Invest Agrar: Sist Recur For (2006) 15(3), 277-295

Characterization and phytoclimatic potentialities of *Quercus petraea* (Matt.) Liebl. and *Quercus robur* L. forests in Spain

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Abstract

This paper presents some contributions to the phytoclimatic characterization of stands of *Quercus petraea* (Matt.) Liebl. and *Quercus robur* L. in España. For the phytoclimatic characterization, 577 sampling points from the 2nd National Forest Inventory of actual vegetation in which *Quercus petraea* was the principle especies in the forest were considered and 1,780 sampling points for *Quercus robur*. The phytoclimatic diagnosis followed the phytoclimatic models of Allué-Andrade. Phytoclimatic territorial models were constructed in digital format on the basis of preliminary territorial factorial estimations, wich were used to determine climatic factors and phytoclimatic terns. The potential phytoclimatic area and the factorial ambits for the existence of oak stands was performed in five phases of increasing strictness, based on factorial comparison (convex hull), phytoclimatic terns comparison, phytoclimatic suitability and evaluation of competitor forest species. *Quercus petraea* stands are found in the phytoclimatic subtypes $VI(IV)_2$, $VI(IV)_4$, VI(V), VI(VII), VI and VIII(VI). Subtype VI is both the most prevalent of the species and the one with the highest index of phytoclimatic suitability. The highest phytoclimatic suitability is found in the phytoclimatic terns with genuine subtype in VI and first analogous subtype in VI(V). In the strictest phase this calculation determined potential areas of high phytoclimatic viability for *Quercus petraea* totalling 1,969,000 ha in the north of Spain. *Quercus robur* stands are found in the phytoclimatic subtypes $VI(IV)_2$, $VI(IV)_3$, $VI(IV)_4$, VI(V) and VI. Subtype VI(V) is both the most prevalent of the species and the one with the highest index of phytoclimatic suitability. In the strictest phase this calculation determined potential areas of high phytoclimatic viability for *Quercus robur* totalling 2,989,000 ha.

Key words: phytoclimatology, *Quercus petraea, Quercus robur*, oak, convex hull, suitability, Spain.

Resumen

Caracterización y potencialidades fitoclimáticas de los robledales de *Quercus petraea* (Matt.) Liebl. y de *Quercus robur* L. en España

Se realizan diversas aportaciones al conocimiento fitoclimático de los robledales albares [*Quercus petraea* (Matt.) Liebl.] y de los robledales pedunculados (*Quercus robur* L.) en España. La caracterización fitoclimática se efectuó a partir del estudio de 577 puntos de muestreo procedentes del II Inventario Forestal Nacional con presencia de *Quercus petraea* como especie dominante de la formación forestal y de 1.780 para *Quercus robur*. El sistema fitoclimático utilizado fue el de Allué-Andrade modificado, que se aplicó a un modelo climático factorial de variables climáticas regionalizadas sobre un modelo digital de elevaciones de toda la España peninsular. En base a la información climática factorial y fitoclimática extraída de los puntos de muestreo respectivos se aplicaron a la base de datos territorial cinco niveles de filtrado de exigencia creciente, los dos primeros de carácter climático factorial, de los que destaca la utilización del método de la envolvente convexa, y los tres últimos de carácter fitoclimático basados en comparación de ternas, índice de idoneidad y competencia fitoclimática de varias especies forestales, todo ello con objeto de delimitar el área potencial de máxima viabilidad fitoclimática de estos robledales. Los robledales albares se posicionan en los subtipos fitoclimáticos $VI(IV)_2$, $VI(IV)_4$, VI(V), VI(VII), VI y VIII(VI) siendo el subtipo VI el de mayor frecuencia y mayor idoneidad. La máxima idoneidad media aparece en las ternas con subtipo genuino en VI. El área potencial de máxima adecuación fitoclimática después de aplicada la restricción más exigente es de 1.969.000 ha. Los robledales pedunculados se posicionan en los subtipos fitoclimáticos $VI(IV)_2$, $VI(IV)_3$, $VI(IV)_4$, VI(V) y VI siendo el subtipo VI(V) el de mayor frecuencia y mayor idoneidad. El área potencial de máxima adecuación fitoclimática para *Quercus robur* después de aplicada la restricción más exigente es de 2.989.000 ha.

Palabras clave: fitoclimatología, *Quercus petraea*, *Quercus robur,* roble, envolvente convexa, idoneidad, España.

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Received: 12-12-05; Accepted: 12-09-06.

Introduction

Formations of *Quercus robur* and *Quercus petraea* were surely once an important component of the forests covering hilly and mountainous areas of the Eurosiberian region of the Iberian Peninsula; now only a few remnants are well preserved, lying in areas of intense agricultural, and especially stockbreeding activity long subjected to transformation by human agencies. Furthermore, because of the quality of oak wood and the closeness of the forests to the coast, very early on the principal stands were reserved for naval construction and intensely exploited.

The distribution of these woods seems to be determined more by climatic than by edaphic factors, judging by the edaphic plasticity of both species, which are able to live on both acidic and basic substrates. Forest species do not generally adapt as strictly to edaphic conditions as to climatic conditions, which suggests that climate constitutes the most useful set of ecological factors for identifying plant physiognomies and deciding which seed sources are best suited for repopulation (Alía *et al*., 1999).

There is a relative abundance of studies that mention various aspects connected with both types of oak, but the phytoclimatic side has traditionally been the least studied, and the information that is usually provided in the few papers that have addressed the subject consists almost exclusively of the upper and lower limits of a generally small number of phytoclimatic factors (Ruiz de la Torre *et al*., 1979; Rivas-Martínez, 1987; Costa *et al*., 1993; Martín *et al*., 1998, etc.).

These studies all appear to attribute different patterns of ecological behaviour to the two species, although their role in the ecosystems of which they are a part can often be partially masked by a measure of overall similarity in their areas of distribution and numerous problems of identification arising from the prevalence of hybridization (Costa *et al*., 1993).

Although in certain circumstances the two species can coexist in mixed stands (Covadonga, Muniellos etc.), the fact is that *Quercus robur* is normally identified with hilly areas and *Quercus petraea* with mountainous areas in the Eurosiberian region of the Iberian Peninsula, and indeed their areas of distribution are normally considered to be complementary, with very little overlapping between the two. Broadly speaking, the pedunculate oak occupies plains and hills in the Cantabrian/Atlantic region between the sea and the Cantabrian Cordillera, and the gentle landscapes of Galicia and Portugal. The sessile oak, for its part, is found in mountainous areas of the northern Iberian System (Demanda, Moncayo), the north of Spain and the Cantabrian/Pyrenean Cordilleras, and is largely absent from Galicia. Isolated instances of individuals or small woods are not uncommon in areas far from those mentioned, for instance in Las Batuecas or in the vicinity of Olot in the case of *Quercus robur*, or the Central System (Ayllón, Guadarrama) in that of *Quercus petraea*.

These distributions presumably reflect the phytoclimatic preferences of these two types of oak formation, with stands of *Quercus petraea* generally occurring in colder, more continental conditions and presenting greater resistance to moderate summer droughts in transitional Mediterranean areas. In general their preferences seem to coincide to a large extent with those of beech-woods, an issue that has led a number of authors to support the hypothesis that their occurrences may be restricted by competition with woods of this kind (Costa *et al*., 1993). Also, *Quercus petraea* is normally considered to demand less heat in summer and to be more sensitive to late frosts.

One object of this study is to enlarge our phytoclimatic knowledge of woods of *Quercus petraea* and *Quercus robur* in Spain using a methodology that enables us to gain a more comprehensive and numerically quantifiable understanding than has been possible hitherto for these formations. Another is to achieve the widest possible spread and territorial distribution of the results in the form of maps of areas of high potential phytoclimatic viability which can be harnessed to decision-making processes in connection with the management of these formations. The most immediate forerunner of this proposal is the work of García-López and García-Abril (2005c), although that is confined geographically to Castilla y León.

Material and Methods

From the data base of sampling parcels defined in the Second National Forestry Inventory (DGCONA, 1986-1995), 577 and 1,780 points were selected in which *Quercus petraea* and *Quercus robur* respectively occurred naturally as principal forest formation species. Parcels were selected using an IT utility called Basifor (Del Río *et al.,* 2001) and setting apart all registers in which either type of oak occurred naturally as the first dominant species in the formation. Isolated instances of *Quercus robur* in Las Batuecas and Olot and of

A B

Figure 1. A: Situation of the 577 points from the 2nd NFI where *Quercus petraea* occurs as the principal plant formation. B: Situation of the 1,780 points from the 2nd NFI where *Quercus robur* occurs as the principal plant formation.

Quercus petraea in the Central System were ignored in view of the small area covered and their currently subordinate status in the hierarchies of their formations, which means that it would be hazardous to consider them in a macroclimatic study. Figure 1 shows the distribution of the sampling points used in this study.

The phytoclimatic system used is based on the models of Allué-Andrade (1990 and 1997) as modified by García-López and Allué (2003). The reason for choosing this phytoclimatic system for the present study was that it is currently the only system that provides maximum synthesis, and moreover quantitative synthesis: with this system it is possible not only to assign a station to a previously-defined phytoclimatic category on a purely qualitative basis but also to quantify the degree to which such a station fits the category or phytoclimatic type, and also all other types in the system. This is achieved by means of *«positional coordinates»* and *«phytoclimatic distances»* in relation to one another and referenced to factorial phytoclimatoc ambits corresponding to the principal plant life strategies of dominant forest covers based on the vital types of Walter and Lieth (1960). All this is important to our study in that it allows for numeric quantification of a territory's degree of phytoclimatic potential to support oak woods.

