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Regeneration in multi-species in Serra da Lousã

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Abstract

Stand regeneration is one of the most important aspects of silviculture as it ensures stand and production perpetuity. Regeneration occurs after one or several disturbances releasing growing space, usually after the elimination of some adult trees. In Northern and Central Portugal many maritime pine old growth stands have natural regeneration of several broadleaved species, in particular sweet chestnut and English oak. In multi-species stands regeneration and recruitment analysis should consider both density and diversity measures. A series of permanent plots established in Serra da Lousã made it possible to characterise the existing natural regeneration and its evolution with two successive measurements in 2001 and 2009. All individuals with a diameter at breast height equal or less than 5 cm were considered as regeneration. Their recruitment was evaluated in 2009 and analysed as a function of absolute stand density measures and seven diversity indices. The results revealed that recruitment rate was high and that there was a trend towards a balance in terms of species and their proportions, while maintaining a tendency towards clustering and segregation according to the Clark and Evans and the Pielou indices, respectively.

Key words: regeneration; recruitment; multi-species stands; diversity; high forest.

Resumen

Regeneración en bosques mixtos en la Serra da Lousa

La regeneración del rodal es uno de los aspectos más importantes de la silvicultura, ya que garantiza la perpetuidad del rodal y de la producción. La regeneración se produce después de uno o varias intervenciones para liberar el espacio de crecimiento, generalmente después de la eliminación de algunos árboles adultos. En el norte y centro de Portugal muchos rodales de pino negral de edad madura presentan regeneración natural de varias especies de frondosas, en particular, castaño y roble. En rodales con varias especies el análisis de la regeneración y el reclutamiento debe tener en cuenta medidas tanto de densidad como de diversidad. Una serie de parcelas permanentes establecidas en la Serra da Lousã ha permitido caracterizar la regeneración natural existente y su evolución con dos mediciones sucesivas en 2001 y 2009. Se consideran como regenerado todos los individuos con un diámetro a la altura del pecho igual o inferior a 5 cm. Su reclutamiento se evaluó en 2009 y se analizó en función de medidas de la densidad absoluta de la masa y de siete índices de diversidad. Los resultados revelaron que la tasa de reclutamiento fue alta y que hubo una tendencia hacia un equilibrio en términos de especies y sus proporciones, mientras se mantiene una tendencia a la agrupación y segregación de acuerdo con los índices de Clark y Evans y el índice de Pielou, respectivamente.

Palabras clave: regeneración; reclutamiento; rodales multi-específicos; diversidad; bosque.

Introduction

Stand regeneration is one of the most important aspects of silviculture as it ensures stand and production perpetuity. Regeneration occurs after one or several disturbances releasing growing space, usually after the elimination of some adult trees. Regeneration mechanisms can be of two main types: by seed or vegetative (Smith *et al.*, 1997; Oliver e Larson, 1996).

The different types of natural regeneration, though not exclusive, are associated to the stand regime. Vegetative regeneration is usually associated to coppices, though it can also occur in high forest stands: for example sweet chestnut can produce coppices when the aerial part is destroyed by animals or due to other

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natural or human events. Seed regeneration is more frequent in high forest stands, though it can occur to a lesser extent in coppices (Fabião, 1996; Oliver e Larson, 1996; Alves, 1988; Lanier *et al.*, 1986; Natividade, 1950).

According to Harmer (1994a,b, 1995) there has been a renovated interest in natural regeneration as a method for stand establishment. Several authors (Piussi, 1994; Davis and Johnson, 1987; Ayanz, 1986; Lanier *et al.*, 1986) state that natural regeneration is an interesting restocking method, from the economically, silviculturaly and ecologically point of view. This type of regeneration is especially important in ecologically sensitive areas and/or zones with of great landscape value, where the visual impact has to be considered.

