultural parameters [22, 28, 31, 46, 47]: density, number of dead, non-inventoriable and dead specimens of *Q. petraea*, regenerated saplings [3, 14, basimetric area, mean arithmetic and quadratic diameters, standard deviation and coefficient of variation of the height distribution, Assmann's dominant height [35, 48], Hart's index [35, 49] and Czarnowski's index, number of trees in a squared plot of side equal to the arthimetic mean.

2.4. Definition of habitats and statistical analysis

Univariate analysis [50] was applied to the results of all of the parameters under study with the aim of determining the distribution and calculating a series of characteristic values for each parameter [22, 31, 33, 51]: Lower Limit (LL), Lower threshold (LT): 10^{th} percentile, Mean (M), Upper threshold (UT): 90^{th} percentile and Upper limit (UL). The central habitat of *Quercus petraea*, established by recording its presence - and which is comprised between the 10th and 90th percentiles (80% of plots) - allows determination of the most suitable ecological range, and may be considered as the minimum potential area of the species in the study area [22, 31]. Marginal habitats are defined as those between the limits of the central habitat and the absolute extremes; they include 20% of the remaining plots and provide an estimation for the species, of the parameters that remain outside of the habitat, as not all have the same level of significance as biotype descriptors [22, 52, 53]. It was therefore necessary to carry out discriminant analysis of the plots to identify those parameters that have a greater descriptive weight [13, 54, 55, 56], using the methodology proposed by Hill [57, 58], which allows dichotomous classification of the randomly sampled plots [59], such as the presence of plant species [33, 54, 60] and/or the values of certain parameters [14, 22, 29, 53], using Community Analysis Package (CAP) software, more specifically the Twinspan programme [58, 61].

Initial bivariate analysis was carried out using the silvicultural parameters [62] to select wich define the present status of the *Quercus petraea* forests in the northwest Iberian Peninsula. The groups classified using Twinspan were then ratified by considering the selected silvicultural and ecological parameters together or using only those obtained in the discriminant analysis [22, 31]. Principal Components Analysis (PCA) was then applied using the method of extraction by squared minima, creating new variables by combining parameters, which were assigned a value for each plot and were represented spatially, comparing them with the groups created by Twinspan [31, 62, 63].

3. Results and Problem solution

The physiographic data corresponding to the sampled plots are shown in Table 1. In most cases, the stands occur at altitudes above 1000m and with steep slopes, sometimes extremely steep (>75%), and predominantly in the shade.

To characterize the habitat of the oak *Q. petraea* on a regional scale in the northwest Iberian Peninsula, the values corresponding to the parameters selected in the study of biotype and silvicultural status were considered as reference data. The univariate analysis of the physiographic and climatic descriptive statistics (Table II) revealed that the highest variability was obtained in the ORI and CMT parameters, with coefficients of variation (CV) higher than 70% and, in some extreme cases, i.e. AmT and DD, the values were higher than 100 and 200%, respectively. The lowest variability corresponded to TR, AE and HI, with coefficients lower than 10%. Of the 18 edaphic parameters, 12 showed coefficients of variation higher than 40% and in some of these (sP, Ca and sCa), higher than 100%; only the total and surface pH total showed low variability, with coefficients of variation lower than 10% (Table III). Within the silvicultural statistics, the high CV of the parameters NNQ, NDQ, TNNT, TNDT and REG were notable. In contrast, the height variables (MAH, MQH and ADH), the dominant diameter and the basimetric area showed the lowest variability (Table IV).

The physiographic, climatic and edaphic habitats in both central and marginal areas (Figures 2 and 3) were then determined, and in order to identify the most discriminatory ecological parameters in the habitat of the sessile oak, a dichotomous classification of the inventoried plots was made by applying the CAP-Twinspan procedure, using all of the ecological parameters considered (in total 41), because any of these may be discriminatory within the area occupied by the species in the northwest Iberian Peninsula. As a result of the classification, 12 groups of plots were obtained (Table V), which were characterized by physiographic (ALT), climatic (AP and TI), and above all, edaphic parameters (spH, sK, sOM and Ca). Bivariate analysis was then used to select the silvicultural parameters that showed the most significant interrelationships, i.e. NT/h, MAD, MQD, MAH, ADH, MQH and DOD (Table VI). In theory these variables should be the best descriptors of use and present status of *Q. petraea* forests in the area of study.