The 577 points of sessile oak and the 1,780 points of pedunculate oak were identified by their UTM coordinates (Slot 30) and their altitude and were processed with the Fitoclimoal programme (García-López and Allué, 2000) to obtain gross monthly temperature and precipitation data according to the models of Sánchez-Palomares *et al*. (1999). Later, the same programme was used to find the phytoclimatic factors shown in Table 1. Table 2 shows the phytoclimatic subtypes used

Table 1. Phytoclimatic factors used

Abbreviation	Factor	Unit
K	Intensity of aridity. Calculated on the basis of the quotient As/Ah, where Ah is the humid area of the climodiagram (Pi curve above the Ti curve, i.e., 2Ti < Pi) and As is the dry area of the climodiagram (Pi curve above the Ti curve, i.e., 2Ti > Pi).	
A	Duration of aridity in the sense of GAUSSEN, that is the number of months in which the Ti curve is above the Pi curve, i.e., 2T1 > Pi.	Months
P	Total annual precipitation	mm
PE	Minimum summer precipitation (June, July, August or September)	mm
TMF	Lowest monthly mean temperature	°C
T	Mean annual temperature	°C
TMC	Highest monthly mean temperature	°C
TMMF	Average of the minima of the month with the lowest mean temperature.	°C
TMMC	Average of the maxima of the month with the highest mean temperature.	°C
HS	Certainty of frost. Calculated as no. of months in which TMMF ≤ 0	Months
PV	Mean winter precipitation, calculated as the sum of the monthly mean precipitations for January, February, November and December.	Months
IC	Continentality Index. Calculated as TMC-TMF	°C

Table 2. Qualitative numeric code and phytological significance of the pytoclimatic subtypes used

Qualitative code						Assignation		Most common zonal formations
TMMF ≥ 7	AA > 11				III(IV)	Saharian		Azufaifo thomy scrub and *periploca laevigata*
	3 ≤ A < 11	TMMF > 0	TMC >= 9,5	P ≤ 450	IV(III)	Mediterranean	Subsaharian	Lentisks
				P > 450	IV$_2$		True	Wild olives
			TMC < 9,5	P ≤ 400	IV$_1$			Kermes oaks
				400 < P ≤ 500	IV$_3$			Dry holm oaks
				P > 500	IV$_4$			Humid holm oaks
		TMMF ≤ 0	TMF ≤ 2		IV(VII)		Sub-steppe	Padded spiny broom
			TMF > 2		IV(VI)$_1$		Subnemoral	Humid holm oaks with Portuguese or Pyrenean oak
	1,25 ≤ A < 3	TMF ≥ 7,5	P ≤ 850		IV(VI)$_2$			Dry evergreen oak formations
			P > 850		VI(IV)$_3$	Nemoro-Mediterranean	Subnemoral	Dry pedunculate oaks
		TMF < 7,5	P ≤ 725		VI(IV)$_1$		True	Dry Portuguese oaks and melojo oaks with holm oak
			P > 725		VI(IV)$_2$			Humid Portuguese oaks and melojo oaks with holm oak
	0 ≤ A < 1,25	P ≤ 950	TMMF > 0		VI(IV)$_4$		Sub-Mediterranean	Humid evergreen oak formations
			TMMF ≤ 0		VI(VII)	Nemoral	Sub-steppe	Pubescent oaks
		P > 950	TMF > 4		VI(V)		True	Pedunculate oaks
			TMF ≤ 4	HS ≤ 3	VI			Beeches and sessile oaks
				HS > 3	VIII(VI)	Oroborealoid	Subnemoral	Scots pine forests with *Fagus* and *Quercus*
TMMF ≤ 7	A = 0	TMC > 10			X(VIII)		True	Scots or mountain pines
		TMC ≤ 10			X(IX)$_1$	Oroarticoid	Thermoxeric	Alpine pastures
	A > 0				X(IX)$_2$		Thermoxeric	Alpinoid pastures

by the system, their factorial dichotomic code and their principal phytological significance.

The methodology followed in this study is based on six consecutive filter phases or levels.

The first two are factorial climatic phases. This means that they operate in factorial hyperspaces and consist in the application of a first factorial filter based on the consideration of situations inside or outside the box to which the initial cluster of points or stations of oak are assigned, excluding external points. The second phase operates on the basis of the results of the first; it involves an added level of strictness in that it considers factorial situations inside or outside a convex hull surrounding the cluster of points, excluding external points. Consideration of the theory of the convex hull in binary combinations of phytoclimatic factors instead of the factorial box provided the basis for the modification of the Allué-Andrade phytoclimatic system undertaken by García-López and Allué (2003). For details readers should consult the original source, as the explanation is too long for inclusion in this paper.

The next four phases are phytoclimatic rather than factorial, that is the hyperspaces within which they operate are phytoclimatic and not factorial and their axes coincide with the scalars of adjustment to the previously-defined factorial ambits:

— In phase 3 the data base produced by phase 2 (filtering) is asked for phytoclimatic diagnosis terns coinciding with terns from the original data base of 2nd NFI sampling points, discarding all points whose terns do not coincide. By considering phytoclimatic diagnostic terns based on the subtypes in Table 2, we can arrive at a polythetic approximation – that is, one that provides an overall comparison with all the subtypes considered in the phytoclimatic system. In this way, an abbreviated entry (G; A1; A2; A3; D1; D2) will be sufficient for our purposes to define a phytoclimate by considering all together the True subtype (G), its analogous subtypes (A1, A2 and A3) in descending order of adjustment scalars and its disparate subtypes in descending order of positive adjustment scalars.

— Phase 4 works on the data base produced by phase 3 and discards all points with a void adjustment scalar in any of the diagnostic factorial planes. To that end, two autoecological phytoclimatic systems, each with a single subtype, were constructed respectively from the 577 points of sessile oak and the 1,780 points of pedunculate oak in the 2nd NFI. The characterising powers used were from an analogous system but one made up of 18 forest species for all of Peninsular Spain, following the methodology of García-López and Allué (2005d). The purpose of this phase is to detect masked marginal situations in the intermediate adjustment scalars of each oak with respect to its ambit of existence.

— Phase 5 works on the data base produced by phase 4 and discards all points with Phytoclimatic Suitability Indexes in the lower half of the range of suitable values found for the species. For the purposes of this article, «phytoclimatic suitability» means the degree to which a site is suited to host certain taxa or syntaxa, in terms of both staying power (self-regenerating capacity) and ability to compete with other species (Allué Camacho, 1996). Readers are referred to the original reference sources for details of the «suitability»-based phytoclimatic model and of calculating Phytoclimatic Suitability Indexes; since 1993, scientists have been testing these indexes for different Spanish plant species and communities, including *Quercus coccifera* (Cañellas, 1993), *Pinus pinea* (Allué-Andrade and Martín, 1994), pasture communities (Allué Camacho, 1995), *Pinus halepensis* (Cámara, 1997), *Pinus sylvestris, Pinus nigra* and *Pinus pinaster* (Grau *et al*,. 1999), *Abies pinsapo* (Gonzalo *et al.*, 2004) and *Juniperus thurifera* (García-López and Allué, 2005a).

— Phase 6 consists in phytoclimatic analysis of the data base produced by phase 5, using an autoecological phytoclimatic system constructed from stations with some forest species formations of which come into contact with oak woods, discarding all points at which neither *Quercus petraea* nor *Quercus robur* is the species with the largest adjustment scalar in the diagnostic spectrum. The importance of the competition factor in the distribution of plant species is such that according to some authors (Walter, 1977), the natural limits of distribution of a species will occur where its ability to compete is so depleted by variable environmental conditions that it is supplanted by other species; generally speaking, ecological factors are only decisive at the absolute limits of distribution. Along with phytoclimate, competition with other forest tree species —and especially with *Fagus sylvatica*— is normally identified as one of the major factors determining the distribution of sessile oak (Ruiz de la Torre, 1979; Costa *et al.*, 2001). In view of this, a new phytoclimatic system was devised according to the models proposed by Allué-Andrade (1990 and 1997) and modified by García-López and Allué (2003). It was based on the preliminary determination of phytoclimatic ambits of a number of forest tree species of the genera *Pinus*, *Abies*, *Quercus* and *Fagus*, habitually capable of forming stands that come into contact with the oak woods addressed in this study. Each of these ambits was established using a methodology akin to that used for oaks – that is, by taking the 2nd NFI points of each species and assigning them phytoclimatic factors using the thermopluviometric estimative models of Sánchez-Palomares *et al.* (1999). Each forest species was assigned an autoecological phytoclimatic type of its own. The species considered, with their corresponding 2nd NFI points, are listed in Table 3. *Quercus faginea* and *Quercus pyrenaica* are taken together because edaphic (basic or acid substrates) rather than phytoclimatic factors determine a large proportion of their relative territorial distributions.

Table 3. Forestry headings used in the construction of the phytoclimatic model for analysis of species in competition with *Quercus petraea* and *Quercus robur*

Code	Species	No. of 2nd NFI points
Pni	*Pinus nigra*	1,049
Psy	*Pinus sylvestris*	4,741
Pun	*Pinus uncinata*	551
Aal	*Abies alba*	162
Fsy	*Fagus sylvatica*	1,855
Qro	*Quercus robur*	1,780
Qpe	*Quercus petraea*	577
Qil	*Quercus ilex*	16,770
Qsu	*Quercus suber*	2,188
Qfp	*Quercus faginea/pyrenaica*	7,284
Qpu	*Quercus pubescens*	563
Jth	*Juniperus thurifera*	1,158

Results

First approximation: factorial box

A first possible approximation for determining the potential phytoclimatic area of stands of sessile and pedunculate oak is to consider those stations that fall within the box formed by the respective clusters of 577 and 1,780 points in a factorial hyperspace with one dimension for every climatic factor considered (in the present case the 12 factors listed in Table 1), with boundaries formed by parallel-running edges that coincide with the maximum and minimum factorial values of each factor. The results are shown in Table 4.

