Characterization of natural regeneration in stands of carballo (*Quercus robur* L.) in Galicia (NW Spain): relation to topography, climate and soil.

RODRIGUEZ-CAMPOS, A., DIAZ-MAROTO, I. J., BARCALA-PEREZ, E., VILA-LAMEIRO, P.

1.Introduction

Quercus robur L. is the species of the genus *Quercus* with the largest distribution area, covering almost all Europe and a big part of Asia Minor and of the Caucasus. The best oak forests are found in the Danube Basin (Hungary, Rumania, etc.), in Germany (Silesia and Bavaria) and in France (Normandy and Brittany) (RUIZ DE LA TORRE, 1979). In Galicia, it is distributed almost all over the territory, from the sea level to 1600 m of altitude. The *carballeiras* or *fragas* are forests of *Quercus robur* or *Q. petraea* in which *carballos* or *carbas* are dominant together with other tree species in lower proportion and different types of shrubs and herbaceous (SILVA-PANDO and RIGUEIRO, 1992). In Galicia, the *carballeiras* are the climax forests which should cover the main part of the territory. Their location in deep lands with gentle orography, transformable into grass-cutting lands, and the quality of their wood, favoured the disappearance of what in past times should have been a continuous covering of this species in the main part of Western Europe to the South of Scandinavia (RUIZ DE LA TORRE, 1979). Nowadays, a great part of their potential area is occupied by short-term growth species, grasslands and agricultural lands. Despite this, the area covered by deciduous broadleaves in Galicia has noticeably increased. According to the data of the III National Forest Inventory, the pure stands of broadleaves occupy a 27% of the whole forested area, 375,922 ha, standing out the area covered by *Q. robur* with 187,789 ha, a 13,4% of the forest cover (XUNTA DE GALICIA, 2001).

Almost all the *carballo* stands in Galicia lack silvicultural management, due to the lack of economical interest in their exploitation (DIAZ-MAROTO et al., 2005; DIAZ-MAROTO and VILA LAMEIRO, 2008). However, they have an elevated environmental interest (GUITIAN RIVERA, 1993), representing habitats of community interest (Decree 92/43/EU) which will be included in the 2000 Natura Net.

In accordance with the principle of persistence of a forest cover, this must be based in its natural regeneration once it reaches maturity (SERRADA, 2005), beginning this persistence when the thick and mature woodland is substituted by another coming from seed, process which is quite long and complicated in the oaklands and which usually presents any of the following situations (PULIDO, 2002; BARRIO et al., 2003, DIAZ et al., 2004):

- Scarce acorn production and problems for the development of seedlings.

- In the establishment stage, the seedlings and the woody saplings suffer the defoliation and the mechanical damage from the invertebrates and mammals.
- Short development of the saplings due to an excessively closed canopy.
- Damaged and scarce regeneration, due to the fires and the pressure by herbivores.
- Very abundant regeneration by stock and root shoot in clear cut stands, which makes difficult the introduction of the acorns.

The regeneration by seeding presents quite a lot of uncertainty, because this is a mast fruiting species, it is random and discontinuous because, although the formation of the acorns is annual, the abundant crops happen in intervals of 3 and 5 years which can even reach 10. The mast year seems to be motivated by the climatic conditions, to a large extent, but it is also related to the fact that after a good crop year, the tree remains exhausted and needs a period to accumulate reserves and produce acorns again (BARRIO, 2003).

The way of dissemination by gravity which *Quercus spp.* present does not favour the fruit dispersion neither, because the acorn is big and heavy. In this case, the Eurasian Jay (*Garrulus glandarius* L.) plays an important and favourable role in the spreading of the species; it is known that these birds are the most important and almost the only dispersant agents of acorns (PONS and PAUSAS, 2007). TISCAR (2003) suggests creating a grid of stands each 500 m to get an adequate spreading, which would contribute in a very positive way to the restoration process of these forests. Other animals (bears, wild boars, rodents and birds as wood pigeons), affect in a negative way to their regeneration, as the acorns are a source of feeding for them. Even saplings are very appetizing for roe deer.

Works about natural regeneration of *Quercus robur* stands in Galicia are scarce. MCEVOY (2006) studied the effect of grazing over the regeneration of the species and BARRIO *et al.* (2003) analyzed the problems of the regeneration of deciduous and semideciduous oaks in the NW of Spain. In the rest of Europe, the studies about the regeneration of the species are numerous and are about the analysis of the natural regeneration according to its silviculture, ecology, cultural treatments over the ground vegetation, etc., (HAMER and MORGAN, 2007; DIACI *et al.*, 2008; DOBROWOLSKA, 2008).

The aim of this work is to study the natural regeneration in natural stands of *Quercus robur* distributed all over the Galician geography, comparing the evolution of the regeneration under different tree canopy covers: closed canopy, semi-closed and opened, besides quantifying and comparing the acorn production.

2. Material and Methods

2.1 Study area

Based on the current distribution of the *carballo* forests in Galicia and their physiographic, climatic and edaphic habitats (DIAZ-MAROTO, 1997; DIAZ-MAROTO et al., 2005), 4 natural stands were selected within the Galician territory (Fig. 1).