Finally, PCA was used to create five new variables from combinations of the previous parameters, which account for more than 79% of the existing variability and the significance of which can be established by with the maturity of the stand: surface pH, surface potassium, altitude of the stand and continentality of the site. By assigning the value of these variables to each plot and creating a spatial representation of the most significant (maturity, sPH and sK), was obtained the distribution of the groups resulting from the Twinspan classification (Fig.4).

4. Discussion and conclusions

4.1. Univariate analysis of the physiographic and climatic parameters

The lack of drought in most of the plots gave rise to extreme variation in the duration of drought (DD) parameter, ranging between 0 and 1 in all plots (Table II) [31, 36, 39]. The pattern in the values of mean annual temperature of the absolute minima (AmT) and of the mean temperature in the coldest month (CMT), was previously observed in a study of the autoecology of *Quercus robur* in Galicia [22], and the wide temperature range is accentuated by the range of altidudes within the study area [3, 6]. Despite the existing variation in the orientation, shady locations predominate (Table I), independently of the robust nature of the species [1, 3, 7], as many of these stands have survived in sites where felling would be difficult because of the physiographic conditions [3, 6, 10, 23]. In contrast, the parameters TR, AE and HI show a CV < 10% and that corresponding to the remaining climatic parameters was rarely higher than 30%, which may indicate the existence of a fairly homogenous climate of humid oceanic type, with some continental influence in certain areas [3, 8, 12, 15]

The high variability in several edaphic parameters (Table III), even more evident than in *Quercus robur* [14, 22], is due to the wide range of substrates existing, with lithologies of silicaceous nature and limestone, although the pH values show little variation, corresponding to acidic soils [64] (Wilde, 1946).

4.2. Physiographic-climatic habitat of Quercus petraea in the northwest Iberian Peninsula

As regards the central habitat (Figure 3), the stands of sessile oak are located in areas of high altitude and slope, in which the orography of the land makes felling of the trees difficult and favours their conservation [3, 6]. Northern orientations predominate, in accordance with the values for the sunshine parameter [65]. The soil may be considered deep, except in the areas of steepest slope. The continentality is not very apparent and is compensated for by the high altitudes [8, 36]. The central values of the annual precipitation range between 1200 and 1850 mm, with precipitations in summer between 150 and 227 mm, indicative of a high demand for moisture, although somewhat less than in *Quercus robur* [14, 22], as demonstrated by the values of the hydric index, which indicate a perhumid climate [42] and by the duration of drought, which is non-existent in most of the stands [3, 6, 8]. The central habitat varies widely in terms of temperature parameters (Figure 3), and thus the temperatures in the study area appear to be ideal for *Quercus petraea* [22, 51] and allow the climate to be classified as mesothermic [41] according to the values of ETP.

Analysis of the marginal habitats (Figure 3) shows that certain parameters are not suitable for fixing the lower value of the central habitat, given the extent of the lower marginal intervals [22, 31, 33], specifically the temperature index (TI) and the sum of the surpluses (SUR). For the remaining parameters there were few plots outwith the central habitat.

4.3. Edaphic habitat of Quercus petraea in the northwest Iberian Peninsula

The edaphic parameters surface phosphorous and total potassium, as well as both total and surface calcium, (Figure 4), did not allow accurate determination of the upper limit of the central edaphic habitat of the sessile oak, due to the wide range of the upper marginal intervals [14, 29, 31]. Furthermore, the central values of the parameters C/N, sC/N and P ranged widely, which may indicate that edaphic conditions are very suitable for the development of the species [3, 6, 22]. In the remaining parameters, the most relevant characteristics are as follows (Figure 4):

- The soils are developed on different lithologies, both silicaceous and limestone, however, in general they are strongly acidic [64] (Wilde, 1946) with a little variation of the pH values [3, 6, 30]. According to the FAO classification [16], they belong to five different groups, with a clear dominance of Umbric Regosols, which represent almost 79% of all of the soils studied. Humic Umbrisols account for 12% of the total and finally, Cambisols, Dystric Regosols and Lithic Leptosols each have a single representative. This shows that most of the stands inventoried grow on less well developed soils than *Quercus robur* forests [14, 22].