Evans (1988) states that, in silvicultural terms, the reasons for the interest in natural regeneration are: its capacity to occupy small areas, protection of natural regeneration by adult trees and as a potential source of species different from the existing main species. In addition, natural regeneration has many possibilities of becoming efficient through time, due to multiple seed productions, especially if favoured by adequate silvicultural practices (McDonald and Abbott, 1994; Ayanz, 1986).

Many references can be found about regeneration processes and conditions (Kathke and Bruelheide, 2010; Barja *et al.*, 2009; Maltez-Mouro *et al.*, 2009; Kabrick *et al.*, 2008; Darabant *et al.*, 2007; Oliver, 2007; Bolte and Villanueva, 2006; Paluch, 2005; Oliver, 2003; Rozas, 2002; Page *et al.*, 2001; Burschel *et al.*, 1992) as well as to stand diversity analysis (Ruprecht *et al.*, 2010; Graz, 2004; Pommerening, 2006; Pommerening, 2002; Pretzsch, 1998).

The goal of this study is to analyse absolute stand density measures and diversity of regeneration and recruitment, in maritime pine (*Pinus pinaster* Aiton.) old growth stands with natural regeneration of several broadleaved species, in particular sweet chestnut (*Castanea sativa* Miller.) and English oak (*Quercus robur* L.).

Material and methods

Data

Serra da Lousã is a mountainous range (40° 04' 51" N and 8° 14' 44" W) about 250 km northeast of Lisbon. This forest area is mainly composed of maritime pine (*Pinus pinaster* Aiton.) stands, pure about 12.1% of the total area and mixed with sweet chestnut (*Castanea sativa* Miller), about 40.1% of the total area. Other softwood and hardwood species are also present in pure or mixed stands, namely Douglas fir (*Pseudotsuga menziesii* Franco.), Mexican cypress (*Cupressus lusitanica* Miller.), Lawson cypress (*Chamaecyparis lawsoniana* Parl.), English oak (*Quercus robur* L.), red oak (*Quercus rubra* L.), wild cherry (*Prunus avium* L.), beech (*Fagus sylvatica* L.) and Tasmanian blue gum (*Eucalyptus globulus* Labill.) (Gonçalves, 2003).

Mixed maritime pine and sweet chestnut stands are characterised by old growth maritime pine trees in the superior and intermediate layers and several broadleaved and softwood species of natural regeneration in the intermediate and inferior layers, especially sweet chestnut and English oak. The stands are high forest, but some coppices are also present, mainly of sweet chestnut (Gonçalves, 2003).

The data set is composed of 8 plots, situated in the mixed maritime pine and sweet chestnut stands, with the characteristics shown in Table 1. In these plots, dendrometric parameters of all the trees, namely diameter at breast height, total height and crown radii in 4 directions (North, South, East and West) were measured in 2001 and 2009, and the coordinates were registered in 2001.

After the first measurement, cuttings were carried out, in order to promote a transformation process towards the increase of broadleaved species. The selection cuttings, of low intensity, removed mainly maritime pine individuals. The best poles of sweet chestnut coppices, namely straight stems, vigorous crowns and those with expected high growth rates were selected to be maintained and the other poles were removed. As the stand density and diversity measures did not showed significant differences (Wilcoxon test for a significance level of 0.05) before and after the cuttings, the effect of the cuttings has been considered not to affect the analysis.

Methods

The main stand was defined as all individuals with greater than 5 cm diameter at breast height. As all trees were measured in 2001 it was possible to evaluate the recruitment in 2009, that is the individuals that attained a diameter at breast height greater than 5 cm in 2009.