Figures 2a and 2b show the results for *Quercus petraea* and *Quercus robur* respectively of applying the factorial box method —that is, the phytoclimatic ambits in Table 4— to a digital model of elevations in Spain with an approximate resolution of 1,000 m per side, previously processed by Fitoclimoal to find the values of the phytoclimatic factors for each point in it.

The result of this first factorial filter confirms its scant precision, with 56,637 points selected for *Quercus petraea* (approximately 5,663,700 ha) and 50,828 points for *Quercus robur* (about 5,082,800 ha). These areas are clearly excessive and encompass zones where these oaks do not currently occur naturally and there is no historical memory of their ever having been present in the past.

Second approximation: convex factorial hull

A more detailed factorial study of the real points of oak stand shows that there are certain synergic or antagonic relationships among their values which are masked by the use of the factorial box, and that by considering a geometric figure like the convex hull which adjusts more closely than the box to the factorial reality of the cluster of points analysed, the system's predictive effectiveness can be enhanced (García-López and Allué, 2003).

Figures 3a and 3b show the result of applying the convex factorial hull to the Digital Elevations Model for *Quercus petraea* and *Quercus robur* respectively. As a simple comparison of Figures 2a and 2b shows, the potential factorial area of oak wood fits the present geographic situation much more closely, with 30,205 geographic points selected from the data base as true for *Quercus petraea* and covering approximately 3,020,500 ha instead of 5,663,700 ha as calculated by the factorial box method. In the case of *Quercus robur*, 43,615 points are selected from the data base as true, covering approximately 4,361,500 ha as compared to 5,082,800 ha calculated with the factorial box method.

Of these areas (6,988,400 ha of oak), only 393,600 ha are shared by the two species, while 3,967,900 ha are

Table 4. Factorial phytoclimatic ambits of stands of sessile and pedunculate oak in Spain (first approximation)

Factor	*Quercus petraea*						*Quercus robur*					
	K	A	P	PE	T	TMF	K	A	P	PE	T	TMF
Max.	0.11	1.36	1,958	109	13.2	6.6	0.026	1.85	3,059	140	15.1	10.4
Min.	0	0	760	24	6.3	–0.7	0	0	805	23	10	3.6

Factor	*Quercus petraea*						*Quercus robur*					
	TMC	TMMF	TMMC	HS	PV	IC	TMC	TMMF	TMMC	HS	PV	IC
Max.	21.7	2.7	27.1	5	844	18.6	22.1	7.5	29.8	1	1,597	15.8
Min.	13.9	–4.2	19.2	0	171	11.2	15.2	–0.3	19.4	0	225	8.3

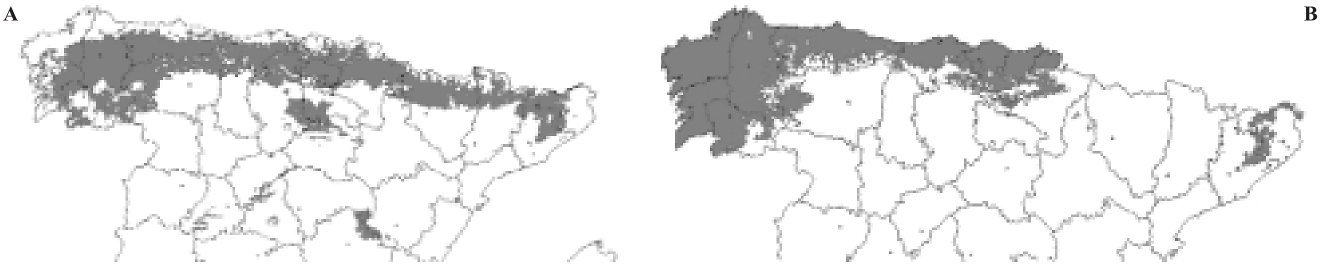

Figure 2. A: Potential factorial climatic area of sessile oak in Spain (approximately 5,663,700 ha) calculated using the first approximation (factorial box method). B: Potential factorial climatic area of pedunculate oak in spain (approximately 5,082,800 ha) calculated using the first approximation (factorial box method).

Figure 3. A: Potential factorial phytoclimatic area of sessile oak in Spain (approximately 3,020,500 ha) calculated using the second approximation (convex factorial hull). B: Potential factorial phytoclimatic area of pedunculate oak in Spain (approximately 4,361,500 ha) calculated using the second approximation (convex factorial hull).

selected exclusively for *Quercus robur* and 2,626,900 ha exclusively for *Quercus petraea*.

Third approximation: phytoclimatic terns

The results of diagnosis of the 577 points of sessile oak and 1780 points of pedunculate oak studied in Spain, using the Phytoclimatic System of Allué-Andrade (1990), are shown in Tables 5a and 5b respectively.

As Table 5a shows, the sessile oak woods of the Iberian Peninsula are situated in 73 types of phytoclimatic tern. In 209 cases no true subtype was found according to the ambits originally defined by Allué-Andrade (1990) from a thousand stations. For the 368 remaining stations, at which true subtypes were found, more than half (203 stations) belonged to true nemoral subtype VI, followed in equal measures by subtypes VI(V), VI(VIII) and VIII(VI).

In the case of pedunculate oak woods (Table 5b), the points studied belonged to 63 types of phytoclimatic tern. In only 66 of the 1,780 cases studied was no true subtype found. The reason for the small number of stations lacking a true subtype as compared to the case of *Quercus petrae*a is that most of the area occupied by *Quercus robur* lies at low altitude, which is precisely where the weather stations originally used to determine its ambits are most abundant. Of the 1714 stations with a true subtype, practically all (1684 points) belong to nemorolauroid subtype VI(V), followed at a considerable distance by subtype $VI(IV)_2$.

For yet stricter analysis, the 30,205 points of sessile oak and the 43,615 points of pedunculate oak from the second approximation were filtered to select only those points with one or more of the phytoclimatic terns listed in Tables 5a and 5b respectively. In the case of *Quercus petraea* 27,407 points were selected; the corresponding territorial area (approximately 2,740,700 ha) is shown in Figure 4a, and the factorial ambits of existence are shown in Table 6. In the case of *Quercus robur* 43,223 points were selected (ca. 4,322,300 ha); the territorial area is shown in Figure 4a, and the factorial ambits of existence are shown in Table 6.

Fourth approximation: minimum scalars

In this fourth phase, the table composed of 27,407 points of sessile oak from the third approximation was filtered to select only those points for which there was no void scalar in any of the factorial planes. To this end an autoecological phytoclimatic system was constructed

Table 5a. Phytoclimatic terns corresponding to the 577 sessile oak sampling points from the Second National Forest Inventory