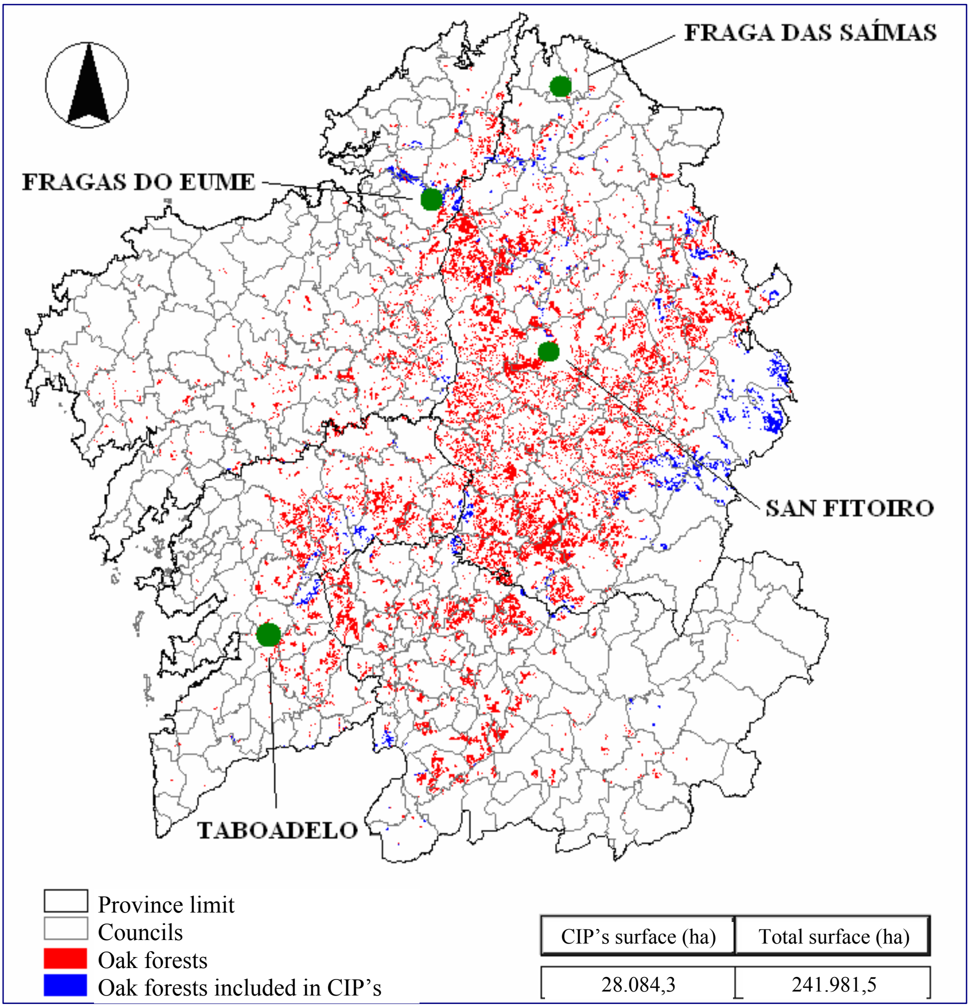

Figure 1. Studied *Quercus robur* forests localization in the context of the species distribution in Galicia according to the III National Forest Inventory. Source: Barrio (2003)

The stands had to fulfill three requirements: 1) To be a single-species stand (< 20% of stems belonging to other species in the tree canopy); 2) Minimum area between 0,5-1 ha, to install non border-effect plots; 3) To belong to the different phytosociological associations of the species in Galicia (SILVA PANDO and RIGUEIRO, 1992). The aim, through this selection, was to cover a big range of possibilities of tree canopy opening, ecological and seasonal diversity of the species:

1) Natural Park of "Fragas do Eume" (province of A Coruña): more than 9000 ha which constitute the best European termophile Atlantic forest, due to its extension and conservation. The plots were located in the purest stands of Q.robur and they belong to the association *"Blechno spicanti-Quercetum roboris termophyle facies of Laurus nobilis"*.

2) Fraga das Saímas (Viveiro, province of Lugo): 50 ha of /communal forest which belong to the association *“Blechno spicanti-Quercetum roboris typical facies”*.

3) San Fitoiro oakland (Lugo): it has an area of nearly 100 ha of communal forest belonging to the association *“Vaccinio myrtilli-Quercetum roboris”*.

4) Oakland of Taboadelo, (Pontecaldelas, province of Pontevedra): it has an approximated area of 45 ha of the association *“Rusco aculeati-Quercetum roboris”*.

2.2 Dendrometrical measurements

Each forest was divided into three levels, according to the grade of canopy opening: closed stands, stands with partial opening and stands with a clear opened canopy. Attending to this, 4 permanent inventory plots were installed in each stand, two under closed canopy and two under semi-closed, altogether 16 rectangular plots with changeable dimensions, depending on the density of the stand, so each of them had at least 40-50 trees (MADRIGAL *et al.,* 1999). The dimensions varied between 500-1200 m^2. Once the sampling point was chosen, the plots were made out with a metric tape, optical square, 5 sticks and one Vertex III, setting out the largest side parallel to the contour-line. This is very important in high slopes, being necessary, in this case, to correct the slope to work over the horizontal. Subsequently, all the inventoriable stems of *Q. robur* were marked (normal diameter $\geq$ 5 cm) with a numbered identification tag at 1,3 m, as a reference for the monitoring of the installed plots, and for subsequent inventories. The measured variables in the forest inventory have been:

- Normal diameter of the inventoriable stems in cross with millimetric calliper.
- Total height of the inventoriable stems, using a Vertex III.

With these data were calculated the following stand variables: number of stems/ha (N), basal area (G), normal diameter (d_n), cuadratic mean diameter (d_g), mean height (H_m), Assman top height (H_o), slenderness quotient (SQ) and Hart Index (HI).

2.3 Data collecting of the regeneration and seed production

It is called regeneration the seedlings which are in the upgrowth stage or in borning seeding, or the ones which have not reached yet the necessary dimensions to be considered minor stems and which are part of the low or herbaceous level (DIAZ-MAROTO, 1997). To get these data, permanent sampling points of 1 m^2 were established. Altogether, 60 points were installed in each forest: 20 under closed canopy, 20 under semi-closed and 20 in clearings which were distributed along transects 50 m long (HAMER, 2005). In all of them were established 10 sampling points separated 5 m. Altogether, 6 transects in each forest, two under closed canopy, two under semi-closed and two in clearings. The points were marked with wooden piquets and with GPS, to facilitate their finding in subsequent measurements. In each transect it was made a note of its altitude, slope and orientation. Furthermore, all the oak saplings present in each point of 1 m^2 were labelled (diameter < 5 cm), using a folding wooden square of that area and using coloured bridles; it was measured their length with a millimetric precision ruler, their ages were estimated and the possible evidences of cattle presence were annotated (RENT *et al.,* 2003).

To quantify the acorn production, it was taken a sample in each stand, selecting for that 8 1 m^2 points close to the transects under closed canopy, where all the acorns were collected. In the lab litter, etc. were removed, and later the acorns were weigh and measured, its length and diameter. Subsequently, they were dried at 70º C, 48 hours in an air-forced heat, to weigh and measure them again (in their dry state) (LOPEZ-CARRASCO *et al.,* 2005).

To consider how the presence of cattle and wild herbivorous affect to the regeneration, three cages with an area of 1 m^2 and 1 m high were installed in each of the four stands. To locate the cages it was taken into consideration the division made in accordance with the different canopy openings, so one cage was located in one of the 20 measured gap points, another in the points under semi-closed canopy and the third one in a point under closed canopy, being installed in total 12 cages.