Table 1. Plot characterisation

Plot	Area (m^2)	Species	Altitude (m)	Slope (%)
17C1	1,200	Pb, Ct, Cr	868,1	21,6
20C1	1,225	Pb, Ct, Cr	701,5	26,2
23A1	1,200	Pb, Ct, Cr, Cam, Fg, Cn	641,9	17,0
24B2	1,200	Pb, Ct, Cr	807,3	12,2
25B2	1,320	Pb, Ct, Cr	614,3	16,4
27B2	1,200	Pb, Ct, Cr	650,0	0,0
29A1	1,225	Pb, Ct, Cr, Sb	477,4	28,9
29A2	1,200	Pb, Ct, Cr, Ac, Pt, Md, Cla	549,7	17,8

Pb: maritime pine. Ct: sweet chestnut. Cr: English oak. Cla: Lawson cypress. Sb: cork oak. Pt: Douglas fir. Cam: red oak. Cn: Pyrenean oak. Md: strawberry tree. Ac: mimosa. Fg: alder buckthorn.

The recruitment was analysed as a function of absolute density parameters: number of trees per hectare (N), basal area per hectare (G) and ground cover (GC), the latter calculation assuming the crown has a circular projection whose radius is the arithmetic mean of the four measured crown radii. To evaluate diversity seven diversity indices (Table 2) were used to characterize the horizontal and spatial distribution of the individuals in multi-species stands (Gilliam, 2002; Neumann and Starlinger, 2001; Staudhammer and Lemay, 2001; Biber and Weyerhaeuser, 1998).

The absolute density measures and the diversity indices for regeneration, in 2001, and recruitment, in 2009, as well as for the main stand, in 2001, were statis-

Table 2. Diversity indices

Name	Acronym	Formula	Diversity measure	Target population
Species richness	RS	$RS = \sum_{i=1}^{K} Sp_i$	Horizontal	Stand
Relative density	RD_i	$RD_i = \frac{N_i}{N} \times 100$	Horizontal	Species
Relative basal area	RBA_i	$RBA_i = \frac{G_i}{G} \times 100$	Horizontal	Species
Simpson index	D	$D = \sum_{i=1}^{N} \left(\frac{N_i (N_i - 1)}{N (N-1)} \right)$	Horizontal	Stand
Shannon and Weaver index	H	$H = -\sum_{i=1}^{k} p_i \times \ln p_i$	Horizontal	Stand
Clark and Evans aggregation index	R_i	$R_i = \frac{\bar{r}_{obs}}{\bar{r}_{\exp}}$	Spatial distribution	Species
Pielou segregation index	S_i	$S_i = 1 - \frac{N(b+c)}{(vn+wm)}$	Spatial distribution	Species

Sp_i: specie i. N_i: number of individuals of specie i. N: total number of individuals. G_i: basal area of specie i. G: total basal area. p_i: probability of an individual belonging to k^{th} specie. r_{obs}: average observed distance of a tree to its nearest neighbour. r_{esp}: average expected distance to the nearest neighbour. m: total number of pairs of trees of specie 1. n: total number of pairs of trees of specie 2. b and c number of pairs whose nearest neighbour is of a different species, a and d number of pairs whose nearest neighbour is of the same species, v = a + c, w = b + d.

tically compared with the non parametric Wilcoxon test (Maroco, 2007) with the SPSS (version 18.0 for Windows) for a significance level of 0.05.

Results

Natural regeneration was found for the following plant species: maritime pine, sweet chestnut, English oak, red oak, wild cherry, Pyrenean oak (*Quercus pyrenaica* Willd.), cork oak (*Quercus suber* L.), alder buckthorn (*Frangula alnus* Miler.), strawberry tree (*Arbutus unedo* L.), acacia (*Acacia* sp.), Douglas fir and Lawson cypress.