- There is little variation between the total and surface values of the percentage of organic matter, and the sOM was higher than 20% in only a few plots, which in combination with the existing granulometric composition gives rise to permeable soils [3, 5].

- Although the mean value of C/N ratio was close to 18, the low values of pH do not allow optimal moisture conditions, giving rise to a moder type humus in most of the plots [8, 30, 37].

- The concentrations of macronutrientes, except for phosphorous, show higher values than those observed in *Quercus robur* forests, indicating intermediate soil fertility [14, 22, 66]. The concentrations of phosphorous were also lower than obtained by other authors for these stands [66, 67], which may indicate that the areas presently occupied by sessile oak forests have not undergone changes in land use [3, 6] because this macronutrient is highly associated with rocks containing apatite minerals, which are scarce in the study area.

4.4. Silvicultural characteristics of Quercus petraea forests

The stands under study show a wide range of ages and qualities as a result of the different harvesting techniques to which they have been subjected, and at present pure stands do not exist [3, 6, 14]. The descriptive statistics corresponding to the 19 dendrometric/slvicultural parameters used (Table IV) provide an idea of the heterogeneity existing, mainly in the regenerated, non-inventoriable and dead trees, with coefficients of variation that are much higher than the mean value. Although the presence of non-inventoriable specimens of sessile oak is rare, the mortality is high, in contrast with the accompanying species, which adapt well to the closed undergrowth with little available light in these forests - at least in the early stages of development [2, 3, 17, 18, 40]. The coefficients of variation for the remaining parameters, except for density and Czarnowski's index, were lower than 40% (Table IV), with the least variation corresponding to the parameters MQH, MAH, DOD, BA and ADH [17, 22, 25].

Most of the stands sampled are located in low-lying areas, are well adapted to the surroundings and lack health problems, but have not been managed, because of the lack of any tradition of carrying out silvicultural treatments on slow growing broadleaf species in the northwest Iberian Peninsula [3, 6]; it would therefore be necessary to convert them into regular or semirregular forest before undertaking their management [14, 22], however in this case, management would be more complex [17, 20, 40]. The development of productive silviculture for *Quercus petraea* in the study area may only be considered in areas in which the site quality is intermediate-high [3].

4.5. Relationship between silvicultural parameters and biotype

The dendrometric/silvicultural parameters that would in theory be most suitable for comparison with the biotype parameters are those that were significantly related to all of the other parameters [22, 38, 44], in this case, NT/h, MAD, MQD, MAH, ADH, MQH and DOD (Table VI). Of these, the coefficient of variation for the number of trees per hectare (NT/h) was higher than that corresponding to others (Table IV) and the dominant height (ADH) was affected by the silvicultural treatments carried out, some with negative effects on the correct development of the trees, such as crown cropping [22], and thus it was considered not appropriate to use these in the factorial analysis comparing with the ecological parameters, and only the discriminant functions obtained by applying the Twinspan procedure were used (ALT, PI, IT, PHS, KS, MOS and Ca) (Table V).

The principal components analysis identified stand maturity, spH and sK as the factors that best explain the variability in the stands analyzed [3]. The results obtained, in relation to the grouping of plots, derived from the PCA (Figure 4) are consistent with the dichotomous classification obtained with the Twinspan procedure, with the repetition of groups such as “H” and “I” (Table V) (plots in the Asturian mountains), “E” (plots in Os Ancares in Galicia and Leon) and “L” (plots in Leonese valleys) being notable. However, the groups D”, “F” and “K” appear disperse, because although they are geographically very similar, as reflected by the Twinspan analysis, the stands are very different.

Acknowledgements

The present study was financed by the collaboration between Pernod Ricard and Irish Distillers Inc. with the research group GI-1720 of the Department of Agroforestry Engeneering of the University of Santiago de Compostela.

