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Land cover change and afforestation of marginal and abandoned agricultural land: A 10 year analysis in a Mediterranean region

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ABSTRACT

In Mediterranean countries land abandonment, the loss of traditional land-use systems and the action of fire are causing forests degradation, increasing erosion risk and desertification. The Rural Development Programme–Afforestation of Agricultural Land (RURIS–AAL) is an afforestation programme for marginal and abandoned agricultural land which intends to contribute to the rehabilitation of degraded lands and to mitigate the effects of desertification.

The study was conducted in a Mediterranean region under desertification risk. The goal of the study was twofold: (i) to explore the main drivers of land cover change and the impact of RURIS–AAL on both agriculture area loss and on native oaks area recovery and (ii) to assess the appropriateness of the species used and the levels of afforestation success of RURIS–AAL from 2002 until 2011. The analysis was conducted through spatial analysis in a Geographical Information System and by statistical analysis using both nonparametric correlations and Categorical Principal Components Analysis (CATPCA).

The results proved that the study area's land cover change (2000–2006) was mainly due to forest fires and as result, a decrease in forest areas (ground cover higher than 30%) as opposed to an increase of open forests (ground cover between 10% and 30%), cuts and new plantations areas was observed. The impact of RURIS–AAL on agricultural area loss was found to be very weak (−1009 ha; −0.6%). The species used in RURIS–AAL were well selected in relation to theirs ecological zoning and the levels of afforestation success were high (76%). A total of 3363 ha were forested mainly with pure cork oak and mixtures of cork oak and holm oak (86%) which was very positive to recover oak forest area. Moreover, the CATPCA proved that the combination of the necessary biophysical conditions for each species together with the most appropriated procedures for stand establishment was verified in RURIS–AAL. High afforestation success rates were obtained for both pure cork oak stands (79%) and mixed stands of cork oak (89%), namely mixed umbrella pine and cork oak stands (95%).

Both species, cork oak and umbrella pine, are very well adapted to Mediterranean environments and offer non-wood products (cork and cone) of high market value which will both improve farm's multi-functionality and provide extra incomes in the long-term. These findings are important guidelines to be kept in consideration for successful afforestation in future programmes in Mediterranean regions.

1. Introduction

Land abandonment and the loss of traditional land-use systems are widespread in most of Mediterranean Europe. In the mid 1950s an increase of forested area in relation to the loss of semi-natural and agriculture area was observed in several Mediterranean countries such as Spain, Italy and Portugal. This occurred mainly in mountainous areas with a significant loss of agro-forestry ecosystems and the homogenisation of landscape patterns (Jones et al., 2011). Furthermore, during the last decades, fire has destroyed large forest areas in all Mediterranean countries causing its degradation and increasing erosion risk and desertification (Piussi and Farrell, 2000; FAO, 2013).

Forests are mentioned in all national plans for combating desertification (FAO, 2013). The Rural Development Programme–Afforestation of Agricultural Land (RURIS–AAL), is an afforestation programme for marginal and abandoned agricultural land, that intends to contribute to the rehabilitation of degraded lands and to mitigate the effects of desertification by favoring soil fertility recovery and ultimately for the diversification of farming activity reinforcing its multi-functionality. Both high quality and environmentally well adapted afforestations are promoted for high quality wood, cork and other non-timber product supply.

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In Portugal, the afforestation plan started back in 1931 and since 1986 several European Union (EU) programmes have been supporting Portuguese afforestation projects (Jones et al., 2011). As a result, the forested area has been increasing since then, from 7% in 1875 to 33% in 1965 and enlarging to 35% in 1985 to the current existing 39% (3.5 million ha). Currently, agriculture and scrubland areas correspond to 33% (3.1 million ha) and 22% (2.0 million ha), respectively (DGRF, 2006a; Mendes and Fernandes, 2007; AFN, 2010).

The main driving forces of Portuguese land cover change in the last two decades (1990–2006) have been due to the action of forest fires and both to the increase of abandonment agricultural land and the afforestation under investment. Regarding agricultural areas, non-irrigated arable land and agro-forestry areas have changed the most and have been often converted into new forest plantations (Painho and Caetano, 2006; Caetano et al., 2009; Jones et al., 2011).