Analysis of the density measures considered the three main species in the mixture while all the other individuals were grouped under the «other» class (Table 3). This was because their numbers were too small and would lead to a biased analysis, especially with regard to the spatial diversity indices. More than half of the regeneration individuals were recruited to the main stand in 2009. Maritime pine and English oak, though the latter in a smaller proportion, had a high rate of recruitment, in the plots with lower crown cover or where their regeneration was located in gaps, which corresponds well to the shade intolerant behaviour of these species, with statistically significant differences for maritime pine (exact 1-sided p value of 0.08) but not for English oak. Sweet chestnut, being a shade tolerant species, had high rates of recruitment in all plots. From 2001 to 2009 the individuals of this species were able to overcome the competition and increased

Table 3. Number of trees per hectare (N), basal area per hectare (G) and crown cover (GC)

Plot	Species	N			G (m^2)			GC (%)		
		Reg01	Reg09	Rec	Reg01	Reg09	Rec	Reg01	Reg09	Rec
17C1	Pb	75	17	58	0.10	0.03	0.26	0.80	0.25	1.24
	Ct	142	25	117	0.14	0.04	0.58	1.01	2.47	13.65
	Cr	67	34	33	0.07	0.04	0.09	0.61	0.70	1.89
20C1	Pb	16	16	0	0.03	0.03	0.00	0.00	0.38	0.00
	Ct	302	73	229	0.29	0.11	0.98	2.04	4.96	28.85
	Cr	82	17	65	0.07	0.03	0.26	1.59	1.65	7.34
	Other	33	9	24	0.09	0.01	0.14	0.00	1.99	6.25
23A1	Pb	25	17	8	0.02	0.02	0.02	0.28	0.16	0.09
	Ct	58	0	58	0.08	0.00	0.25	5.73	0.00	23.49
	Cr	50	33	17	0.07	0.05	0.05	2.60	1.14	0.61
	Other	50	9	41	0.07	0.02	0.14	3.80	3.37	6.41
24B2	Pb	133	66	67	0.14	0.09	0.26	1.66	0.46	1.91
	Ct	100	50	50	0.06	0.08	0.16	3.23	3.49	4.45
	Cr	17	17	0	0.01	0.03	0.00	0.21	0.48	0.00
25B2	Pb	150	50	100	0.05	0.07	0.42	0.29	0.41	2.13
	Ct	42	0	42	0.03	0.00	0.21	1.31	0.00	18.94
	Cr	25	0	25	0.02	0.00	0.06	1.03	0.00	1.73
	Other	16	0	16	0.02	0.00	0.19	0.44	0.00	0.97
27B2	Pb	133	50	83	0.08	0.08	0.32	1.44	0.48	1.79
	Ct	50	25	25	0.04	0.04	0.09	1.40	0.47	2.50
29A1	Pb	359	163	196	0.24	0.24	0.69	0.62	2.85	5.84
	Ct	457	245	212	0.31	0.30	0.76	11.38	11.52	28.86
	Cr	16	0	16	0.02	0.00	0.04	0.88	0.00	1.78
	Other	41	8	33	0.04	0.01	0.12	1.84	0.15	3.58
29A2	Pb	808	300	508	0.82	0.47	1.66	1.35	3.09	7.27
	Ct	58	8	50	0.06	0.01	0.25	1.19	0.13	10.62
	Cr	50	17	33	0.04	0.02	0.09	0.26	0.54	1.83
	Other	33	0	33	0.08	0.00	0.15	0.38	0.00	2.99

Pb: maritime pine. Ct: sweet chestnut. Cr: English oak. Reg01: regeneration in 2001. Reg09: regeneration in 2009. Rec: recruitment.

Table 4. Species richness (RS) and species

Plot	Regeneration in 2001		Recruitment in 2009	
	RS	**Species**	**RS**	**Species**
17C1	4	Pb, Ct, Cr, Fg	3	Pb, Ct, Cr
20C1	4	Pb, Ct, Cr, Cam	4	Pb, Ct, Cr, Cam
23A1	6	Pb, Ct, Cr, Cb, Fg, Cn	5	Pb, Ct, Cr, Cb, Fg
24B2	5	Pb, Ct, Cr, Pt, Fg	3	Pb, Ct, Cr
25B2	5	Pb, Ct, Cr, Ac, Sb	5	Pb, Ct, Cr, Ac, Sb
27B2	5	Pb, Ct, Cr, Fg, Sb	2	Pb, Ct
29A1	6	Pb, Ct, Cr, Cam, Cb, Sb	4	Pb, Ct, Cr, Cam
29A2	9	Pb, Ct, Cr, Cam, Ac, Pt, Fg, Md, Cla	6	Pb, Ct, Cr, Cam, Ac, Md