References:

[1] Ceballos L., Ruiz de la Torre J., 1979. Árboles y arbustos, E.T.S.I. Montes, Madrid.

[2] Bary-Lenger A., Nebout J.P., 1993 Le chêne pédonculé et sessile en France et en Belguique, Gerfaut Club, Editions du Perron, Alleur-Liège.

[3] Vila P., 2003. Estudio epidométrico y xilológico de las masas de Quercus petraea (Mattuschka) Liebl. en el noroeste de la Península Ibérica, Tesis Doctoral, Universidade de Santiago de Compostela.

[4] Amaral J., 1990. Quercus, En: Castroviejo, S. et al., (eds.), Flora Ibérica II, C.S.I.C., Madrid.

[5] Ruiz de la Torre J., 1991. Mapa Forestal de España, Dirección General de Conservación de la Naturaleza, Instituto Geográfico Nacional, Ministerio de Medio Ambiente, Madrid.

[6] Vila P., Díaz-Maroto I.J., 2002. Las masas actuales de Quercus petraea en Galicia, Inv. Agr. Sis. Rec. For. Vol. 11(1): 5-29.

[7] Silva-Pando F.J., Rigueiro A., 1992, Guía das árbores e bosques de Galicia, Galaxia.

[8] Amigo J., Romero M.I., 1994. Vegetación atlántica bajo clima mediterráneo: un caso en el noroeste ibérico, Phytocoenología 22 (4): 583-603.

[9] Kremer A., Dupouey J.L., Deans J.D., Cottrell J., Csaikl U., Finkeldey R., Espinel S., Jensen J., Kleinschmit J., Van Dam B., Ducousso A., Forrest I., de Heredia U.L., Lowe A.J., Tutkova M., Munro R.C., Steinhoff, S. Badeau V., 2002. Leaf morphological differentiation between Quercus robur and Quercus petraea is stable across western European mixed oak stands, Ann. Sci. For. 59 (7): 777-787.

[10] Fernández Prieto J.A., Vázquez V., 1985. Datos sobre los bosques asturianos orocantábricos occidentales, Lazaroa 7: 363-382.

[11] Rivas-Martínez S., 1987. Memoria y mapas de series de vegetación de España 1:400.000, ICONA, Ministerio de Agricultura, Pesca y Alimentación, Madrid.

[12] Díaz T.E., Fernández Prieto J.A., 1994. La vegetación de Asturias, Itinera Geobotánica 8: 243-528.

[13] Timbal J., Aussenac G., 1996. An overview of ecology and silviculture of indigenous oaks in France, Ann. Sci. For. 53 (2-3): 649-661.

[14] Díaz-Maroto I.J., 1997. Estudio ecológico y dasométrico de las masas de carballo (Quercus

robur L.) en Galicia, Tesis doctoral, Universidad Politécnica de Madrid.

[15] Allué-Andrade J.L., 1990. Atlas Fitoclimático de España. Taxonomías. Ministerio de Agricultura, Pesca y Alimentación, INIA, Madrid.

[16] FAO, 1999. World Reference Base for Soil Resources, World Soil Resources Reports, 84.

[17] Jarret P., 1996. Sylviculture de chêne sessile, Bulletin technique 31: 21-29, Office National des Forêts.

[18] Kelly D.L., 2002. The regeneration of Quercus petraea (sessile oak) in southwest Ireland: a 25-year experimental sudy, For. Ecol. Manag. 166: 207-226.

[19] Lebourgeois F., Cousseau G., Ducos Y., 2004. Climate-tree-growth relationships of Quercus petraea Mill. stand in the forest of Bercé ("Futaie des Clos", Sarthe, France), Ann. Sci. For. 61(4): 361-372.

[20] Le Goff N., 1984. Indice de productivité des taillis-sous-futaie de chêne dans la région Centre, Ann. Sci. For. 41(1): 1-34.

[21] Hochbichler E., 1993. Methods of oaks silviculture in Austria, Ann. Sci. For. 50 (6): 583-591.

[22] Díaz-Maroto I.J., Vila P., Silva-Pando F.J., 2005. Autoecology of oaks (Quercus robur L.) in Galicia (Spain), Ann. Sci. For. 62 (7) (in press).