2.4 Statistical analysis

There was done a summary of the synthesis statistics (mean, maximum, minimum and standard deviation) of the frequency of distribution for each variable (density, total height, normal diameter, stand variables, abundance and average height of the regeneration and number of acorns). Subsequently, through variance analysis, the behaviour of the dependant variable was analyzed (stand density and height of the regeneration) in the established groups by the independent variable (canopy cover and type of stand) (SAS, 1990). When interpreting the results, the "F" test analyzes the variation among groups with the estimated in each group. It indicates that not all the measures are the same, but it does not indicate which means are different among them. In the other hand, the p-value has to be lower than the signification level, 5%, so the null hypothesis can be rejected, concluding that the averages for the groups are significantly different, in this case for a 95% of signification (CAO, 2001). To determine which averages present significant differences, Multiple Comparison Tests were done.

3. Results and discussion

3.1Description of the stands and their tree canopy

In Table 1, are shown the physiographical and climatic characteristics, the type of canopy cover, plot area and deepness of the parent rock in each plot. The greater continentality corresponds to San Fitoiro, which also presents the highest altitude. The rest, are stands located relatively close to the coast and where the marine influence can be appreciated in a higher or lower grade. In general, all of them present sharp slopes, with extreme values which exceeded the 50%. Referred to the area, the biggest plots were installed in Taboadelo, as this present a lower stem density.

Table 1. Inventory plots physiographic climatic and descriptive characteristics

FOREST	PLOT	CANOPY	ALT. (m)	ORIEN. (º)	SLP. (%)	S (m^2)	P (mm)	T (ºC)	Soil Depth
FRAGAS DO EUME	1	CLOSED	330	N	40	500	2.292	11,7	High
	2	CLOSED	337	W	53	600			
	3	SEMICLOSED	472	NE	25	900			
	4	SEMICLOSED	435	W	37	750			
SAÍMAS	1	CLOSED	514	SE	40	625	1.500	11,5	Intermediate Low
	2	CLOSED	532	W	30	800			
	3	SEMICLOSED	509	SW	47	1050			
	4	SEMICLOSED	519	W	45	750			
SAN FITOIRO	1	CLOSED	600	ALL	0	500	1.200	11,9	High
	2	CLOSED	610	ALL	0	625			
	3	SEMICLOSED	675	W	14	625			
	4	SEMICLOSED	624	NW	20	750			
TABOADELO	1	CLOSED	143	SW	40	1200	2.000	11,6	High
	2	CLOSED	160	N	50	1000			
	3	SEMICLOSED	138	E	32	1200			
	4	SEMICLOSED	113	W	45	1000			

(ALT.: Altitude, ORIEN.: Orientation, SLP.: Slope, S: Surface, P: Anual mean rainfall and T: Anual mean temperature)

In the four stands, the precipitation exceeds widely the 1000 mm per year and the temperature is in the optimal range for the species in the study area (DIAZ-MAROTO and VILA-LAMEIRO, 2008). The climatic factor with the most negative influence, as it affects to the regeneration, are the late frosts, which cause serious damages in the fructification (AUSSENAC, 1975). The stands where this risk is higher are: Fraga de Saímas and the robledal of San Fitoiro. All the stands have deep soils except Saímas. In Table 2, there is a list with the most abundant species on the ground vegetation of each plot. In general, brackens, blueberries, heaths, gorse, wild pear trees and blackberry bushes are abundant, as other tree species like *Betula alba* L. and *Corylus avellana* L.

Table 3 shows the descriptive statistics of the normal diameter and total height in each of the inventoried plots. It stands out that the biggest stems, in diameter as in height, are located in the stand of Taboadelo, while the smallest ones correspond to the stand of San Fitoiro. In Fragas do Eume and Saímas there are numerous dead stems, 14% in both stands, while Taboadelo has 6% and San Fitoiro 7%.

Table 2. Understory vegetation by plot

FOREST	PLOT	COMPANION VEGETATION
FRAGAS DO EUME	1	*Pteridium aquilinum, Erica arborea* and *Daboecia cantabrica*
	2	*Pteridium aquilinum, Erica arborea, Ilex aquifolium, Pyrus cordata* and *Castanea sativa*
	3	*Pteridium aquilinum, Vaccinium myrtillus, Prunus* spp. and *Betula alba*
	4	*Pteridium aquilinum, Erica arborea, Daboecia cantabrica* and *Vaccinium myrtillus*
SAÍMAS	1	*Pteridium aquilinum, Erica arborea, Daboecia cantabrica* and *Ilex aquifolium*
	2	*Ilex aquifolium* and *Quercus pyrenaica*
	3	*Erica arborea, Vaccinium myrtillus, Coryllus avellana, Ulex europaeus* and *Frangula alnus*
	4	*Erica mackaiana, Daboecia cantabrica, Quercus pyrenaica* and *Ilex aquifolium*
SAN FITOIRO	1	*Pteridium aquilinum, Vaccinium myrtillus* and *Ruscus aculeatus*
	2	*Pteridium aquilinum, Vaccinium myrtillus* and *Ruscus aculeatus*
	3	*Pteridium aquilinum, Vaccinium myrtillus, Ulex europaeus, Rubus* spp. and *Erica arborea*
	4	*Pteridium aquilinum*
TABOADELO	1	*Pteridium aquilinum, Ruscus aculeatus* and *Rubus* spp.
	2	*Pteridium aquilinum, Erica arborea, Blechnum spicant, Pyrus cordata* and *Frangula alnus*
	3	*Pteridium aquilinum, Frangula alnus, Polypodium cambricum* and *Woodwardia radicans*
	4	*Pteridium aquilinum, Frangula alnus* and *Rubus* spp.

San Fitoiro is a *Quercus robur* pure stand, while Saímas has an 18% of other species, specially *Ilex aquifolium* L., which under closed canopy strongly competes with the oak, so we can find some places where there are even more holly tree seedlings than oak ones.

Table 3. Descriptive statistics of the variables diameter at breast heigh (dn) and total height (H)

STATISTICS	FRAGAS DO EUME		SAN FITOIRO		SAÍMAS		TABOADELO	
	Dn (cm)	H (m)	Dn (cm)	H (m)	Dn (cm)	H (m)	Dn (cm)	H (m)
n	137	137	95	95	207	207	267	267
Mean	21,7	13	36,2	16,6	21,9	14,4	18,2	15,4
Minimum	5,1	1,8	12,6	4,3	7,7	2,6	5,0	3,0
Maximum	56,2	20,7	81,0	39,6	37,3	22,2	34,1	23,0
σ_{n-1}	8,6	3,7	15,0	6,8	6,1	3,9	4,7	3,0

(n: number of trees in the sample; σ_{n-1}: Tipical deviation)

Taboadelo has a 7% of other species and Fragas do Eume a 6%. In both cases, the most abundant species are *Castanea sativa* Mill., *Betula alba* and *Laurus nobilis* L. The following figures show the diametric distribution according to the canopy cover.