Tern	Points
(VI(IV)$_2$; — ; — ; — ; — ; —)	6
(VI(IV)$_2$; — ; — ; — ; VI ; —)	3
(VI(IV)$_2$; — ; — ; — ; VI ; VI(VII))	1
Total VI(IV)$_2$	10
(VI(IV)$_4$; VI(IV)$_2$; — ; — ; — ; —)	1
(VI(IV)$_4$; VI(V) ; — ; — ; VI(VII) ; —)	1
Total VI(IV)$_4$	2
(VI(VII) ; — ; — ; — ; VI ; —)	3
(VI(VII) ; VI(IV)$_4$; — ; — ; — ; —)	1
(VI(VII) ; VI(IV)$_4$; — ; — ; VI(V) ; —)	1
(VI(VII) ; VI(IV)$_4$; — ; — ; VI ; —)	2
(VI(VII) ; VI(IV)$_4$; VI ; — ; — ; —)	1
(VI(VII) ; VI ; — ; — ; — ; —)	32
(VI(VII) ; VI ; — ; — ; VI(V) ; —)	1
(VI(VII) ; VI ; VI(IV)$_4$; — ; — ; —)	2
(VI(VII) ; VI ; VI(V) ; — ; — ; —)	10
Total VI(VII)	53
(VI(V) ; — ; — ; — ; — ; —)	15
(VI(V) ; — ; — ; — ; VI ; —)	13
(VI(V) ; VI(VII) ; — ; — ; — ; —)	3
(VI(V) ; VI(VII) ; VI ; — ; — ; —)	1
(VI(V) ; VI ; — ; — ; — ; —)	24
Total VI(V)	56
(VI ; — ; — ; — ; — ; —)	34
(VI ; — ; — ; — ; VI(VII) ; —)	3
(VI ; — ; — ; — ; VI(V) ; —)	4
(VI ; — ; — ; — ; VIII(VI) ; —)	36
(VI ; VI(IV)$_2$; — ; — ; VIII(VI) ; —)	1
(VI ; VI(VII) ; — ; — ; — ; —)	33
(VI ; VI(VII) ; VI(IV)$_4$; — ; — ; —)	1
(VI ; VI(VII) ; VI(V) ; — ; — ; —)	3
(VI ; VI(V) ; — ; — ; — ; —)	88
Total VI	203
(VIII(VI) ; — ; — ; — ; — ; —)	31
(VIII(VI) ; VI(VII) ; — ; — ; — ; —)	1
(VIII(VI) ; VI ; — ; — ; — ; —)	11
(VIII(VI) ; VI ; VI(VII) ; — ; — ; —)	1
Total VIII(VI)	44
(— ; — ; — ; — ; — ; —)	1
(— ; VI(IV)$_2$; — ; — ; — ; —)	12
(— ; VI(IV)$_2$; — ; — ; VI ; —)	1
(— ; VI(IV)$_2$; — ; — ; VIII(VI) ; —)	7
(— ; VI(IV)$_2$; — ; — ; VIII(VI) ; VI)	1
(— ; VI(IV)$_2$; VI ; — ; — ; —)	1
(— ; VI(IV)$_2$; VI ; — ; VIII(VI) ; —)	6
(— ; VI(IV)$_4$; — ; — ; VI(VII) ; —)	3
(— ; VI(IV)$_4$; VI(VII) ; — ; — ; —)	1
(— ; VI(IV)$_4$; VI(VII) ; — ; VI ; —)	1
(— ; VI(IV)$_4$; VI(VII) ; VI(V) ; — ; —)	2
(— ; VI(IV)$_4$; VI(V) ; — ; VI(VII) ; —)	2
(— ; VI(VII) ; — ; — ; — ; —)	25
(— ; VI(VII) ; — ; — ; VI ; —)	3
(— ; VI(VII) ; VI(IV)$_4$; — ; — ; —)	1
(— ; VI(VII) ; VI(V) ; — ; — ; —)	6
(— ; VI(VII) ; VI(V) ; — ; VI ; —)	2
(— ; VI(VII) ; VI(V) ; VI ; — ; —)	2
(— ; VI(VII) ; VI ; — ; — ; —)	29
(— ; VI(VII) ; VI ; VI(V) ; — ; —)	7
(— ; VI(V) ; — ; — ; — ; —)	11
(— ; VI(V) ; — ; — ; VI(VII) ; —)	12
(— ; VI(V) ; VI(IV)$_4$; — ; VI(VII) ; —)	1
(— ; VI(V) ; VI(VII) ; — ; — ; —)	5
(— ; VI(V) ; VI(VII) ; — ; VI ; —)	2
(— ; VI(V) ; VI ; — ; — ; —)	1
(— ; VI(V) ; VI ; VI(VII) ; — ; —)	4
(— ; VI ; — ; — ; — ; —)	7
(— ; VI ; — ; — ; VI(IV)$_2$; —)	1
(— ; VI ; — ; — ; VI(IV)$_2$; VIII(VI))	1
(— ; VI ; — ; — ; VI(VII) ; —)	1
(— ; VI ; — ; — ; VIII(VI) ; —)	23
(— ; VI ; VI(IV)$_2$; — ; — ; —)	6
(— ; VI ; VI(IV)$_2$; — ; VIII(VI) ; —)	2
(— ; VI ; VI(VII) ; — ; — ; —)	9
(— ; VI ; VI(VII) ; — ; VIII(VI) ; —)	3
(— ; VI ; VI(VII) ; — ; VIII(VI) ; VI(IV)$_2$)	1
(— ; VI ; VI(V) ; — ; — ; —)	1
(— ; VI ; VIII(VI) ; — ; — ; —)	1
(— ; VIII(VI) ; — ; — ; — ; —)	3
(— ; VIII(VI) ; VI(VII) ; — ; — ; —)	1
Total minus True	209
OVERALL TOTAL	577

with a single subtype comprising 577 points of sessile oak from the 2nd NFI. The characterising powers used were from an analogous system but in this case one made up of 18 forest species for all of Peninsular Spain, following the methodology of García-López and Allué (2005d). After filtering out void scalars, 19,904 points were selected; the corresponding territorial area (approximately 1,990,400 ha) is shown in Figure 5a and the factorial ambits of existence are shown in Table 7.

In the case of *Quercus robur*, following the contsruction of the phytoclimatic system and after filtering of the table of 43,223 points from the third approximation to select only those points with no void scalar in any factorial plane, 39,414 points of high phytoclimatic suitabi-

Table 5b. Phytoclimatic terns corresponding to the 1,780 pedunculate oak sampling points from the Second National Forest Inventory

Tern	Points	Tern	Points
(VI(IV)$_2$; — ; — ; — ; — ; —)	9	(VI(V) ; VI(IV)$_2$; — ; — ; — ; —)	92
(VI(IV)$_2$; — ; — ; — ; VI(IV)$_3$; —)	5	(VI(V) ; VI(IV)$_2$; — ; — ; VI(IV)$_3$; —)	1
(VI(IV)$_2$; — ; — ; — ; VI(IV)$_3$; VI(V))	2	(VI(V) ; VI(IV)$_2$; — ; — ; VI ; —)	15
(VI(IV)$_2$; — ; — ; — ; VI(V) ; —)	12	(VI(V) ; VI(IV)$_3$; — ; — ; — ; —)	12
(VI(IV)$_2$; — ; — ; — ; VI(V) ; VI(IV)$_3$)	3	(VI(V) ; VI(IV)$_3$; VI(IV)$_2$; — ; — ; —)	12
(VI(IV)$_2$; VI(IV)$_3$; — ; — ; — ; —)	15	(VI(V) ; VI(IV)$_4$; — ; — ; — ; —)	77
(VI(IV)$_2$; VI(IV)$_3$; — ; — ; VI(V) ; —)	12	(VI(V) ; VI ; — ; — ; — ; —)	65
(VI(IV)$_2$; VI(IV)$_3$; VI(V) ; — ; — ; —)	3	(VI(V) ; VI ; — ; — ; VI(IV)$_2$; —)	1
(VI(IV)$_2$; VI(V) ; — ; — ; — ; —)	73	(VI(V) ; VI ; VI(IV)$_4$; VI(VII) ; — ; —)	2
(VI(IV)$_2$; VI(V) ; — ; — ; VI(IV)$_3$; —)	21	(VI(V) ; VI ; VI(VII) ; VI(IV)$_4$; — ; —)	1
(VI(IV)$_2$; VI(V) ; VI(IV)$_3$; — ; — ; —)	5	Total VI(V)	1.684
Total VI(IV)$_2$	160	(VI ; VI(VII) ; VI(IV)$_4$; — ; — ; —)	1
(VI(IV)$_3$; — ; — ; — ; — ; —)	4	(VI ; VI(VII) ; VI(V) ; VI(IV)$_4$; — ; —)	1
(VI(IV)$_3$; — ; — ; — ; VI(V) ; —)	4	(VI ; VI(V) ; — ; — ; — ; —)	17
(VI(IV)$_3$; VI(IV)$_2$; — ; — ; — ; —)	11	(VI ; VI(V) ; VI(VII) ; — ; — ; —)	3
(VI(IV)$_3$; VI(IV)$_2$; — ; — ; VI(V) ; —)	2	Total VI	22
(VI(IV)$_3$; VI(IV)$_2$; VI(V) ; — ; — ; —)	3	(— ; VI(IV)$_2$; — ; — ; VI(V) ; —)	1
(VI(IV)$_3$; VI(V) ; — ; — ; — ; —)	4	(— ; VI(IV)$_2$; VI(IV)$_3$; — ; — ; —)	3
(VI(IV)$_3$; VI(V) ; VI(IV)$_2$; — ; — ; —)	4	(— ; VI(IV)$_2$; VI(IV)$_3$; — ; VI(V) ; —)	1
(VI(IV)$_3$; VI(V) ; VI(IV)$_4$; — ; — ; —)	4	(— ; VI(IV)$_3$; — ; — ; — ; —)	2
Total VI(IV)$_3$	36	(— ; VI(IV)$_3$; VI(IV)$_2$; — ; — ; —)	5
(VI(IV)$_4$; VI(IV)$_2$; VI(V) ; — ; VI(IV)$_1$; —)	1	(— ; VI(IV)$_3$; VI(IV)$_2$; — ; VI(V) ; —)	5
(VI(IV)$_4$; VI(VII) ; VI ; — ; — ; —)	1	(— ; VI(IV)$_3$; VI(IV)$_2$; VI(V) ; — ; —)	1
(VI(IV)$_4$; VI(VII) ; VI ; VI(V) ; — ; —)	1	(— ; VI(IV)$_3$; VI(V) ; — ; — ; —)	6
(VI(IV)$_4$; VI(V) ; — ; — ; — ; —)	2	(— ; VI(IV)$_4$; — ; — ; — ; —)	6
(VI(IV)$_4$; VI(V) ; — ; — ; VI(VII) ; —)	1	(— ; VI(IV)$_4$; — ; — ; VI(VII) ; —)	3
Total VI(IV)$_4$	6	(— ; VI(IV)$_4$; — ; — ; VI(VII) ; VI)	2
(VI(V) ; — ; — ; — ; — ; —)	1.191	(— ; VI(IV)$_4$; VI(IV)$_2$; VI(V) ; — ; —)	1
(VI(V) ; — ; — ; — ; VI(IV)$_2$; —)	14	(— ; VI(IV)$_4$; VI(V) ; — ; — ; —)	3
(VI(V) ; — ; — ; — ; VI(IV)$_2$; VI)	2	(— ; VI(IV)$_4$; VI ; — ; — ; —)	1
(VI(V) ; — ; — ; — ; VI(IV)$_3$; —)	5	(— ; VI(IV)$_4$; VI ; VI(VII) ; — ; —)	1
(VI(V) ; — ; — ; — ; VI(IV)$_3$; VI(IV)$_2$)	1	(— ; VI(V) ; — ; — ; — ; —)	20
(VI(V) ; — ; — ; — ; VI(IV)$_4$; —)	40	(— ; VI(V) ; VI(IV)$_3$; — ; — ; —)	4
(VI(V) ; — ; — ; — ; VI ; —)	146	Total minus True	66
(VI(V) ; — ; — ; — ; VI ; VI(IV)$_2$)	7	OVERALL TOTAL	1.780

Figure 4. A: Potential factorial phytoclimatic area of sessile oak in Spain (2,740,700 ha) calculated using the third approximation (identity of phytoclimatic terns). B: Potential factorial phytoclimatic area of pedunculate oak in Spain (4,322,300 ha) calculated using the third approximation (identity of phytoclimatic terns).