[23] Fernández Prieto J.A., Bueno A., 1996. La reserva integral de Muniellos: flora y vegetación, Consejería de Agricultura, Principado de Asturias.

[24] Zhang S.Y., Nepveu G., Eyono R., 1994. Intratree and intertree variation in selected wood quality characteristics of European oaks (Quercus petraea and Quercus robur), Can. J. For. Res. 24: 1818-1823.

[25] Duplant P., 1997. Croissance en hauteur dominante du chêne sessile (Quercus petraea Liebl.) en futaie régulière, Bulletin technique 33: 49-58, Office National des Forêts.

[26] Bergès L., Hervé J.C., Franc A., Gilbert J.M., Nepveu G., 1999. Influence of ecological factors and individual effects on radial growth and wood density components for sessile oak (Quercus petraea Liebl.) in Paris Basin and North-Eastern by use of mixed models, Proceedings Workshop IUFRO S5.01-04: 205-222.

[27] Bèrges L., 2000. Variabilité individuelle et collective de la croissance et de la densité du bois de Quercus petraea en relation avec les facteurs écologiques, Thèse doctorale, École National des Eaux et Forêts, INRA, Nancy.

[28] Polge H., 1973. Facteurs écologiques et qualité du bois, Ann. Sci. For. 30(3): 307-328.

[29] Rubio A., Escudero A., Gandullo J.M., 1997. Sweet chestnut silviculture in a ecological extreme of its range in the west of Spain (Extremadura), Ann. Sci. For. 54(7): 667-680.

[30] Gandullo J.M., Sánchez O., González S., 1983. Estudio ecológico de las tierras altas de Asturias y Cantabria, Monografías INIA 49, Madrid.

[31] Blanco A., Rubio A., Sánchez O., Elena R., Gómez V., Graña D., 2000. Autoecología de los castañares de Galicia (España), Inv. Agr. Sis. Rec. For., Vol. 9 (2): 337-361.

[32] DGCONA, 2003. Tercer Inventario Forestal Nacional, Principado de Asturias, Ministerio de Medio Ambiente.

[33] Gandullo J.M., Bañares A., Blanco A., Castroviejo M., Fernández A., Muñoz L., Sánchez O., Serrada R., 1991. Estudio ecológico de la laurisilva canaria, ICONA.

[34] Hummel F.C., 1959. Code of Sample Plot Procedure, Forestry Commission Booklet 34.

[35] Rondeux J., 1993. La mesure des arbres et des peuplements forestiers, Les Presses Agronomiques de Gembloux.

[36] Carballeira, A., Devesa, C., Retuerto, R., Santillan, E., Ucieda, F., 1983. Bioclimatología de Galicia, Xunta de Galicia-Fundación Barrie de la Maza.

[37] Castroviejo M., 1988. Fitoecología de los montes de Buio y Sierra del Xistral (Lugo), Consellería de Agricultura, Gandería e Pesca, Xunta de Galicia.

[38] Aussenac G., 2000. Interactions between forest stands and microclimate: Ecophysiological aspects and consequences for silviculture, Ann. Sci. For. 57 (3): 287-301. [28] Guilley E., Herve J.C., Nepveu G., 2004. The influence of site quality, silviculture and region on wood density mixed model in Quercus petraea Liebl., For. Ecol. Manag. 189 (1-3): 111-121.

[39] Retuerto R., Carballeira A., 1990. Phytoecological importance, mutual redundancy and phytological threshold values of certain climatic factors, Vegetatio 90: 47-62.

[40] Johnson P.S., Shifley S.R., Rogers R., 2002. The ecology and silviculture of oaks, CABI Publishing.

[42] Thornthwaite C.W., Mather J., 1955. The water balance, Climatology 8: 1-104.

[43] Gaussen H., 1955. Détermination des climats par la méthode des courbes ombrothermiques, Compt. Rend. Hebd. Séances Acad. Sci. 240: 642-644.

[44] Bravo-Oviedo A., Montero G., 2005. Site index in relation to edaphic variables in stone pine (Pinus pinea L.) stands in Southwest Spain, Ann. Sci. For. 62 (1): 61-72.