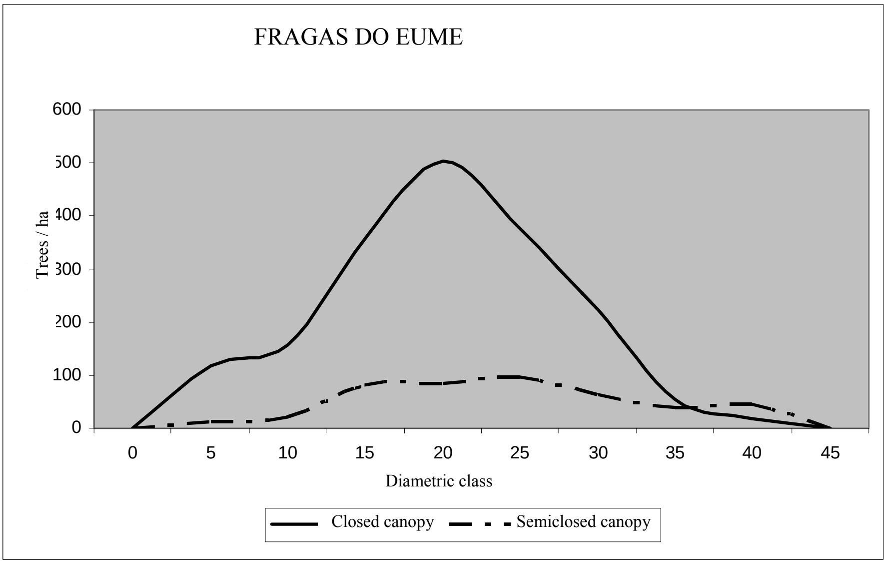

Figure 2. Trees distribution by diametric classes

The diametric distribution of Fragas do Eume (Fig. 2), shows the low number of feet installed under semi-closed canopy compared to the closed-canopy, very near to the curve of an irregular stand. Saímas also presents a distribution under closed canopy very next to the “normal”, typical in regular stands, but under semi-closed canopy, the distribution presents two maximums ,indicative of a semirregular stand (PARDÉ, 1961), due to the harvests made to put up an electrical installation in the proximities (Fig. 3).

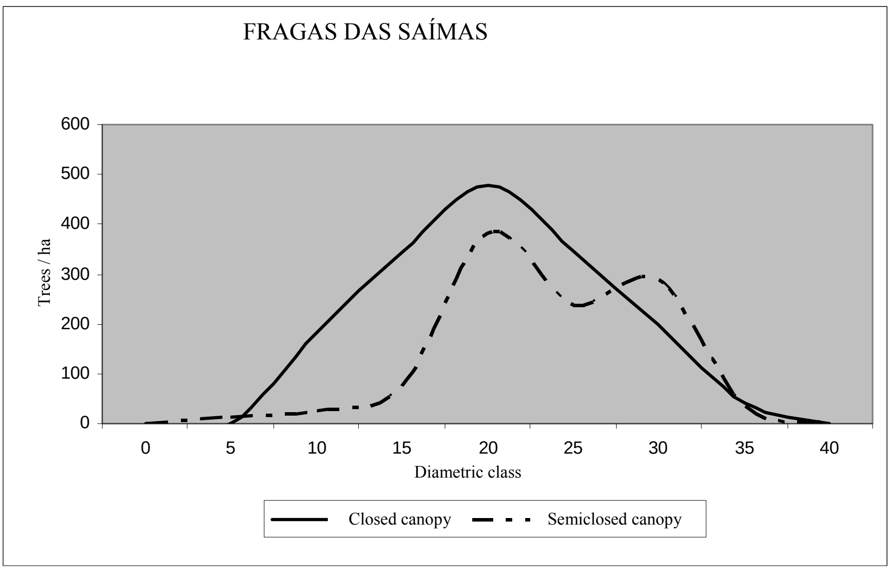

Figure 3. Trees distribution by diametric classes

The stems distribution which is closest to a Gaussian function is found in Fitoiro, being this a typical regular stand (Fig. 4), under closed canopy as under semi-closed, due to the harvesting for firewood practiced till the 80s with clear cuts.

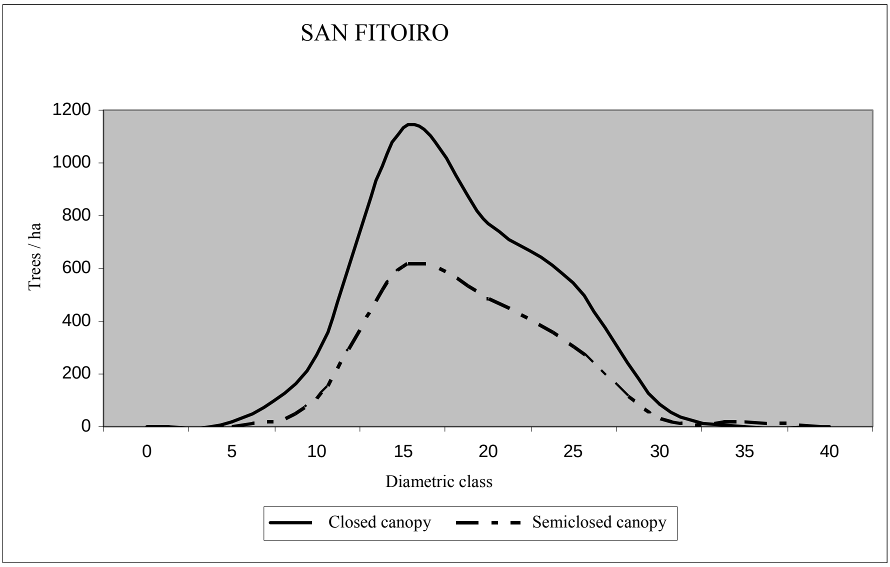

Figure 4. Trees distribution by diametric classes

Taboadelo presents the most complex distribution (Fig. 5). Under closed canopy, there is a group of very mature stems belonging to the D.C. 75 and the rest belong to the classes 45 and 50.