Presently, according to the last National Forest Inventory in 2005–2006, the Portuguese forest is mainly composed of maritime pine (*Pinus pinaster* Aiton) (27%), eucalyptus (*Eucalyptus globulus* Labill.) (23%), cork oak (*Quercus suber* L.) (23%) and holm oak (*Quercus rotundifolia* Lam.) (13%). The remaining forest area is occupied by other oaks (e.g. *Quercus pyrenaica* Willd., *Quercus faginea* Lam. and *Quercus robur* L.), umbrella pine (*Pinus pinea* L.), chestnut (*Castanea sativa* Mill.), acacia (*Acacia* sp.), other broadleaves and other coniferous (AFN, 2010). Cork oak and holm oak belong to Portuguese oak native forest and afforestation programmes have positively favoured the use of this species however when analysing the National Forest Inventory data over the past 40 years (1963–2006) these species areas have not significantly increased (AFN, 2010).

To explore the main drivers of land cover change and the impact of RURIS–AAL afforestation programme on both agriculture area loss and on native oaks area recovery, a Mediterranean region of Portugal under desertification risk was used as a case study. The first hypothesis addressed in the study was that the main drivers for this regionś land cover change, in the period of 1990–2006, would both be due to the abandonment of agriculture land and the action of forest fires. However, it would be expected that the loss of agricultural area under the RURIS–AAL programme to have had a small impact on the overall change. The second hypothesis was that high success afforestation rates would be expected in RURIS–AAL programme as better soils are used, as well as appropriate selection of species and mixtures.

To test these hypotheses, the land cover change in the study area between 1990 and 2006 was first clarified, wherein a detail analysis for the period of 2000 to 2006 was performed to assess the impact of afforestation under the RURIS–AAL programme (2002–2007). Secondly, a detailed analysis of the RURIS–AAL programme was conducted in order to assess the appropriateness of the species used and the levels of afforestation success from 2002 until 2011. Two field monitoring moments were used: the first, at the end of the afforestation establishment stage (2002–2007) and the second, at the afforestation maintenance stage (2007–2011). Based on the data collected, during these two fields monitoring campaigns, afforestation success rates were assessed and possible causes were explored with respect to both the observed biophysical and the stand establishment conditions.

2. Methods

2.1. Study area

The region of Beira Interior Sul (BIS) (Fig. 1) includes four municipalities, Castelo Branco, Idanha-a-Nova, Penamacor and Vila Velha de Rodão comprising a total of 373,827 ha. These municipalities lie either on the border or inside the sub-humid climate area under desertification risk (Jones et al., 2011). Elevation ranges from 200 to 400 m in most parts of the study area. The higher elevations are located in the north-west and north-east (700–1300 m). Climatic data, referring to a 30 year period (1960–1990), indicates that the average annual rainfall ranges between 700 and 1200 mm in the majority of this region. Areas of less precipitation (500–600 mm) are located in the south-east as opposed to areas with higher precipitation (1200–1600 mm) located in the north-west. The average temperature lies between 7.5 °C and 16.0 °C, where the highest temperatures (15.0–16.0 °C) are observed at the centre and the coldest (7.5–10.0 °C) in the north-west. The most common soil types are eutric lithosols, distric cambisols, and hortic luvisolss. In a smaller proportion, humic cambisols, ferric luvisols and eutric cambisols are also observed (APA, 2007).

2.2. Land cover change analysis (1990–2006)

To assess the impact of the RURIS–AAL programme in the BIS region's land cover change, the CORINE land cover maps (CLC) for 1990, 2000 and 2006 (Painho and Caetano, 2006; Caetano et al., 2009) were used. The digital CLC maps were produced at a 1:100,000 scale using a minimum mapping unit (MMU) of 25 ha and a three-level classification system of 44 land cover classes (Caetano et al., 2009). The CLC classes (third classification level) observed and considered for analysis were the following: Artificial surfaces (1) – Discontinuous urban fabric (112), Industrial or commercial units (121), Road and rail networks and associated land (122), Dump sites (132), Construction sites (133), Sport and leisure facilities (142); Agricultural areas (2) – Non-irrigated arable land (211), Permanently irrigated land (212), Fruit trees and berry plantations (222), Vineyards (221), Olive groves (223), Pastures (231), Complex cultivation patterns (242), Land principally occupied by agriculture with significant areas of natural vegetation (243), Agro-forestry areas (244); Forests and semi-natural areas (3) – Broad-leaved forest (311), Coniferous forest (312), Mixed forest (313), Natural grasslands (321), Moors and heathland (322), Sclerophyllous vegetation (323), Transitional woodland-shrub (e.g. open forests, cuts and new plantations) (324); Burnt areas (334); Water bodies (5) – Water bodies (512) (Bossard et al., 2000).