Pb: maritime pine. Ct : sweet chestnut. Cr: English oak. Cla: Lawson cypress. Cb: wild cherry. Sb: coak oak. Pt: Douglas fir. Cam: red oak. Cn: Pyrenean oak. Md: strawberry tree. Ac: acacia, Fg: alder buckthorn.

their growing space and had diameter growth rates that allowed their recruitment to the main stand, with statically significant differences of regeneration in relation to recruitment (exact 1-sided p value of 0.016).

In basal area, there was a considerable increase for the three species, maritime pine, sweet chestnut and English oak, corresponding to an annual mean increment of 0.43 cm, 0.51 cm and 0.35 cm, respectively, as confirmed by the significant differences between regeneration and recruitment (exact 1-sided p values of 0.016, 0.04 and 0.047, respectively). The same trend was observed for crown cover with an annual crown radius increment of 0.11 m and 0.31 m, respectively for maritime pine and sweet chestnut, showing significant differences for these two species (exact 1-sided p values of 0.016 and 0.004), but not for English oak with a more moderate increment in crown radius, of 0.08 m.

Species richness (RS) of regeneration varies between 4 and 9 and that of recruitment between 2 and 6 (Table 4). Maritime pine and sweet chestnut are present in all plots, English oak in seven, and the other species are present in one two or three plots. The changes that have occurred in the number of species reflect the fact that either the species did not overcome competition pressure and, consequently, were not recruited (English oak in plot 24B2 and 29B1), or were present with a very limited number of individuals that did not survived (for example, Pyrenean oak, Douglas fir and Lawson cypress).

For relative density (RD) and relative basal area (RBA) no clear trend between regeneration and recruitment was found. This is in conformity with the fact that no significant differences were detected, as it could be expected, considering the proportions of the different species.

Simpson index (D) increased where there was a balanced number of recruited individuals per species (Table 6). The opposite was observed in plots 25B2 and 29A2 where the number of recruited maritime pine

Table 5. Relative density (RD) and relative basal area (RBA)

Plot	RD								RBA							
	Pb		**Ct**		**Cr**		**Other**		**Pb**		**Ct**		**Cr**		**Other**	
	Reg	**Rec**	**Reg**	**Rec**	**Reg**	**Rec**	**Reg**	**Rec**	**Reg**	**Rec**	**Reg**	**Rec**	**Reg**	**Rec**	**Reg**	**Rec**
17C1	26.5	28.0	50.0	56.0	23.5	16.0			27.3	27.5	62.7	62.7	12.8	9.8		
20C1	3.8	0.0	69.8	71.8	18.9	20.5	7.6	7.7	1.7	0.0	70.0	71.0	18.5	18.9	9.8	10.1
23A1	13.6	6.7	31.8	46.7	27.3	13.3	27.3	33.3	7.5	4.3	45.6	54.2	18.0	10.7	28.9	30.9
24B2	53.3	57.1	40.0	42.9	6.7	0.0			56.7	62.4	38.7	37.6	4.7	0.0		
25B2	64.3	54.6	17.9	22.7	10.7	13.6	7.1	9.1	51.4	47.8	22.2	23.8	6.7	7.2	19.7	21.2
27B2	72.7	76.9	27.3	23.1					76.1	78.6	23.9	21.4				
29A1	41.1	42.9	52.3	46.4	1.9	3.6	4.7	7.1	43.2	43.1	49.1	47.1	2.0	2.7	5.7	7.2
29A2	85.1	81.3	6.1	8.0	5.3	5.3	3.5	5.3	80.1	77.2	9.9	11.6	4.3	4.2	5.7	7.0

Pb: maritime pine. Ct: sweet chestnut. Cr: English oak. Reg: regeneration. Rec: recruitment.