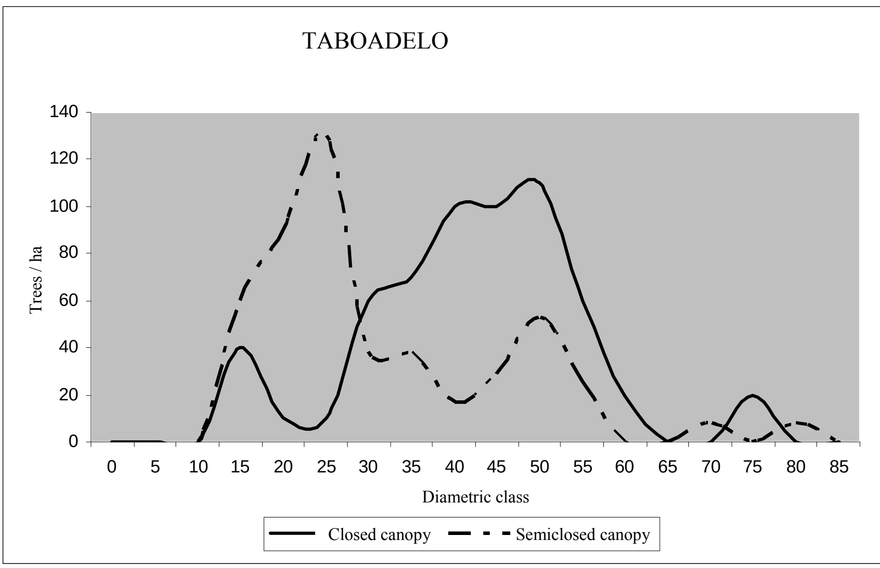

Figure 5. Trees distribution by diametric classes

Under semi-closed canopy, there is a group of stems of the D.C. 20 and 25. This is an old growth stand and the evolution of the young trees is not the adequate. Approximately 40 years ago, the agricultural use was abandoned and the oak grove began to become established from the natural regeneration of the mature trees, used to produce acorns for cattle.

Table 4 shows the statistics of the stand variables. San Fitoiro presents the highest density, 1122 stems/ha; Fragas do Eume and Fraga das Saímas have a similar density, approximately 600 stems/ha, being Taboadelo the stand with the lower density, 229 stems/ha.

Table 4. Descriptive statistics of the forest parameters

FOREST	STATISTICS	N (trees/ha)	H_o (m)	d_g (cm)	G (m^2/ha)	CE	IH
FRAGAS DO EUME	Average ± σ_{n-1}	571 ± 407	14,9 ± 2,0	24,2 ± 3,4	23,2 ± 12,6	56,7 ± 11,2	35,1 ± 17,4
	Minimum	227	12,3	19,3	12,2	46,8	19,4
	Maximum	1040	16,9	26,7	37,4	70,4	54,0
SAÍMAS	Average ± σ_{n-1}	664 ± 164	16,9 ± 2,0	22,8 ± 1,7	26,5 ± 2,6	65,2 ± 7,3	23,6 ± 3,7
	Minimum	495	14,5	20,8	23,3	55,4	21,0
	Maximum	864	19,3	24,5	29,4	73,0	28,8
SAN FITOIRO	Average ± σ_{n-1}	1122 ± 364	17,7 ± 1,2	18,6 ± 0,2	30,5 ± 10,0	82,8 ± 8,2	17,6 ± 3,9
	Minimum	768	16,6	18,4	20,5	74,3	13,4
	Maximum	1488	19,3	18,8	39,8	93,9	21,7
TABOADELO	Average ± σ_{n-1}	229 ± 131	20,2 ± 5,4	41,5 ± 11,0	25,9 ± 1,5	46,3 ± 9,7	36,8 ± 11,7
	Minimum	117	15,1	27,2	23,9	31,9	29,5
	Maximum	410	27,1	52,8	27,2	51,7	54,1
TOTAL	Average ± σ_{n-1}	647 ± 421	17,4 ± 3,4	26,8 ± 10,5	26,5 ± 7,8	62,7 ± 16,1	28,3±12,7
	Minimum	117	12,3	18,4	12,2	31,8	13,4
	Maximum	1488	27,1	52,8	39,8	93,9	54,1

(N: number of trees by hectare; H_o: dominant heigh; d_g: quadratic mean diameter; G: basal area; CE: slenderness coefficient; IH: Hart-Becking Index; σ_{n-1}: Typical deviation)

The values of the quadratic mean diameter (d_g) and the mean height (H_m) show that the stands, in general, belong to a stand age of sapling with a H_o of 17,4 m and with certain particularities (Table 4). So, Fragas do Eume and Saímas belong clearly to the sapling stand, but San Fitoiro, which has a lower d_g, is a high polewood, while Taboadelo, with a d_g of 41,5 cm, would be in the stand age of middle-size trunk with a H_o of 20,2 m, presenting the highest heights. San Fitoiro has the highest basal area (G), 30,5 m^2/ha and the other stands have values around

25 m^2/ha. The Hart Index (HI) behaves inversely proportional to the density. Finally, a stand with values higher than 80 % of the slenderness quotient (SQ) is considered as stable (JOHNSON et al., 2002); consequently, in the basis of the obtained results, the only stand which would have stability problems would be San Fitoiro (SQ = 82,8 %).

3.2 Gaps description

The election of the clearings was complicated, as our intention was to have a minimum area between 100-120 m^2 and, in the selected stands the gaps are not abundant. It was specially difficult to find clearings of this size in San Fitoiro and in Saímas, which are the ones with the highest density. This minimum area is the threshold which lets the right development of the young seedlings, as gaps smaller than 70 m^2 let the regeneration survive for 4 or 6 years, but then it becomes weak, the seedlings dry up and they die. (BRUCIAMACCHIE *et al.*, 1994).

3.3 Stand ages (density and mean height of the regeneration)

The lack of stems in the young growth stage, thicket or low polewood was general in all the stands. According to BARRIO *et al.* (2003), this absence of minor stems in the Galician *carballeiras* is due to the absolute absence of silvicultutal treatments. This makes the saplings die due to the lack of light. This situation can be frequently appreciated in the Galician forests as the abundant regeneration of some years survives one or two seasons and then they disappear due to the lack of light, this happens continuously, preventing the saplings which are initially established, become part of the thicket (DIAZ-MAROTO et al., 2005).

The seedlings established within the permanent sampling points do not exceed in any case 1,3 m of height, so it can be said that the natural regeneration of these stands belongs to the stand age of upgrowth. These are recently germinated seedlings or seedlings which reach a mean height of 25 cm.