The CLC maps were considered to obtain: "Forests" (311, 312 and 313; ground cover higher than 30%) versus "Transitional woodland-shrub" (324) – open forests (ground cover between 10% and 30%), cuts and new plantations – and to subdivide the category "Forests" in "Broad-leaved forest" (311), "Coniferous forest" (312) and "Mixed forest" (313). The annual burnt area maps, for the period of 1990–2010 (AFN, 2011), produced by the National Forest Authority were also used to get a better understanding of land cover change dynamics. The CLC change maps, for both 1990–2000 and 2000–2006 (Painho and Caetano, 2006; Caetano et al., 2009), combined with the annual burnt area map were used to assess the impact of forest fires on land cover change. ArcGis software (ESRI, 2004) was used for this spatial analysis. Since the RURIS–AAL programme has started to be applied in BIS region in 2002, a detail analysis for the period of 2000–2006 was conducted to evaluate the impact of this programme in the region's land cover change. Additionally, the National Forest Inventory statistics for 2005–2006 (AFN, 2010) were used to obtain species area.

2.3. Afforestation success analysis (2002–2011)

The recommend species for afforestation in BIS Regional Forest Management Plans (BIS RFMP) are mainly maritime pine, eucalyptus, cork oak and holm oak. Other oak species (e.g. *Quercus robur* L. and *Quercus pyrenaica* Willd.), chestnut (*Castanea sativa* Mill.),

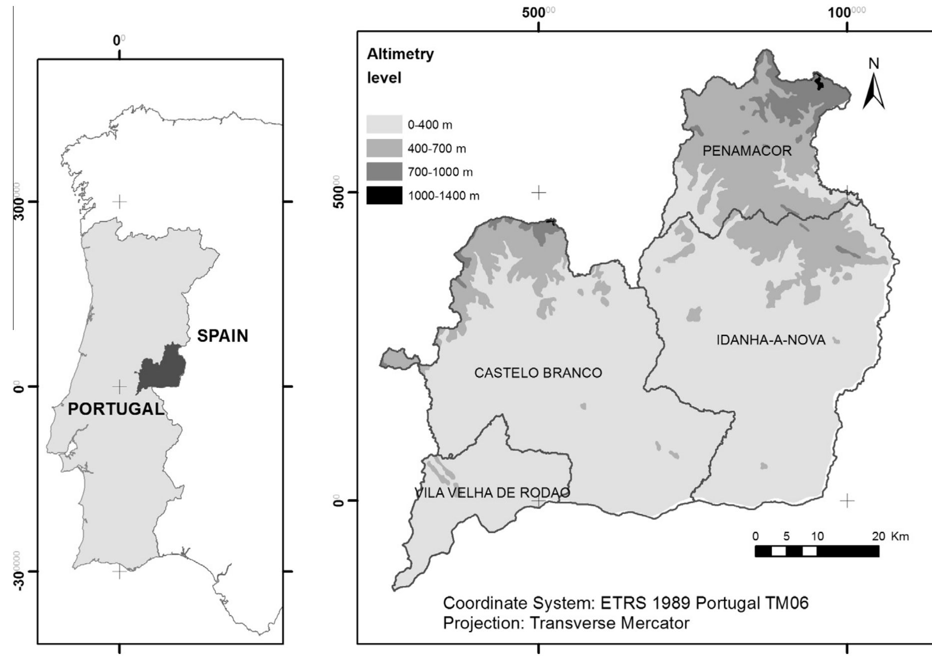


Fig. 1. Study area geographical location.

other broadleaves (e.g. *Prunus avium* L., *Populus* sp., *Fraxinus angustifolia* Vahl and *Juglans nigra* L.), other coniferous (e.g. *Pinus pinea* L., *Pinus sylvestris* L., *Pseudotsuga menziesiiand* (Mirb.) Franco and *Cupressus* sp.) and strawberry tree (*Arbutus unedo* L.) are also considered to be promoted but on a smaller scale (DGRF, 2006b).