[45] Russell J.S., Moore A.W., 1968. Comparison of

Figure 2. Central and marginal physiographic-climatic habitats of *Quercus petraea* in the northwest Iberian Peninsula.

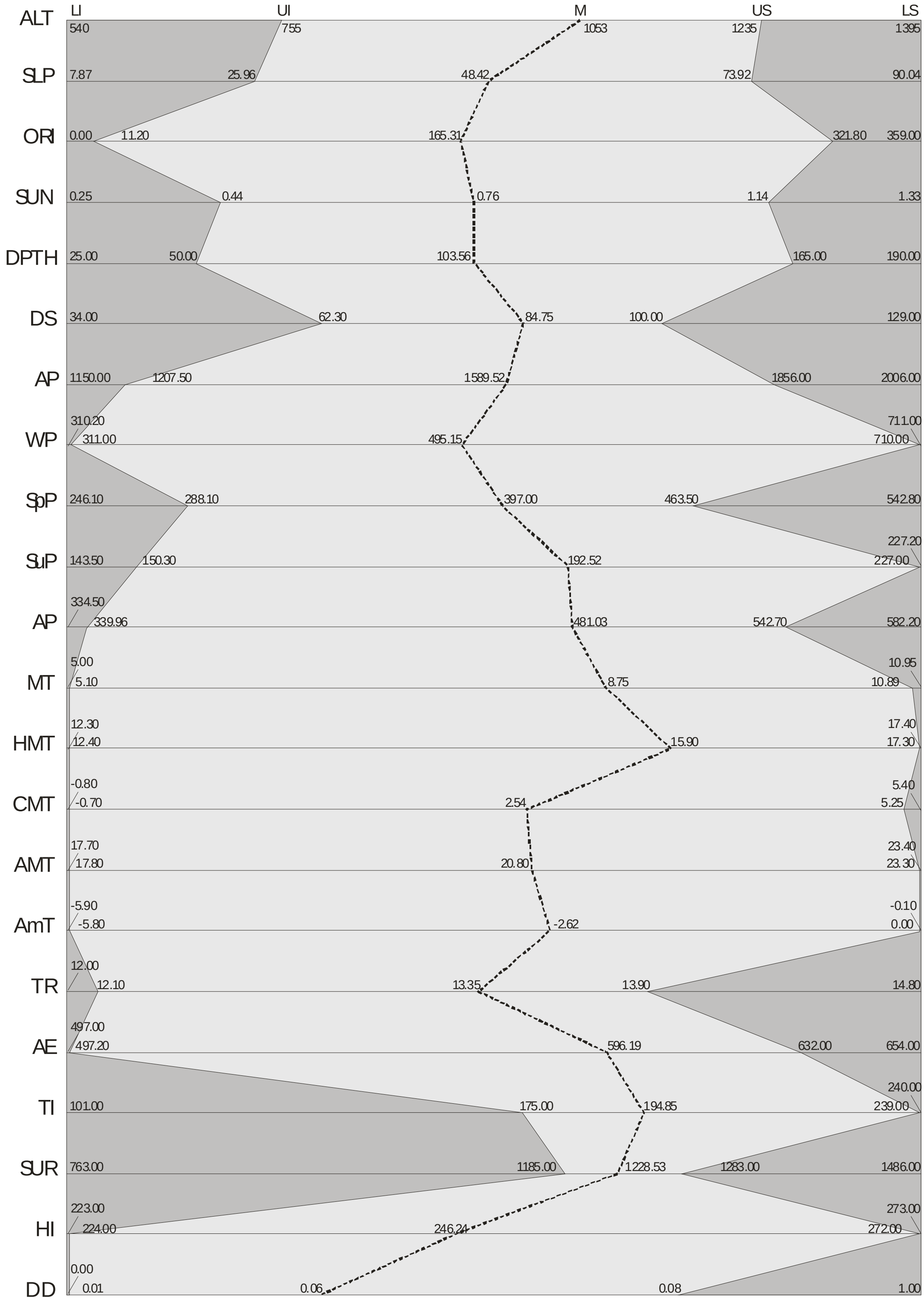

Figure 3. Central and marginal edaphic habitats of *Quercus petraea* in the northwest

Iberian Peninsula.