Table 6. Factorial phytoclimatic ambits of stands of sessile and pedunculate oak in Spain (third approximation)

Factor	*Quercus petraea*						*Quercus robur*					
	K	**A**	**P**	**PE**	**T**	**TMF**	**K**	**A**	**P**	**PE**	**T**	**TMF**
Max.	0.011	1.36	1,948	102	13.1	6.6	0.026	1.75	2,210	115	14.8	9.6
Min.	0	0	761	24	6.4	–0.6	0	0	846	23	10.0	3.6

Factor	*Quercus petraea*						*Quercus robur*					
	TMC	**TMMF**	**TMMC**	**HS**	**PV**	**IC**	**TMC**	**TMMF**	**TMMC**	**HS**	**PV**	**IC**
Max.	21.7	2.7	27.1	5	837	18.1	21.1	5.5	26.3	1	951	15.6
Min.	14.0	–4.1	19.4	0	175	11.7	15.9	–0.1	20.3	0	230	8.8

A B


Figure 5. A: Potential high-viability factorial phytoclimatic area of sessile oak in Spain (1,990,400 ha) calculated using the fourth approximation (minimum scalars). B: Potential high-viability factorial phytoclimatic area of pedunculate oak in Spain (3,941,400 ha) calculated using the fourth approximation (minimum scalars).

lity were selected; the corresponding territorial area (approximately 3,941,400 ha) is shown in Figure 5b and the factorial ambits of existence are shown in Table 7.

Fifth approximation: phytoclimatic suitability

In this fifth phase after filtering of the table of 19,904 points of sessile oak from the fourth approximation to select only those points with a Phytoclimatic Suitability Index of 0.50 (mid-range of the possibles) or higher, the 19,904 initial points were selected, all presenting a phytoclimatic suitability of over 0.60. Only 27 stations (2,700 ha) in this phase were shared with *Quercus robur*.

In the case of *Quercus robur*, after filtering of the table of 39,414 points from the fourth approximation in the same way as for *Quercus petraea*, 39,166 points of high phytoclimatic viability were selected (3,916,600 ha). Only 29 stations (2,900 ha) in this phase were shared with *Quercus petraea*.

Since this filter affected *Quercus petraea* not at all and *Quercus robur* very little (only 24,800 ha), the final result was not mapped for the corresponding factorial ambits calculated as in the previous filters.

Table 7. Factorial phytoclimatic ambits of stands of sessile and pedunculate oak in Spain (fourth approximation)

Factor	*Quercus petraea*						*Quercus robur*					
	K	**A**	**P**	**PE**	**T**	**TMF**	**K**	**A**	**P**	**PE**	**T**	**TMF**
Max.	0.010	1.35	1,948	102	11.9	3.7	0.025	1.73	2,210	115	14.8	9.6
Min.	0	0	761	25	6.9	–0.2	0	0	851	24	10.1	3.6

Factor	*Quercus petraea*						*Quercus robur*					
	TMC	**TMMF**	**TMMC**	**HS**	**PV**	**IC**	**TMC**	**TMMF**	**TMMC**	**HS**	**PV**	**IC**
Max.	21.2	0	27.0	4	837	18.1	20.7	5.5	25.3	1	951	14.7
Min.	14.3	–3.7	19.4	1	176	12.2	15.9	–0.1	20.3	0	365	8.8

Tables 8a and 8b show, for *Quercus petraea* and *Quercus robur* respectively, the mean suitability values of the phytoclimatic terns existing in Spain for the points selected by the third approximation following elimination of terns with no true subtype (23,374 out of 27,407 stations for *Quercus petraea* and 42,778 out of 43,223 stations for *Quercus robur*).

Sixth approximation: phytoclimatic diagnosis of competing forest species

The results of diagnosis of the 19,904 points of sessile oak and 39,166 points of pedunculate oak selected in the fourth approximation using the system of competing forest species are shown in Table 9. There, each tern

Table 8a. Phytoclimatic terns and mean suitability for phytoclimatically potential points of sessile oak selected by the third approximation

Phytoclimatic tern	Stations	Mean suitability	St. dev. suitab.
($VI(IV)_2$; — ; — ; — ; — ; —)	177	74.3	2.1
($VI(IV)_2$; — ; — ; — ; VI ; —)	47	76.1	2.1
($VI(IV)_2$; — ; — ; — ; VI ; VI(VII))	7	78.0	0.0
Total $VI(IV)_2$	231	74.8	2.3
($VI(IV)_4$; $VI(IV)_2$; — ; — ; — ; —)	8	72.4	1.1
($VI(IV)_4$; VI(V) ; — ; — ; VI(VII) ; —)	4	53.8	5.8
Total $VI(IV)_4$	12	66.2	9.7
(VI(VII) ; — ; — ; — ; VI ; —)	9	68.6	4.5
(VI(VII) ; $VI(IV)_4$; — ; — ; — ; —)	767	78.4	3.8
(VI(VII) ; $VI(IV)_4$; — ; — ; VI(V) ; —)	47	71.5	1.9
(VI(VII) ; $VI(IV)_4$; VI ; — ; — ; —)	523	81.2	3.4
(VI(VII) ; VI ; — ; — ; — ; —)	2,503	80.9	4.0
(VI(VII) ; VI ; — ; — ; VI(V) ; —)	11	60.7	5.1
(VI(VII) ; VI ; VI(IV)4 ; — ; — ; —)	460	79.6	5.7
(VI(VII) ; VI ; VI(V) ; — ; — ; —)	204	73.3	4.9
Total VI(VII)	4,524	79.9	4.7
(VI(V) ; — ; — ; — ; — ; —)	866	74.6	2.7
(VI(V) ; — ; — ; — ; VI ; —)	1,305	77.6	2.0
(VI(V) ; VI(VII) ; — ; — ; — ; —)	30	73.9	2.4
(VI(V) ; VI(VII) ; VI ; — ; — ; —)	5	76.2	1.3
(VI(V) ; VI ; — ; — ; — ; —)	1,429	79.9	1.8
Total VI(V)	3,635	77.7	2.9
(VI ; — ; — ; — ; — ; —)	2,288	88.7	1.8
(VI ; — ; — ; — ; VI(VII) ; —)	723	89.5	1.3
(VI ; — ; — ; — ; VI(V) ; —)	234	89.1	0.8
(VI ; — ; — ; — ; VIII(VI) ; —)	3,450	89.4	1.4
(VI ; $VI(IV)_2$; — ; — ; VIII(VI) ; —)	2	83.0	1.4
(VI ; VI(VII) ; — ; — ; — ; —)	1,598	86.5	2.9
(VI ; VI(VII) ; $VI(IV)_4$; — ; — ; —)	261	84.6	3.0
(VI ; VI(VII) ; VI(V) ; — ; — ; —)	33	86.5	3.5
(VI ; VI(V) ; — ; — ; — ; —)	4,241	86.5	3.5
Total VI	12,830	87.9	2.9
(VIII(VI) ; — ; — ; — ; — ; —)	870	71.4	5.7
(VIII(VI) ; VI(VII) ; — ; — ; — ; —)	65	77.2	4.9
(VIII(VI) ; VI ; — ; — ; — ; —)	1,196	84.5	2.3
(VIII(VI) ; VI ; VI(VII) ; — ; — ; —)	11	83.8	3.0
Total VIII(VI)	2,142	79.0	7.6

Table 8b. Phytoclimatic terns and mean suitability for phytoclimatically potential points of pedunculate oak selected by the third approximation