Table 6. Simpson index (D), Shannon and Weaver index (H), Clark and Evans aggregation index (R) and Pielou segregation index (S)

Plot	D		H		R						S					
					Pb		Ct		Cr		Pb		Ct		Cr	
	Reg	Rec	Reg	Rec	Reg	Rec	Reg	Rec	Reg	Rec	Reg	Rec	Reg	Rec	Reg	Rec
17C1	0.39	0.43	1.04	0.97	0.49	0.47	0.34	0.32	0.45	0.30	0.92	0.94	0.61	0.68	0.70	0.85
20C1	0.55	0.58	0.88	0.76	0.44		0.04	0.01	0.51	0.55	0.00		0.80	0.85	0.85	0.88
23A1	0.25	0.31	1.46	1.34	0.22	0.06	0.39	0.39	0.61	0.42	1.00	1.00	0.75	0.75	1.00	1.00
24B2	0.45	0.54	0.89	0.68	0.87	0.53	0.51	0.36	0.12		–0.06	0.47	0.08	0.54	0.86	
25B2	0.47	0.38	1.07	1.22	0.66	0.51	0.66	0.66	0.42	0.42	0.69	0.80	0.84	0.84	0.84	0.84
27B2	0.63	0.68	0.58	0.54	0.37	0.32	0.11	0.10			1.00	1.00	1.00	1.00		
29A1	0.45	0.41	0.92	1.03	0.38	0.30	0.41	0.29	0.11	0.11	0.80	0.89	0.57	0.80	0.96	0.96
29A2	0.73	0.68	0.61	0.75	0.81	0.67	0.35	0.35	0.22	0.16	0.01	0.38	0.90	0.92	0.94	0.96

Pb: maritime pine. Ct: sweet chestnut. Cr: English oak. Reg: regeneration. Rec: recruitment.

individuals was much higher than that of the other species, and in plot 29A1 where the number of maritime pine and sweet chestnut accounted for 80% of the recruited individuals. For the Shannon and Weaver index (H) the opposite was observed. In the plots where the proportions of maritime pine and/or sweet chestnut increased (see Table 5), there was a reduction of this index. The similarity of species' proportions in regeneration and recruitment might explain the non statistical differences.

Clark and Evans aggregation index (R) shows that the three species have a tendency towards a cluster distribution (Table 6), indicating that the distances between their individuals are smaller than expected according to the Poisson distribution. The Pielou segregation index (S) shows a tendency towards segregation, for the three species, indicating that the nearest neighbours of an individual belong to the same species, except for the regeneration of maritime pine in plot 24B2 that had a tendency towards intermingling or association. The reduction of the value of Clark and Evans aggregation index and the increase of the Pielou index for maritime pine in recruitment indicates a higher tendency towards clustering, with statistically significant differences (exact 1-sided p values of 0.008 and 0.031, respectively). In fact, seed dispersal, germination and early survival are constrained by the climate, site and seed trees (*e.g.* Oliver e Larson, 1996; Lanier *et al.*, 1986). Although maritime pine has a light seed and germinates well, its survival is determined by the presence of direct sunlight. The presence of sweet chestnut in the inferior and intermediate layers, leads to sparse survival of maritime pine in shaded conditions. On the other hand, all plots had canopy gaps where the maritime pine recruited individuals were mainly located, that is in clusters. Sweet chestnut and English oak seeds are heavy, so dissemination tends to take place in small patches close to the seed tree, unless animals transport the seeds to further away. This justifies their tendency towards clustering, even though their behaviour is different. Sweet chestnut has an even more marked tendency towards clustering due to its natural ability to produce coppices (observed in all the plots) and because its early development is not limited by direct sunlight, as it is a shade tolerant species. The faster growth of the dominant poles reducing the number of poles per coppice in the recruitment as well as the cuttings might explain the significant differences in relation to regeneration for both indices (exact 1-sided p values of 0.031 and 0.031, respectively). English oak is a shade intolerant species whose seedlings' initial development occurs when sunlight is not a limiting factor. The fact that these individuals are mainly located in the canopy gaps might explain the non significant differences between regeneration and recruitment.