The ecological map of Portugal (APA, 2007) by Albuquerque (1954) was used to obtain the ecological zoning for the species used in the RURIS–AAL programme in the BIS region. The ecological map includes two main vectors that influence species potential geographic distribution: one related to maritime influence (coastal to inland) versus Mediterranean influence (north to south) and the other related to elevation (bottom land to mountain areas). With respect to the BIS region, the dominant ecological zones are ‘‘Sub-Mediterranean’’ (SM – less than 400 m) and ‘‘Sub-Mediterranean.Iberian-Mediterranean’’ (SM.IM – less than 400 m) located at the centre. Ecological zones ‘‘Sub-Atlantic.Atlantic-Mediterranean’’ (SA.AM – 400–700 m), ‘‘Sub-Atlantic.Mediterranean-Atlantic.Atlantic-Mediterranean’’ (SA.MA.AM – 400–700 m), ‘‘Sub-Atlantic’’ (SA – 700–1000 m) and ‘‘Sub-Atlantic.Oro-Atlantic’’ (SA.OA – 1000–1300 m) are also present but only in the north-west. Ecological zones ‘‘Atlantic-Mediterranean.Sub-Mediterranean’’ (AM.SM – less than 400 m), ‘‘Sub-Atlantic.Sub-Mediterranean’’ (SA.SM – 400–700 m) and ‘‘Sub-Atlantic’’ (SA – 700–1000 m) are observed in the north-east. The ecological zone ‘‘Iberian-Mediterranean’’ (IM – less than 400 m) is observed in the south and south-east. Additionally, the forest species rating conditions proposed by Dias et al. (2008) were considered in assessing the appropriateness of species selection (Table 1). According to these authors eucalyptus, maritime pine, umbrella pine and cork oak, all thrive very well in the SM ecological zone. However, for holm oak, the best ecological zone is IM. Both SM.IM and SA.SM zones are considered to be a reference for umbrella pine, cork oak and holm oak. Spatial data analysis using the ArcGis software (ESRI, 2004) was performed to evaluate the appropriateness of projects species selection and its ecological zoning by crossing the afforestation projects areas map with the ecological map.

Table 1
Forest species rating conditions.

	Inferior	Reference	Superior
SM	–	Qr	Qs, Pp, Pn, Ec
SM.IM	Pp	Qr, Qs, Pn, Ec	–
SA.AM	Qr, Pn	Qs, Ec	Pp
SA.MA.AM	–	–	–
SA	Qr, Qs, Pn, Ec	–	Pp
SA.OA	–	–	–
AM.SM	–	–	–
SA.SM	–	Qr, Qs, Pp, Pn, Ec	–
IM	Qs, Pp, Pn, Ec	–	Qr

SM – Sub-Mediterranean; SM.IM – Sub-Mediterranean.Iberian-Mediterranean; SA.AM – Sub-Atlantic.Atlantic-Mediterranean; SA.MA.AM – Sub-Atlantic. Mediterranean-Atlantic.Atlantic-Mediterranean; SA – Sub-Atlantic; SA.OA – Sub-Atlantic.Oro-Atlantic; AM.SM – Atlantic-Mediterranean.Sub-Mediterranean; SA.SM – Sub-Atlantic.Sub-Mediterranean; IM – Iberian-Mediterranean; Qs – *Quercus suber*; Qr – *Quercus rotundifolia*; Pp – *Pinus pinaster*; Pn – *Pinus pinea*; Ec – *Eucalyptus globulus*.