Table 5. Descriptive statistics of the regeneration density (seedling/ha) and mean height (cm)

FOREST	FRAGAS DO EUME		TABOADELO		SAÍMAS		SAN FITOIRO	
STATISTICS	Density	H_m	Density	H_m	Density	H_m	Density	H_m
N	60	22	60	66	60	86	60	163
Mean	3667	14,8	11000	18,1	14333	21,1	25.000	21,9
Minimum	0	6,5	0	5,0	0	5,0	0	5,0
Maximum	40000	58,0	60000	57,0	100000	100	110000	58,5
σ_{n-1}	8227	10,7	16743	8,0	20697	15,4	24391	9,9

(n: number of trees in the sample; σ_{n-1}: Typical deviation)

In Table 5 are shown the descriptive statistics for the density of the seedlings per hectare and their mean heights in each stand. The oak stand with the higher density is San Fitoiro, with 25000 seedlings/ha, while Fragas do Eume presents the lowest value of the four stands, with 3667 seedlings/ha. Fraga das Saímas and Taboadelo present similar values included between 10000 and 15000 seedlings/ha. These results tally with the ones obtained by BARRIO *et al.* (2003), who defend that, as a general rule, in the Galician *Quercus robur* stands the regeneration is more abundant in stands with high density and it decreases in the clearer and more mature ones. Despite the robledal of Taboadelo is the oldest stand, it presents a more abundant regeneration than Fragas do Eume, which can be due to the higher cattle pressure and presence of wild fauna on this last one, which affects negatively to the regeneration. Attending to the mean height of the seedlings, the same as for the density, is in Fragas do Eume where exists a lower mean height, 14,8 cm, while the other three stands present similar values, around 20 cm of average height.

3.4 Density analysis and mean height of the regeneration

The density of the regeneration and its mean height were also classified according to the different types of canopy cover. Under closed canopy there is a higher number of seedlings of *Quercus robur*, with an average of 16000 seedlings/ha. The lowest value for the density of the seedlings corresponds to the area of gaps with a mean value of 10000 seedlings/ha. Under semi-closed canopy it was obtained a medium value of 14500 seedlings/ha (Table 6). This means that, initially, more seedlings are established under closed canopy because inside a oakland the acorns germination is much higher in the areas with the highest density of stems, as these stems avoid the occupation of the soil by dense herbaceous covers which would make difficult the establishment of the regeneration (DIACI et al., 2008). Moreover, the abundant litter vegetable which is formed on the soil after the acorns fall, favours the existence of a well oxygenated medium and with enough moisture content, creating the optimal conditions for germination (JOHNSON *et al*., 2002; SOLYMOS, 1993).

Table 6. Descriptive statistics of the regeneration density (seedling/ha) and mean height (cm) by canopy type

	OPENED		SEMICLOSED CANOPY		CLOSED CANOPY	
STATISTICS	Density	H_m	Density	H_m	Density	H_m
n	80	93	80	116	80	128
MeaN	10000	24,5	14500	20,0	16000	18,1
Minimum	0	5,0	0	5,0	0	6,0
Maximum	100000	100,0	80000	57,0	110000	58,0
σ_{n-1}	16304	16,2	19086	8,3	23524	8,9

(n:number of trees in the sample; σ_{n-1}: Typical deviation)

Opposite, in the gaps less seedlings are established due to the strong competence of the present vegetation, as it was formerly described, reaching a mean height of 1,3 m and composed mainly by *Pteridium aquilinum*, *Rubus* ssp., *Erica arborea*, *Pyrus cordata, Vaccinium myrtillus, Ulex europaeus* and numerous herbaceous.

Attending to the mean height of the seedlings, the saplings under gaps present the highest heights, with a mean value of 24,5 cm, opposite to the 20 and 18,1 cm which present the saplings under semi-closed and closed canopy, respectively. This is because the growth in height of the regeneration of *Quercus robur*, is favored with high light intensities, that´ s why, once the plants become established in a gap, they grow better than the ones which grow under the tree canopy (DIACI et al., 2008). The *carballo* regenerates adequately when the levels of luminosity are not lower than 15-20 %, this, reflected as a grade of canopy covering, is equivalent to saying that the oak regeneration is favored by the existence of small gaps with an area between 225 and 314 m^2 (JARVIS, 1964; LÜPKE, 1998; DIACI *et al*., 2008). This minimum area of gap is higher than the recommended by BRUCIAMACCHIE *et al*. (1994), as it was already mentioned, who advice a mean gap size between 100-120 m^2.

The data referred to the regeneration density and mean height were analyzed through variance analysis, distinguishing them in the basis of the different stands and canopy type. In the Fig. 6, are shown the results of the number of seedlings of *Quercus robur* per m^2, in the different possible combinations. As we can see, there is a clear difference in the initial establishment of the seedlings among the different studied stands, (F = 13,55; p-value = 0,000). Attending only to the different grades of covering, the result was not statistically significant, however the combination of both factors, stand type and canopy cover, gave a significant result (F = 17,13; p-value = 0,000) (SAS, 1990).

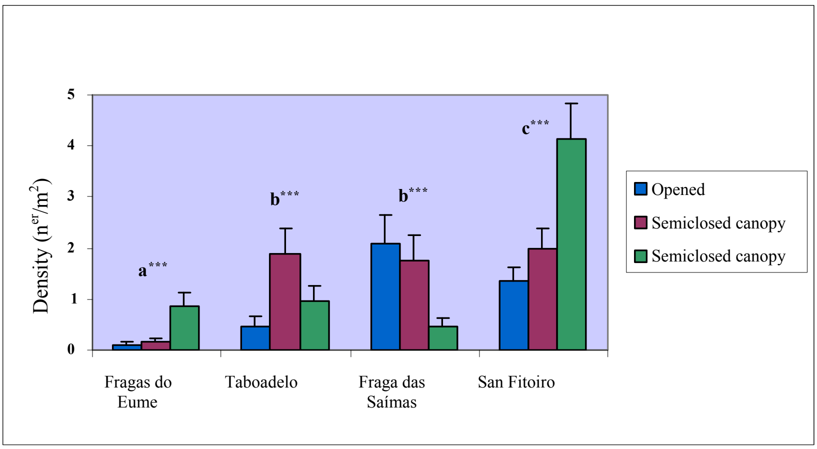

Figure 6. Seedling mean density by surface (seedling/m^2) ± standard error (n = 340); a, b and c indicate significant differences between forests, ***p < 0,001

Fragas do Eume and the robledal of San Fitoiro differ significantly in the number of seedlings which are naturally established, while the robledal of Taboadelo and Fraga das Saímas do not present significant differences between them, but they do with the formers (Fig. 6). It is in San Fitoiro where exists a higher number of seedlings, with a maximum of 5 seedlings/plot, while in Fragas do Eume are hardly found values of one seedling/plot.