The main stand in 2001 (see Gonçalves *et al.*, 2010) was compared with both regeneration and recruitment. In regeneration and recruitment a reduction of the proportion of maritime pine and an increase in sweet chestnut can be observed with statistically significant differences for relative density and relative basal area (exact 1-sided p values of 0.004, 0.004, 0.004, 0.004, 0.008, 0.008, 0.004, 0.004, respectively) and for relative basal area for English oak regeneration (exact 1-sided p value of 0.023). The statistically significant differences between the main stand, in 2001, and regeneration and recruitment are also reflected in the Simpson and the Shannon and Weaver indices (exact 1-sided p values of 0.012, 0.008, 0.004 and 0.004) revealing that the probability for two randomly individuals belonging to the same species and the probability of one individual of the k^{th} species belonging to the k^{th} species, respectively, is smaller for the younger individuals.

In the main stand maritime pine has a tendency towards regular distribution, due to its uniform special distribution, while sweet chestnut has a tendency towards clustering mainly due to coppicing (Gonçalves *et al.*, 2010). Regarding the spatial distribution indices, the Clark and Evans index showed a higher tendency towards clustering in regeneration and recruitment than in the main stand for maritime pine (exact 1-sided p values of 0.008 and 0.008) and the Pielou index presented a higher tendency towards segregation in regeneration for sweet chestnut (exact 1-sided p value of 0.012) and in recruitment for maritime pine and sweet chestnut (exact 1-sided p values of 0.039 and 0.012, respectively). The increased tendency towards clustering in regeneration and recruitment is due to the spatial distribution of the niches without light constraints for maritime pine and is mainly caused by the number of poles per coppice for sweet chestnut.

Discussion

Recruitment and natural regeneration individuals occur in all plots for all species, except in plot 20C1 for maritime pine and in plot 24B2 for English oak. The species' spatial distribution vary with the species' shade tolerance: maritime pine and English oak individuals are mainly located in niches with full sunlight, as opposed to sweet chestnut which does not seem to show a clear trend. Several authors (*e.g.* Maltez-Mouro *et al.*, 2009; Oliver, 2007; Paluch, 2005; Rozas, 2002) have detected a similar spatial distribution pattern according the species' shade tolerance: the intolerant species are located in canopy gaps while tolerant ones are found under the canopy of the main stand.

In recruitment the species proportions showed a trend towards a transformation in stand composition. In the main stand, maritime pine has a relative density varying between 52% and 92% in 2001 and in 2009, respectively, and a relative basal area was greater than 90% in both measurements (Gonçalves *et al.*, 2010). Recruitment shows more balanced proportions, both for relative density and for relative basal area, revealing the ability of natural regeneration to occupy small areas and different niches, as referred to by Evans (1988). The Simpson and the Shannon and Weaver indices for recruitment show a trend towards higher diversity than they do in the main stand, due to the increase in the number of the two broadleaved species. The Clark and Evans index indicates a clustering tendency and the Pielou index a tendency towards segregation, due to the canopy gap and the different species' shade tolerance and coppicing. Enhancement of diversity observed in recruitment is reflected in the main stand, in the second measurement, in 2009 (for details see, Gonçalves *et al.*, 2010).

The individuals of the other recruited species, in spite of their small proportion in 2009, can also contribute towards increasing stand diversity in the future. However, acacia though with a small number of individuals in plots 25B2 and 29A2, should be removed, as it is an invasive species in Portugal.

Analysis of natural regeneration development and recruitment with density and diversity measures in multi-species stands makes it possible to obtain further detail with regard to the proportions of the different species and their spatial distribution, especially relevant if the species have different shade tolerances.

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