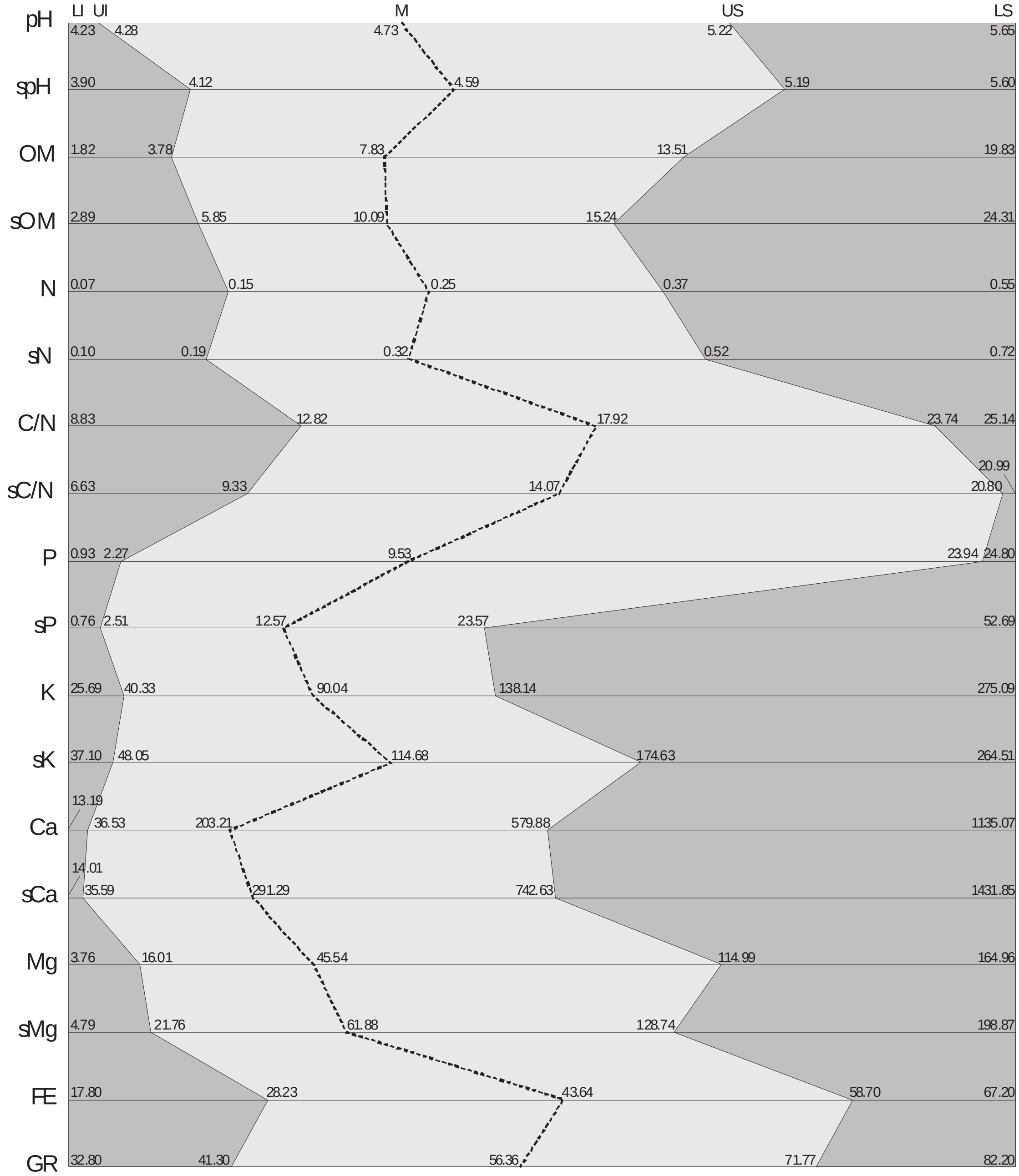

Figure 4. Spatial distribution of the plots identified according to the groups obtained by

discriminant analysis.