Fraga das Saímas and the robledal of Taboadelo present intermediate values among the previous ones. This can be due, as it was mentioned, to the presence of a higher number of herbivores and cattle in Fragas do Eume, which affects negatively to the establishment of the seedlings, as to their later development (PULIDO, 2002). In the other two stands were found more evidences of the presence of cattle than in San Fitoiro, which justify the intermediate values obtained in the quantity of regeneration (Fig. 6). The mean height of the seedlings was also analyzed according to the type of stand and canopy cover (Fig. 7). In San Fitoiro the results were significantly different to the obtained from Fragas do Eume and Taboadelo (F = 3,92; p-value = 0,011), while Fraga das Saímas did not present significant differences with any of the other three stands.

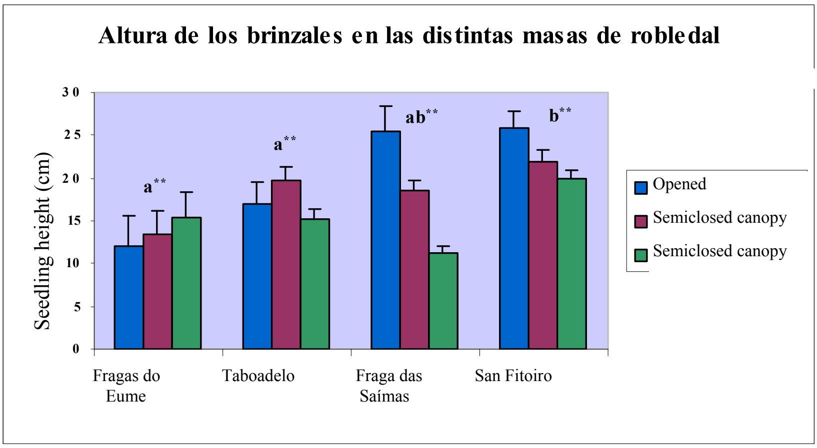

Figure 7. Seedling mean height (cm) ± standard error (n = 337); a and b indicate significant differences between forests, **p < 0,01

There are significant differences in the number of seedlings as in their mean height among the plots under closed canopy and the ones installed on gaps, in any of the stands, and the same trend was observed between Fraga das Saímas and the robledal of San Fitoiro (Fig. 7). In both stands, the seedlings which grow under closed canopy have a shorter height than the ones which grow under clearings, this is because of this species is tolerant to light or semi-light and the clearings favour their growth (MACCARTHY, 2001; JOHNSON *et al*., 2002; DOBROWOLSKA, 2008). In most of the species, it can be considered the regeneration is enough when the mean density is 1-4 seedlings/m^2, with a mean height lower than 50 cm.

With these values and a homogeneous distribution of the regeneration of the stand, as it happens in San Fitoiro, which in the three types of canopy cover has higher densities than 1 seedling/m^2 (Fig. 7), we could say that the initial establishment of the regeneration is adequate. For the others, we cannot say the values of regeneration are enough, as, although in Taboadelo and Fraga das Saímas they reach values of 2 seedlings/m^2, the regeneration is not homogeneously distributed as, for instance, in the case of Taboadelo, under clearing, or in Fraga das Saímas, under closed canopy, they do not reach 1 seedling/m2.

3.5 Quantification and analysis of the acorns production

The acorns in San Fitoiro and Fragas do Eume have a similar size, with a mean dry weigh of 0,59 and 0,54 respectively (Table 7). The biggest ones were found in Taboadelo, with almost 2 g in dry. In this stand, was also collected the highest number, around 160000 acorns/ha opposite to the 70000 in San Fitoiro and the 40000 seedlings/ha in Fragas do Eume. According to MATIC (1996), to get a successful natural regeneration, the number of acorns/ha must be around 160000, it means, near 800 Kg/ha. So, under natural conditions, it will approximately germinate a percentage between 20-30 %, so the density will be 40000 seedlings/ha, which corresponds with the values obtained in Taboadelo, so it could be predicted a good future regeneration in this stand.

Table 7. Number, longitude, diameter and dry weight acorn mean values by forest

FOREST	Acorn ner / ha	Longitude (mm)	Diameter (mm)	Dry weight (g)
FRAGAS DO EUME	40.000	13,43	10,75	0,54
TABOADELO	160.000	23,32	13,26	1,96
SAN FITOIRO	70.000	12,89	10,21	0,59

In Fraga das Saímas no acorns were found, although this can be because the oak is a mast fruiting species and the abundant crops usually happen within intervals of time of 3 to 5 years which even reach 10, besides the presence of cattle (JOHNSON *et al.*, 2002; BARRIO et al., 2003).

4. Conclusions

Within the four studied stands, the one which presented the best conditions for the establishment of the seedlings was the oakland of San Fitoiro. The higher stand density of this forest provides shade conditions, which resulted to be a key point for the germination of the acorns and, in their later development, to achieve an abundant natural regenerated under the tree canopy. The lack of cattle, was also a factor which contributed to the success of the initial establishment of the seedlings. On the contrary, in Taboadelo and Fragas do Eume, with a clear lower density of stems, the germination values obtained were lower, which were accentuated in Fragas do Eume, where there was a higher cattle pressure and an important presence of wild herbivores.

The most abundant acorn production, in number as in size, was found in the oakland of Taboadelo, as this is a less dense stand and more mature, with favourable light conditions to achieve a greater fruit production. The seedlings developed under clearings showed better development, once established, thanks to the greater luminosity existent in these canopy gaps. Fraga das Saímas together with the oakland of San Fitoiro showed a similar tendency in terms of seedlings height, reaching higher heights in the gaps with regard to the areas under closed canopy.

This work has provided the initial analysis of the evolution of the natural regeneration of *Quercus robur* in different stands of this species in Galicia, which will be useful for the knowledge of the establishment process of the saplings in these ecosystems.

The monitoring of the plots already established, through the re-measurement of the seedlings and the evaluation of the closing systems against herbivores, recently installed, will let us quantify the regeneration growth, as well as estimating the possible damages made by cattle or wild fauna. This subsequently monitoring, will also let us evaluate if the shade conditions which initially favoured the installation of the seedlings, would fit the best for the future development of them, in accordance with the tolerance of the species aimed to study.

Acknowledgements

This work is being financed by Xunta de Galicia, within the investigation project (07MRU046291PR), passed by Consellería de Innovación e Industria on the 13 November 2007 (DOGA of 14 November 2007).

References

Aussenac, G. 1975. Étude des relations climat-régéneration du chêne dans la region de Nancy de 1865 a 1972. Rev. For. Fr. XXVII: 37−38.

Barrio, M., Diaz-Maroto, I.J., Alvarez, J.G.; Vila-Lameiro, P. 2003. El problema de la regeneración natural de los robles caducifolios y marcescentes en el noroeste de España. Cuad. Soc. Esp. Cien. For. 15: 95−100.