To assess the success rate of the 164 RURIS–AAL afforestation projects (3363 ha) installed in BIS region, information about both the biophysical (previous land cover, soil type, soil depth and altitude class) and stand establishment conditions (species, composition, site preparation, seedlings protection and animal damage) was gathered for each project, during the afforestation establishment stage (2002–2007). Later, additional data was collected in 157 field samples from 97 projects (1638 ha), during the afforestation maintenance stage (2007–2011), to assess if the minimum stand density (N – number of trees per hectare) established in the RURIS–AAL programme for each species was observed (e.g. maritime pine and other coniferous – 1200 trees ha^{-1}; umbrella pine – 800 trees ha^{-1}; holm cork and cork oak – 300 trees ha^{-1}; broadleaves – 800 trees ha^{-1}; mixtures – trees ha^{-1} considered for the dominant species). Field samples were obtained through casual sampling using the random sites.avx tool in ArcGis software (ESRI, 2004). Sampling intensity was established according to afforestation project area and site variability with respect to stand density (N). The distribution of field samples by species area followed the same proportion as the projects: pure cork oak stands (54%) and mixed stands of cork oak and holm oak (32%; e.g. *Pinus pinea* × *Quercus suber*, *Pinus pinea* × *Quercus rotundifolia*, *Quercus suber*× *Pinus pinaster*, *Quercus suber*× *Cupressus* sp., *Quercus suber*× *Quercus rotundifolia*). At the afforestattion establishment stage, projects were considered as having a regular status when both the observed stand density (*N*) did not exceed a deviation higher than 20% in each project compartments and the required minimum stand density was ensured for each species and project compartments. A regular status was obtained if both the required minimum stand density was confirmed and the management plan (e.g. the silvicultural prescription for the species) was being applied. Otherwise, an irregular status was considered due to either lack of minimum stand density or to deficiencies on meeting management plan goals.

Possible causes for successful afforestation (regular status) were explored by statistical analysis through both nonparametric correlations and Categorical Principal Components Analysis (CATPCA) using the software SPSS Statistics v.19 (SPSS, 2010). The variables considered are categorical and were coded. First, the nonparametric Spearman correlation coefficient was used to understand the association between variables. The sign of the coefficient indicates the direction of the association that is to say that when the correlation is positive variables vary in the same direction and when the correlation is negative variables vary in opposite directions. When interpreting correlation coefficients, it should not be assumed that correlation automatically implies cause. This coefficient is often used when data do not satisfy the normality assumption (Spearman, 1904). Secondly, CATPCA was applied using the variable principal normalisation method (Maroco, 2011) to reduce the original set of variables into a smaller set of uncorrelated components that represent most of the information found in the original variables. In other words, there will be a new set of variables such that each new variable in this set is called a principal component. The first new variable (1st component) explains the maximum variance in the sample data, the second new variable (2nd component) explains the next larger variance, and so forth. The CAPTA is done by recognising the eigenvalues structure of the covariance. The internal consistency of each component was evaluated using the Cronbach's alpha. The number of components to be extracted was assessed by the eigenvalues in each dimension (e.g. eigenvalue larger than one) and in the Scree plots (SPSS, 2010). The CATPCA technique allowed the most important variables for explaining afforestation success (samples with regular status) to be found, and how these variables were associated as the loadings values indicate which variables are determinant for each component (e.g. higher than ±0.5). Finally, the very most successful species and mixtures were analysed.

3. Results

3.1. Land cover change (1990–2006)

According to the CLC map of 2006 "forests and semi-natural areas" occupy the larger share (56%) of the BIS region (211,187 ha). On the other hand, agriculture area comprises a total of 158,795 ha (42%) where agro-forestry systems represent 27,897 ha (Fig. 2a). Forests and open forest, cuts and new plantations correspond to 186,774 ha (50%) (Fig. 2b and c). More detailed information about species area, obtained from the National Forest Inventory data in 2005–2006, indicate that the forested area (142,171 ha) is mainly composed by maritime pine (36%), eucalyptus (33%), cork oak (14%) and holm oak (15%).

The spatial analysis of CLC maps in 1990, 2000 and 2006, proved that land cover change trends in BIS region, during the last two decades, were due to the decrease in agricultural areas (164,469 ha, 159,781 ha, 158,795 ha; 44%, 43% and 42%, respectively) and the increase of forests and semi-natural areas (206,931 ha, 210,414 ha, 211,187 ha; 55%, 56% and 56%, respectively).

During the RURIS–AAL programme implementation, agricultural area loss was only 2% (1309 ha) of the overall land cover change between 2000 and 2006 (Table 2) in which 95% of it was converted into forests and semi-natural areas. In fact, the vast majority of land cover change (Fig. 2c and d) was observed inside the class of forests and semi-natural areas with a substantial increase of the class "open forests, cuts and new plantations" representing about 90% of the overall change. Coniferous forests contributed 65% and broad-leaved forests contributed 25% to the increase of that class whereas the RURIS–AAL programme contribution was only 5% (3363 ha). When crossing burnt areas with "open forests, cuts and new plantations" areas a high association was observed (Fig. 2d and e). This clearly points to forest fires as the main driving force in the regioń s land cover change. Finally, it was verified that a good recovery of the "open forests, cuts and new plantations" area in 2000 in both broad-leaved forests (60%) and coniferous forests (21%) in 2006.