Phytoclimatic tern	Stations	Mean suitability	St. dev. suitab.
($VI(IV)_2$; — ; — ; — ; — ; —)	279	52.1	1.6
($VI(IV)_2$; — ; — ; — ; $VI(IV)_3$; —)	198	53.0	3.8
($VI(IV)_2$; — ; — ; — ; $VI(IV)_3$; VI(V))	42	56.6	1.0
($VI(IV)_2$; — ; — ; — ; VI(V) ; —)	586	56.0	1.1
($VI(IV)_2$; — ; — ; — ; VI(V) ; $VI(IV)_3$)	70	57.1	0.9
($VI(IV)_2$; $VI(IV)_3$; — ; — ; — ; —)	479	55.8	3.3
($VI(IV)_2$; $VI(IV)_3$; — ; — ; VI(V) ; —)	366	57.6	1.3
($VI(IV)_2$; $VI(IV)_3$; VI(V) ; — ; — ; —)	61	59.4	1.2
($VI(IV)_2$; VI(V) ; — ; — ; — ; —)	1,993	56.6	1.3
($VI(IV)_2$; VI(V) ; — ; — ; $VI(IV)_3$; —)	267	57.8	0.6
($VI(IV)_2$; VI(V) ; $VI(IV)_3$; — ; — ; —)	93	58.4	0.8
Total $VI(IV)_2$	4,434	56.2	2.3
($VI(IV)_3$; $VI(IV)_2$; — ; — ; — ; —)	261	58.7	3.3
($VI(IV)_3$; $VI(IV)_2$; — ; — ; VI(V) ; —)	103	59.7	1.5
($VI(IV)_3$; $VI(IV)_2$; VI(V) ; — ; — ; —)	44	61.6	1.7
($VI(IV)_3$; VI(V) ; — ; — ; — ; —)	25	58.8	1.0
($VI(IV)_3$; VI(V) ; $VI(IV)_2$; — ; — ; —)	149	61.7	1.4
Total $VI(IV)_3$	582	59.9	2.8
($VI(IV)_4$; VI(VII) ; VI ; — ; — ; —)	72	52.3	1.1
($VI(IV)_4$; VI(VII) ; VI ; VI(V) ; — ; —)	21	54.1	1.3
($VI(IV)_4$; VI(V) ; — ; — ; — ; —)	48	69.6	1.4
($VI(IV)_4$; VI(V) ; — ; — ; VI(VII) ; —)	1	56.0	0.0
Total $VI(IV)_4$	142	58.4	8.1
(VI(V) ; — ; — ; — ; — ; —)	26,059	62.4	4.1
(VI(V) ; — ; — ; — ; $VI(IV)_2$; —)	323	59.2	0.9
(VI(V) ; — ; — ; — ; $VI(IV)_2$; VI)	23	58.2	0.4
(VI(V) ; — ; — ; — ; $VI(IV)_3$; —)	169	63.5	1.1
(VI(V) ; — ; — ; — ; $VI(IV)_3$; $VI(IV)_2$)	6	63.2	0.8
(VI(V) ; — ; — ; — ; $VI(IV)_4$; —)	964	64.1	3.3
(VI(V) ; — ; — ; — ; VI ; —)	3,334	55.8	2.4
(VI(V) ; — ; — ; — ; VI ; $VI(IV)_2$)	142	57.3	0.9
(VI(V) ; $VI(IV)_2$; — ; — ; — ; —)	1,266	57.7	1.7
(VI(V) ; $VI(IV)_2$; — ; — ; $VI(IV)_3$; —)	4	58.0	0.0
(VI(V) ; $VI(IV)_2$; — ; — ; VI ; —)	249	57.3	0.8
(VI(V) ; $VI(IV)_3$; $VI(IV)_2$; — ; — ; —)	501	62.8	1.3
(VI(V) ; $VI(IV)_4$; — ; — ; — ; —)	2,115	67.3	2.6
(VI(V) ; VI ; — ; — ; — ; —)	1,961	51.7	2.5
(VI(V) ; VI ; — ; — ; $VI(IV)_2$; —)	67	54.2	1.5
(VI(V) ; VI ; $VI(IV)_4$; VI(VII) ; — ; —)	10	52.6	0.5
(VI(V) ; VI ; VI(VII) ; $VI(IV)_4$; — ; —)	13	53.3	0.6
Total VI(V)	37,206	61.3	5.0
(VI ; VI(VII) ; $VI(IV)_4$; — ; — ; —)	24	50.6	1.0
(VI ; VI(VII) ; VI(V) ; $VI(IV)_4$; — ; —)	17	50.7	1.2
(VI ; VI(V) ; — ; — ; — ; —)	333	48.2	3.1
(VI ; VI(V) ; VI(VII) ; — ; — ; —)	40	49.3	3.3
Total VI	414	48.6	3.1

Table 9. Phytoclimatic spectra of species from the diagnosis of 19,690 points of sessile oak and 29,890 points of pedunculate oak, in which one or other species heads the tern constructed with the phytoclimatic system devised from the principal competing forest species

Tern	Points	Tern	Points
(Qpe;)	2	(Qpe;Qpu;Fsy;Qfp;Psy;Qil;)	855
(Qpe;Aal;Fsy;Psy;)	177	(Qpe;Qpu;Fsy;Qfp;Qil;)	951
(Qpe;Aal;Fsy;Psy;Qpu;)	69	(Qpe;Qpu;Fsy;Qfp;Qro;Qil;)	9
(Qpe;Aal;Fsy;Qpu;Psy;)	47	(Qpe;Fsy;Qfp;Qpu;)	3
(Qpe;Aal;Psy;)	102	(Qpe;Fsy;Qfp;Qpu;Qil;)	2
(Qpe;Aal;Psy;Qil;)	21	(Qpe;Fsy;Qfp;Qro;Qil;)	2
(Qpe;Aal;Qpu;Psy;)	9	(Qpe;Fsy;Qil;)	40
(Qpe;Fsy;)	228	(Qpe;Fsy;Qpu;Aal;Psy;)	145
(Qpe;Fsy;Aal;)	15	(Qpe;Fsy;Qpu;Aal;Psy;Qfp;Qil;)	3
(Qpe;Fsy;Aal;Psy;)	106	(Qpe;Fsy;Qpu;Aal;Psy;Qil;)	206
(Qpe;Fsy;Aal;Qfp;)	86	(Qpe;Fsy;Qpu;Aal;Qfp;Psy;Qil;)	321
(Qpe;Fsy;Aal;Qfp;Psy;)	2	(Qpe;Fsy;Qpu;Aal;Qfp;Qil;)	34
(Qpe;Fsy;Aal;Qfp;Psy;Qil;)	1	(Qpe;Fsy;Qpu;Psy;)	8
(Qpe;Fsy;Aal;Qfp;Qil;)	9	(Qpe;Fsy;Qpu;Psy;Qil;)	48
(Qpe;Fsy;Aal;Qfp;Qpu;)	30	(Qpe;Fsy;Qpu;Qfp;Aal;Psy;Qil;)	200
(Qpe;Fsy;Aal;Qpu;)	10	(Qpe;Fsy;Qpu;Qfp;Aal;Qil;)	14
(Qpe;Fsy;Aal;Qpu;Psy;)	132	(Qpe;Fsy;Qpu;Qfp;Psy;Qil;)	338
(Qpe;Fsy;Aal;Qpu;Qfp;)	7	(Qpe;Fsy;Qpu;Qfp;Qil;)	384
(Qpe;Fsy;Aal;Qpu;Qfp;Psy;)	7	(Qpe;Fsy;Qpu;Qfp;Qro;Qil;)	11
(Qpe;Fsy;Aal;Qpu;Qfp;Psy;Qil;)	39	(Qpe;Jth;Fsy;Psy;Qfp;)	2
(Qpe;Fsy;Aal;Qpu;Qfp;Qil;)	6	(Qpe;Jth;Fsy;Psy;Qfp;Qil;)	4
(Qpe;Fsy;Jth;Psy;)	2	(Qpe;Jth;Fsy;Qfp;Psy;)	17
(Qpe;Fsy;Jth;Psy;Qfp;)	45	(Qpe;Jth;Fsy;Qfp;Psy;Qil;)	72
(Qpe;Fsy;Pni;Jth;Qfp; Psy;Qil;)	102	(Qpe;Pni;Fsy;Jth;Qfp;Psy;Qil;)	46
(Qpe;Fsy;Pni;Qfp;Jth;Psy;Qil;)	3	(Qpe;Pni;Fsy;Qfp;Qil;)	1
(Qpe;Fsy;Pni;Qfp;Qil;)	11	(Qpe;Pni;Jth;Fsy;Qfp;Psy;Qil;)	50
(Qpe;Fsy;Psy;)	319	(Qpe;Psy;)	26
(Qpe;Fsy;Psy;Qfp;)	755	(Qpe;Psy;Qfp;)	1
(Qpe;Fsy;Psy;Qil;)	49	(Qpe;Psy;Qil;)	3
(Qpe;Fsy;Qfp;)	2317	(Qpe;Qfp;)	44
(Qpe;Fsy;Qfp;Aal;Qil;)	3	(Qpe;Qpu;Fsy;Qfp;Qil;)	497
(Qpe;Fsy;Qfp;Psy;)	474	(Qpe;Qpu;Fsy;Qil;)	247
(Qpe;Fsy;Qfp;Psy;Qil;)	2659	(Qpe;Qpu;Psy;)	11
(Qpe;Fsy;Qfp;Qil;)	4285	(Qpe;Qpu;Psy;Qil;)	200
(Qpe;Fsy;Qfp;Qro;Qil;)	5	(Qpe;Qpu;Qfp;Aal;Psy;Qil;)	35
(Qpe;Qfp;Fsy;Qil;)	80	(Qpe;Qpu;Qfp;Fsy;Psy;Qil;)	3
(Qpe;Qfp;Psy;)	2	(Qpe;Qpu;Qfp;Fsy;Qil;)	416
(Qpe;Qfp;Psy;Qil;)	5	(Qpe;Qpu;Qfp;Qil;)	1069
(Qpe;Qfp;Qil;)	261	(Qpe;Qpu;Qil;)	226
(Qpe;Qpu;)	12	Total *Quercus petraea*	19,690
(Qpe;Qpu;Aal;Psy;)	22		
(Qpe;Qpu;Aal;Psy;Qil;)	93	(Qro;)	15979
(Qpe;Qpu;Fsy;Aal;Psy;Qil;)	110	(Qro;Qsu;Qil;)	13
(Qpe;Qpu;Fsy;Aal;Qfp;Psy;Qil;)	46	(Qro;Qfp;Qil;)	6400
(Qpe;Qpu;Fsy;Psy;)	1	(Qro;Qfp;)	3579
(Qpe;Qpu;Fsy;Psy;Qil;)	258	(Qro;Qfp;Qsu;Qil;)	9
(Qpe;Qpu;Fsy;Qfp;Aal;Psy;Qil;)	102		
(Qpe;Qpu;Fsy;Qfp;Psy;Aal;Qil;)	3	Total *Quercus robur*	29,890

(A; B; C; D; E; F; G) includes the abbreviations of codes for species in Table 3 inside whose phytoclimatoc ambits, defined by convex hull, is an analysed point, in descending order of adjustment scalar.