Barrio, M. 2003. Crecimiento y producción de masas naturales de *Quercus robur* L. en Galicia. Tesis doctoral (inéd.). Escuela Politécnica Superior, Univesidad de Santiago de Compostela. 254 pp. Lugo.

Bruciamacchie, M., Grandjean, F., Jacobée, F. 1994. Installation de régénerations feuillues dans de petites truées en peuplements irréguliers. Rev. For. Fr. XLVI: 639−653.

Cao, R. 2001. Curso de postgrado de estadística aplicada. Módulo 4: Análisis multivariante. Departamento de Matemáticas. Universidad de A Coruña.
Diaci, J., Gyoerek, N., Gliha, J., Nagel, T. 2008. Response of *Quercus robur* L. seedlings to north-south asymmetry of light within gaps in floodplain forests of Slovenia. Ann. For. Sci. 65: 105p1−105p8.
Diaz, M., Pulido, F., Moller, A. 2004. Herbivore effects on developmental instability and fecundity of holm oaks. Oecología 139: 224−234
Diaz-Maroto, I.J. 1997. Estudio ecológico y dasométrico de las masas de carballo (*Quercus robur* L.) en Galicia. Tesis doctoral (inéd.). Escuela Técnica Superior de Ingenieros de Montes. Universidad Politécnica de Madrid. 607 pp. Madrid.
Diaz-Maroto, I.J., Vila-Lameiro, P., Silva-Pando, F.J. 2005. Autoecology of oaks (*Quercus robur* L.) in Galicia (Spain). Ann. For. Sci. 62: 737−749.
Dobrowolska, D. 2008. Effect of stand density on oak regeneration in flood plain forests in Lower Silesia, Poland. Forestry 81: 511 − 523.
Guitian Rivera, L. 1993. Sistemas de utilización del espacio y evolución del paisaje vegetal en las Sierras Orientales de Lugo. En: Pérez Alberti, A., Guitian Rivera, L., Ramil, P. (eds.): La evolución del paisaje en las montañas del entorno de los Caminos Jacobeos. Cambios ambientales y actividad humana: 211–225. Xunta de Galicia. Santiago de Compostela.
Harmer, R., Boswell, R., Robertson, M. 2005. Survival and growth of tree seedlings in relation to changes in the ground flora during natural regeneration of an oak shelterwood. Forestry 78: 21-32.
Hamer, R. and Morgan, G. 2007. Development of *Q. robur* advance regeneration following canopy reduction in an oak woodland. Forestry 80: 137−149.
Jarvis, P. 1964. The adaptability to light intensity of seedlings of *Quercus petraea*. J. Ecol., 52: 545−571.
Johnson, P.S., Shifley, S.R., Rogers, R. 2002. The ecology and silviculture of oaks. CABI Publishing. 489 pp. Wisconsisn.
Lopez-Carrasco, C., Muñoz, T., Daza, A., Rey, A., Lopez, C. 2005. Variaciones inter e intraanuales de la calidad de bellotas de encina en una dehesa de Castilla-La Mancha. Producciones agroganaderas: Gestión eficiente y conservación del medio natural I. Albacete.
Lüpke, B.v. 1998. Silvicultural methods of oak regeneration with special respect to shade tolerant mixed species. For. Ecol. Manage., 106: 19-26.
Maccarthy, J. 2001. Gap dynamics of forest trees: A review with particular attention to boreal forests. Environ. Rev. 9: 1–59.
Madrigal Collazo, A., Álvarez González, J.G., Rodríguez Soalleiro, R., Rojo Alboreca, A. 1999. Tablas de producción para los montes españoles. Fundación Conde del Valle Salazar. Madrid. 253 pp.
Mcevoy, P.M., McAdam, J.H., Mosquera-Losada, M., Rigueiro-Rodríguez, A. 2006. Tree regeneration and sapling damage of pedunculate oak *Quercus robur* in a grazed forest in Galicia, NW Spain: A comparison of continuous and rotational grazing systems. Agroforestry Systems. 66(2): 85-92.PONS, J.

and Pausas, J.G. 2007. Not only size matters: Acorn selection by the European jay (*Garrulus glandarius* L.). Acta Oecol. 31: 353–360.

Parde, J. 1961. Dendrométrie. École Nationale des Eaux et Forêts. Nancy. France.

Pulido, F. 2002. Biología reproductiva y conservación: el caso de la regeneración de bosques templados y subtropicales de robles (*Quercus* spp.). Rev. Chil. Hist. Nat. 75: 5–15.

Rentch, J.S, Fajvan, M.A., Hicks, R.R. 2003. Oak establishment and canopy accession strategies in five old-growth stands in the central hardwood forest region. For. Ecol. Manage. 184: 285−297.

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.

SAS-STAT™. 1990. User's guide. Release 6. Fourth Edition. Sas Institute Inc. Cary. NC. Estados Unidos de América.

Silva-Pando, F.J. and Rigueiro, A. 1992. Guía das árbores e bosques de Galicia. Ed. Galaxia. Vigo. 294 pp + anexos.

Serrada, R. 2005. Apuntes de Selvicultura II. Escuela Universitaria de Ingeniería Técnica Forestal. Universidad Politécnica de Madrid. Madrid.

Solymos, R. 1993. Improvement and silviculture of oaks in Hungary. Ann. For. Sci. 50: 607−614.

Tiscar, P.A. 2003. El papel de las aves y otros animales en la dispersión del género *Quercus* y arbustos de fruto carnoso en el interior de las repoblaciones de pino. Montes 74: 31–35.

Xunta de Galicia, 2001. O monte galego en cifras. Dirección Xeral de Montes e Medio Ambiente Natural.

Abstract.

Characterization of natural regeneration in stands of carballo (*Quercus robur* L.) in Galicia (NW Spain): relation to topography, climate and soil.

In this work, the regeneration, seed production and stand characteristics of four *Quercus robur* L. stands in Galicia have been studied. The results obtained suggest that the youngest and densest stand, San Fitoiro, presents more suitable conditions for the establishment of saplings, both in number and height. Generally, there are a greater number of seedlings under closed canopy, while the seedlings established in clearings have higher average height.

Key words: Natural regeneration; acorns; *Quercus robur*; silviculture; Galicia

Rodriguez-Campos, A., Diaz-Maroto, I. J., Barcala-Perez, E., Vila-Lameiro, P.
Agroforestry Engineering Department (University of Santiago de Compostela Escuela Politecnica Superior : Campus Universitario s/n ; 27002- Lugo, Spain.
pablo.vila.lameiro@usc.es