3.2. Afforestation success (2002–2011)

Afforestation projects (3363 ha) (Table 3) were mainly established in natural grassland (67%) against 25% in non-irrigated arable land and 5% in olive groves. The soil preparation operations mostly used were mechanical clearing, followed by ripping and bedding (MCRB), ripping and bedding (RB) and subsoiling (S) (87%). Afforestations were mainly of pure cork oak stands (54%) and mixed stands of cork oak and holm oak (32%; e.g. PnQs – *Pinus pinea*× *Quercus suber*, PnQr – *Pinus pinea*× *Quercus rotundifolia*, QsPp – *Quercus suber*× *Pinus pinaster*, QsCu – *Quercus suber*× *Cupressus* sp., QsQr – *Quercus suber*× *Quercus rotundifolia*). As for stand density, several planting spacing densities were used, being the most observed ones the following: 6 × 3 m, 4 × 2.5 m, 4 × 3 m and 4 × 2 m. In addition, a great effort in providing physical tree protection either with individual tree shelters, or fences, or even both (66%) was verified. Even so, animal damage was quite frequently observed (69%).

The species used in the afforestation projects were well selected when crossing projects and field samples with species ecological zoning (Fig. 3). Based on the 157 field samples, 76% of the afforestation projects' area was considered as having a regular status (111 samples). The remaining 24% of the projects' area had an irregular status (65 samples) which was due either to the lack of minimum stand density (12% of the projects' area; 29 samples) or to deficiencies in meeting the forest management plan goals (12% of the projects' area; 17 samples) (Fig. 4a). Considering the species composition, 79% of pure cork oak stands area (Qs) and 89% of mixed stands of cork oak area (PnQs, QsPn, QsCu and QsQr) have shown a regular status (high success rate), namely mixed umbrella pine and cork oak stands area (PnQs) (95%). For the areas of pure stands of maritime pine (Pp), umbrella pine (Pn) and holm oak (Qr) the success rates were lower than 40% (Fig. 4b).

To analyse the most important variables for explaining afforestation success, the nonparametric Spearman correlation coefficient was first performed. Significant correlations at 5%(*) and/or 1%(**) levels were observed between the variables species and composition (+0.708**), composition and seedlings protection (+0.264**), species and seedlings protection (+0.203*) in regular status samples ($n = 111$). While, in irregular status samples due to lack of minimum stand density ($n = 29$) significant correlations between the variables previous land cover and site preparation (+0.371*), soil depth and soil type (+0.385*) and species and composition (+0.671**) were observed. After, the CATPCA technique was applied both for the regular status samples ($n = 111$) and for irregular status samples due to lack of minimum stand density ($n = 29$). Nine