As a result of this analysis and in order to add an extra level of strictness to the four approximations already carried out, the table composed of the 19,690 points of sessile oak and 39,166 points of pedunculate oak from the fourth approximation were filtered to select only those points at which one or other of the two oak species was dominant in the diagnosis spectrum.

As Table 9 shows, in almost every case (19,690 stations out of 19,904 analysed) *Quercus petraea* presents a larger phytoclimatic adjustment scalar than any other species occurring in the spectrum and hence comes before all the rest in the hierarchy of that spectrum. In the case of *Quercus robur*, in 76% of cases (29,890 stations out of 39,166 analysed), this species presents a larger phytoclimatic adjustment scalar than any other species occurring in the spectrum and hence comes before all the rest in the hierarchy of that spectrum.

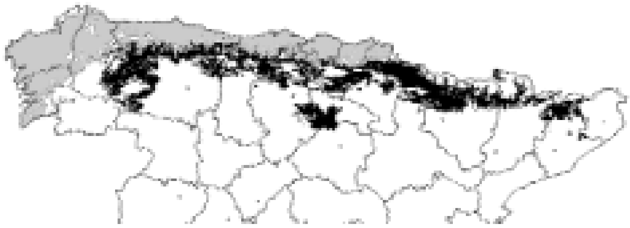

Figure 6. Potential factorial phytoclimatic area of sessile oak in Spain (1,969,00 ha, in black) and pedunculate oak (2,989,000 ha, in grey), calculated using the sixth approximation.

Figure 6 shows the geographic distribution of approximately 1,969,000 ha selected for *Quercus petraea* and 2,989,000 ha for *Quercus robur*, whose factorial ambits of existence are shown in Table 10.

The stations and surface areas retained in each filtering phase are summarised in Table 11.

Table 10. High-viability potential phytoclimatic ambits of sessile and pedunculate oak in spain (sixth approximation)

Factor	*Quercus petraea*						*Quercus robur*					
	K	A	P	PE	T	TMF	K	A	P	PE	T	TMF
Max.	0.009	1.34	1,948	102	11.7	3.7	0.022	1.72	2,210	115	14.8	9.6
Min.	0	0	767	25	6.9	–0.2	0	0	934	24	10.2	4.7
Factor	***Quercus petraea***						***Quercus robur***					
	TMC	**TMMF**	**TMMC**	**HS**	**PV**	**IC**	**TMC**	**TMMF**	**TMMC**	**HS**	**PV**	**IC**
Max.	21.1	0	26.9	4	837	16.5	20.7	5.5	25.3	0	950	14.5
Min.	14.3	–3.7	19.4	1	177	12.6	15.9	0.9	20.3	0	390	12.2

Table 11. Summary of stations and equivalent surface areas retained in each filter phase

No.	Character	Type	*Quercus petraea*	*Quercus robur*	Type of area
1	Factorial	Box	56,637 stations 5,663,700 ha	50,828 stations 5,082,800 ha	Potential
2	Factorial	Convex hull	30,205 stations 3,020,500 ha	43,615 stations 4,361,500 ha	Potential
3	Phytoclimatic	Phytoclimatic terns	27,407 stations 2,740,700 ha	43,223 stations 43,223 ha	Potential
4	Phytoclimatic	Minimum scalars	19,904 stations 1,990,400 ha	39,414 stations 3,941,400 ha	High viability
5	Phytoclimatic	Phytoclimatic suitability	19,904 stations 1,990,400 ha	39,166 stations 3,916,600 ha	High viability
6	Phytoclimatic	Competing species	19,690 stations 1,969,000 ha	29,890 stations 2,989,000 ha	High viability

Discussion

Thanks to the methodology followed in the present study, we have been able to make progress in some specific aspects of phytoclimatic understanding of *Quercus petraea* and *Quercus robur* woods in Spain and to confirm or qualify the validity of some of the results of previous studies.

Specifically, we have drawn up the first viable map of high potential phytoclimatic viability for the two species throughout Spain. With the methodology used, based on increasing levels of factorial climatic and phytoclimatic strictness, multi-purpose mapping is possible in which each station and type of approximation presents its own particular level of reliability, and hence of uncertainty of evaluation; thus they can be utilised in decision making processes concerning forestry management of these formations, ranging from 5,663,700 ha and 5,082,800 ha respectively for *Quercus petraea* and *Quercus robur* in the approximation based on the factorial box to 1,969,000 ha and 2,989,000 ha respectively for the strictest approximation. The exclusion of *Quercus robur* in a position of maximum viability in some small areas in the most northerly extremes of Galicia (Cabo Ortegal, Estaca de Bares) need to be interpreted with caution, given that the absence of sampling points in that area (Fig. 1a) has most probably masked the fitness of these areas for this maximum level of viability.

This progress in the overall view of the territorial phytoclimatic potentialities of these formations, and specifically the areas of maximum viability identified, provides numeric and theoretical confirmation of the impressions of geobotanists, who have traditionally estimated, in an appreciable number of publications, that the area currently occupied by these oak forests is only a small portion of the land area potentially suitable for such formations. We provide numeric corroboration of the very scant overlapping of areas of high potential phytoclimatic viability of the two formations — indeed non-existent in the strictest filter— although from a strictly floristic standpoint the two taxa are fairly often found mingled and there are frequent instances of hybridization between them.

The consideration of territorialized phytoclimatic factors for a large number of stations in the Iberian Peninsula as a whole has made it possible, again for the first time, to establish more comprehensive factorial ambits of existence than those existing hitherto, which were necessarily based on a very small number of weather stations in the national network of the National Meteorological Institute.

By establishing these ambits we are also able to confirm and quantify numerically a number of ideas which have been proposed with some frequency in the literature on these species. Particularly evident are the scant differences between the two oaks in terms of pluviometric or thermopluviometric factors. Indeed, the factorial ambits of K, A, P and PE for both species in Spain are very similar. The same is not true of thermometric factors, in which the differences between the two formations is at times appreciable. In particular, approximate minimum temperature values of TMF = 4°C and TMMF = 0°C clearly seem to differentiate the two species in terms of conditions for high viability, with sessile oak preferring the colder values.

As Figure 7 shows, the mean suitability of the *Quercus petraea* stations considered is greatest between T values of 8 and 10°C, dropping sharply for values below 8°C and less sharply for values above 10°C. In the case of *Quercus robur* the maximum T value occurs between 12 and 14°C, dropping sharply for values above 14°C and less sharply for values below 12°C.

Having regard to box HS, sessile oaks can withstand very high temperatures in conditions of high viability for up to four months, whereas pedunculate oaks are less tolerant and only manifest their most phytoclimatically viable forms at stations where there is absolutely no Certainty of Frost.

Sessile oaks seem to possess a greater tolerance of thermal continentality than pedunculate oaks to judge by the ambits identified by the parameter IC; unlike *Quercus* robur, Quercus *petraea* formations can exist in conditions of high viability with values in excess of 16.5°C.

Quercus robur also exhibits an apparent capacity to withstand somewhat higher levels of aridity than

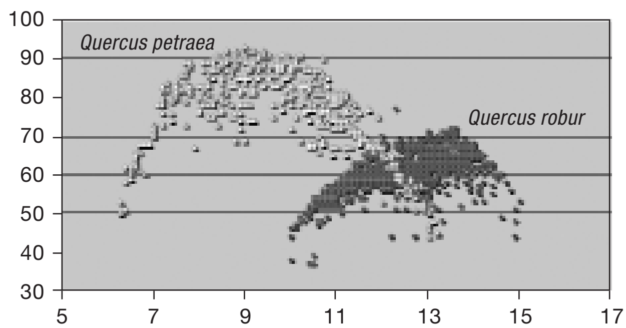

Figure 7. Suitability of *Quercus petraea* and *Quercus robur* stations considered (2nd NFI) in terms of values of the factor T.

Quercus petraea. This might contradict the findings reported in a number of other sources in the literature, but the fact is that other studies (Costa *et al*., 2001) describe the pedunculate oak as more heliophilous than the sessile oak or the beech and better able to withstand states of dehydration, thanks to more xeromorphic leaves, better conductivity of vessels and greater tolerance of poorly-aerated and badly-drained soils where there is an overabundance of water. The maximum aridity value found for *Quercus robur* in high-viability situations in this study (1.73 months) is close to the value of 50 dry days estimated by Ruiz de la Torre (1979). The same does not apply to *Quercus petraea*, for which the cited author estimates drought tolerance at less than 75 days, which is somewhat longer than our own estimations. As Figure 8 shows, formations of pedunculate oak which withstand more than one month in conditions of high phytoclimatic viability are very rare (less than 100,000 ha) and are located exclusively in the southern parts of the provinces of Pontevedra and Orense, where the situation is probably ameliorated by the high level of ambient humidity.

Despite the capacity of pedunculate oak formations in south-western Galicia to maintain positions of high viability even in arid conditions lasting more than 1.5 months, the mean scalar of adjustment, which is used as an index of suitability, is a median of scalars calculated by factorial planes which can mask the isolated occurrence of very low minimum partial scalars, despite the fact that minimum scalars of value 0 were eliminated in the phase 4 filter. For that reason, mean values of minimum partial scalars were calculated as functions of the aridity values for pedunculate oak points in the phase 6 filter, producing the graph in Figure 9. Here we can see that the mean values of the minimum scalars decrease as aridity increases, so that there is a greater risk of limiting situations arising. In fact at aridity values of 1.4 months and upwards, the

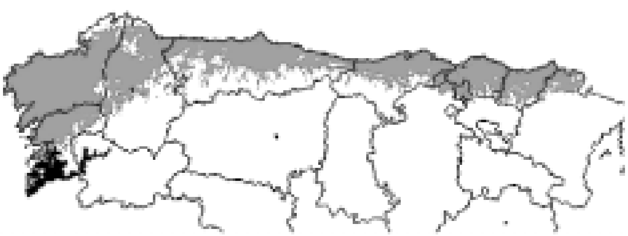

Figure 8. Situation of formations of pedunculate oak withstanding more than one month of aridity in conditions of high phytoclimatic viability (phase 6).

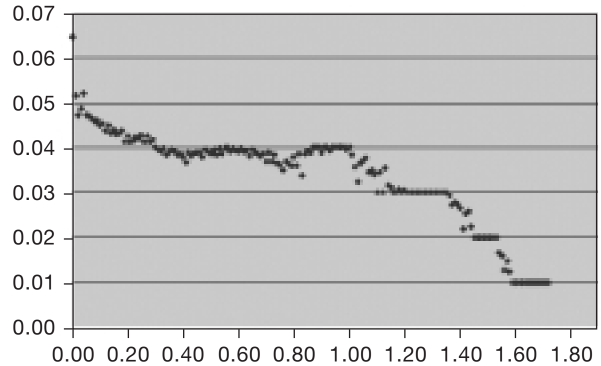

Figure 9. Mean minimum scalar of high-viability pedunculate oak formations (phase 6) as a function of the aridity value (months).

decrease in the mean value of the minimum partial adjustment scalar is accentuated. From this it follows that although the pendunculate oak formations of southern Galicia grow in conditions of high phytoclimatic viability, this is because there are compensating situations very close to positions limiting aridity through highly favourable scalar values produced by other factors.

This study has also served to identify al the phytoclimatic terns that host sessile and pedunculate oak formations in Spain, which constitutes an advance in our knowledge of the subject, and it has confirmed the occurrence of *Quercus petraea* in subtypes VI(IV)$_2$, VI(IV)$_4$, VI(V), VI(VII), VI and VIII(VI), *Quercus robur* has been detected in Spain in subtypes VI(IV)$_2$, VI(IV)$_3$, VI(IV)$_4$, VI(V) and VI.

The bulk of natural instances of *Quercus petraea* as dominant species in a forest formation occur in subtype VI, which is also the most suitable subtype for the species in global terms, followed by cold subtypes like VI(VII) and VIII(VI). The least suitable subtypes are the warmest ones, VI(V) and VI(IV)$_4$. Instances of *Quercus robur* occur almost entirely (1,684 out of 1,780 stations) in subtype VI(V), which is also the most suitable for the species in global terms, followed by warm subtypes like VI(IV)$_3$ and VI(IV)$_4$. The least suitable subtype is the coldest, VI.

As regards phytoclimatic inter-species relationships, thanks to the broader factorial scope of its ambits, *Quercus petraea* can be part of more than a hundred diagnostic terns of species in which its adjustment scalar is the largest and hence it presumably competes with them from a strictly phytoclimatic standpoint. In fact in only 2 cases out of the 29,980 in the strictest

Table 12. Percentage of diagnostic terns of species in the phase 6 filter, as a function of the species belonging to them

%	Pun	Psy	Aal	Pni	Fsy	Qpu	Qfp	Qil	Qsu	Jth
Qpe		43.5	11.3	1.1	88.1	36.8	94.4	73.4		1.1
Qro							33.4	21.5	0.1	

filter is there a tern in which sessile oak is the sole species. The spectrum of species belonging to the terns is very broad, with all those listed in Table 3 present except for the most thermal one, *Quercus suber*, and the extremely cold *Pinus uncinata*. The terns also embrace needleleaf (Pni, Psy, Aal), nemoral (Fsy, Qro), marcescent (Qfp, Qpu) and sclerophyll (Qil) formations. As Table 12 shows, the commonest species in the terns belong to the marcescent group of *Quercus pyrenaica/faginea* and *Fagus sylvatica*, which occur respectively in 94.4% and 88.1% of cases. But most common are terns in which the second species after *Quercus petraea* is *Fagus sylvatica*. The three terns (Qpe;Fsy;Qfp;Qil;), (Qpe;Fsy;Qfp;Psy;Qil;) and (Qpe;Fsy;Qfp;) among them account for 9261 out of a total of 19,690.

One hypothesis that might account for the fact that beech is not the commonest species in the terns is that because this study deals with real rather than potential plant stations, some of the marcescent formations considered are the product of degradation of beech or other cold deciduous broad-leaf formations. Also, the potential phytoclimatic area of beech is clearly much smaller than that of the marcesecent formations, which means that the percentage in relation to these areas must be considered in relative terms.

The high frequency of diagnostic terns of species in which *Quercus petraea* and *Fagus sylvatica* appear together thus reinforces the hypothesis that there is considerable overlapping of the ecological preferences of the two species, as noted in several sources (Costa *et al.*, 2001). Inter-species competition with *Fagus sylvatica* would therefore appear to be extremely important to an understanding of the present distribution and potentialities of sessile oaks. Table 13 compares the high-viability ambits identified in this study for *Quercus petraea* with those reported by García-López *et al.* (2005b) for *Fagus sylvatica* in the Iberian Peninsula as a whole, using the same methodology. As the table shows, the factorial overlap is practically total, with a slight tendency in beech towards colder situations, with somewhat lower values of T, TMF and TMMF. Insofar as they can be interpreted as indirect

Table 13. Comparison of high-viability phyoclimatic ambits of *Quercus petraea* for Spain from the fourth approximation in this study with those found by García-López *et al.* (2005b) for *Fagus sylvatica* in the Iberian Peninsula

			Quercus petraea			
Factor	**K**	**A**	**P**	**PE**	**T**	**TMF**
Max.	0.009	1.34	1,948	102	11.7	3.7
Min.	0	0	767	25	6.9	–0.2
Factor	**TMC**	**TMMF**	**TMMC**	**HS**	**PV**	**IC**
Max.	21.1	0	26.9	4	837	16.5
Min.	14.3	–3.7	19.4	1	177	12.6
			Quercus sylvatica			
Factor	**K**	**A**	**P**	**PE**	**T**	**TMF**
Max.	0.013	1.35	2,397	101	10	3.6
Min.	0	0	606	23	5.9	–0.9
Factor	**TMC**	**TMMF**	**TMMC**	**HS**	**PV**	**IC**
Max.	18.7	–0.1	24.3	6	6	16.8
Min.	13.4	–4.4	18.4	1	2	12

indicators of duration of the vegetative period, the TMC and TMMC values, which are also a little lower, confirm that beech has a greater facility for coexistence with high-mountain conifers proper to ambits with low TMC values which allow only brief periods for the growth of deciduous broad leaves and are therefore more suited to evergreen needle-leaf strategies (Walter, 1977). In fact, according to García-López *et al*. (2005b), beech formations appear to present maxima of global suitability at the colder end of nemoral subtype VI and at the less cold end of the subnemoral oroborealoid subtype VIII(VI). These results suggest that, in the context of a very considerable overlap between the two formations, *Quercus petraea* would give way to *Fagus sylvatica* in the colder parts —that is, in the upper altitudinal sector— of their area of distribution in contact, as the case may be, with oroborealoid formations. If we take these results together with the very recent arrival of the beech in Spain (ca. 5,000 years), the hypothesis which suggests itself is that the beech, as a more modern and aggressive species, occupied the traditional domains of sessile oak and, to a lesser extent given that other physiognomic strategies are more appropriate, those of mountain needle-leaf forests.

In the case of *Quercus robur*, the spectrum of diagnostic terns of species in which it is the species with largest adjustment scalar is very narrow, embracing only 5 types. The range of species belonging to the terns is also very small, with only marcescent (Qfp) and sclerophyll (Qil, Qsu) formations present at the maximum level of potential viability, while formations associated with colder plant strategies such as mountain needle-leaf and nemoral species are excluded. Unlike the situation of sessile oak, pedunculate oak is the only species belonging to the bottom-level diagnostic tern in 15,979 out of 29,890 cases studied (53%). As Table 13 shows, the commonest species in the terns is the marcescent combination *Quercus pyrenaica/faginea* (33.4%) although there is also a considerable presence of holm oak (21.5%). This situation is consistent with the reality observable on the ground, in which the *ilex* subspecies of holm oak is a constant and well-documented presence in the most easterly zones of the potential area for high phytoclimatic viability of sessile oak (Basque Country, Cantabria, eastern Asturias) in rocky limestone locations with skeletal soils (isolated hillocks), whereas in the western part of its potential area (western Asturias and Galicia), where siliceous bedrock predominates, *Quercus robur* usually comes into contact *Quercus pyrenaica*. The presence of *Quercus ilex* and *Quercus suber* in the terns enhances the thermophilic character of these oak woods, as we noted earlier on.

We would also draw attention to the virtual absence of *Quercus robur* from terns of *Quercus petraea* species and vice versa, which tends to confirm that there is practically no ecological overlapping in situations of high viability of either type of oak formation, and that the 600-700 m altitudinal band separates the two formations geographically into respective situations of high phytoclimatic viability.

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