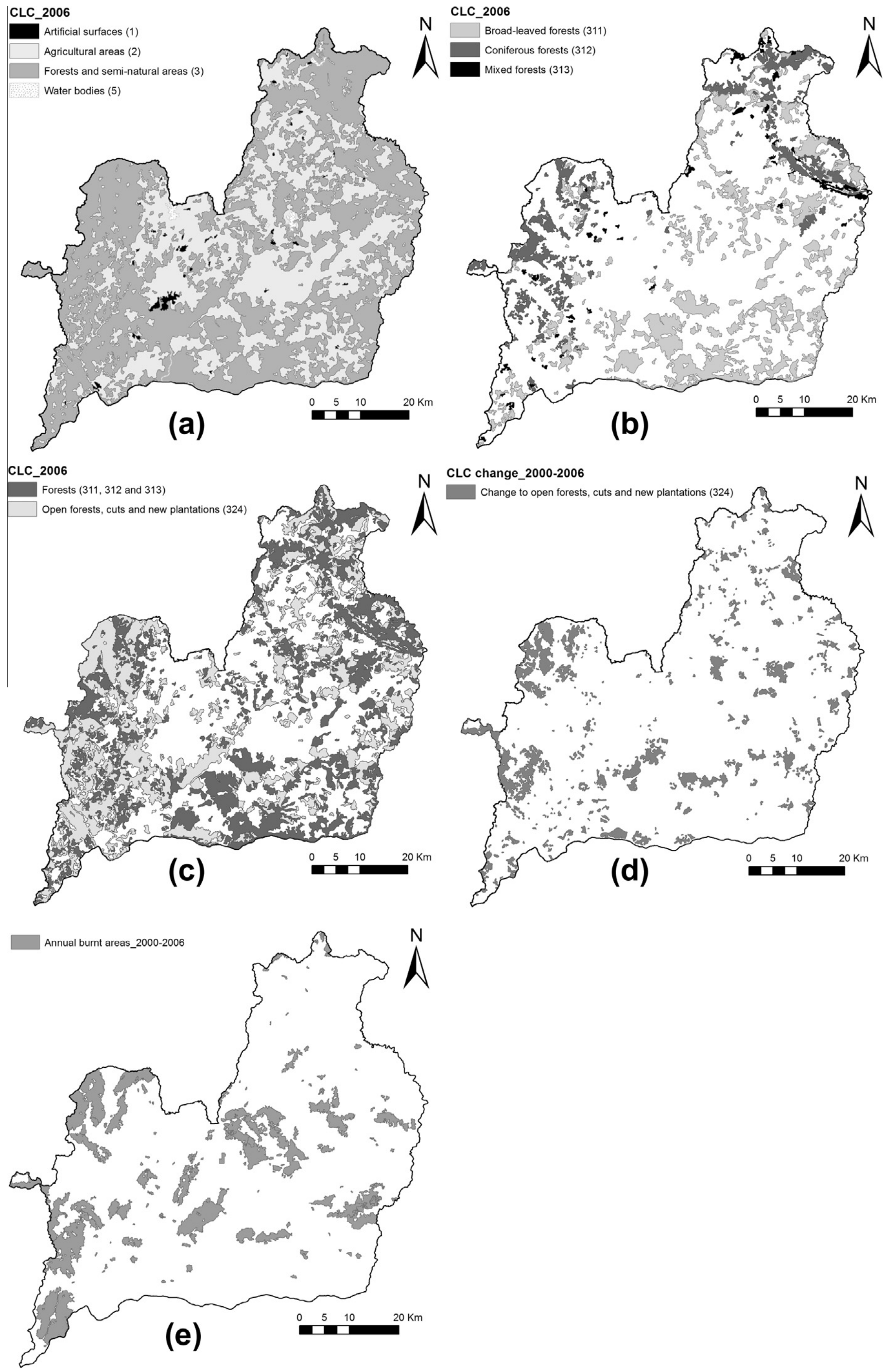


Fig. 2. BIS region: (a) Land cover in 2006; (b) Forests in 2006: broad-leaved, coniferous and mixed forests; (c) Forests and open forests, cuts and new plantations in 2006; (d) Change in open forests, cuts and new plantations between 2000 and 2006; and (e) Annual burnt area during 2000–2006.

components were first extracted since nine variables were under study (previous land cover, soil type, soil depth, altitude class, species, composition, site preparation, seedlings protection and animal damage). The analysis of the Scree plot of component's eigenvalues and the rule of eigenvalues larger than one supported retaining only the two first orthogonal components (more than 50% of the data variability). These criteria could have supported the retention of at least one more component, which would contribute to a slightly increase of total variation percentage explanation but also to an increase of the number of variables under analysis making interpretation difficult and of little use. Additionally, the large Cronbach's alpha values allowed verifying the internal consistency of these two components.

The results of CATPCA using the regular status samples (n = 111) showed internal consistencies of 0.747 and 0.448 respectively, for the 1st and 2nd components. Eigenvalues of 2.980 and 1.661 were observed, respectively. These two components explain around 52% of the data variability (1st component 33% and 2nd component 19%) (Fig. 5a). Looking at the 1st component the variables species (0.911), composition (0.858), site preparation

Table 2
Land cover change (2000–2006) between and within classes in hectares.

2000/2006	112	121	122	132	133	142	211	212	221	223	231	244	311	312	313	323	324	512	Sum	%
211		5.9			13.6			80.1	6.2			16.3	30.4				610.8	6.4	769.6	1.0
212																			0.0	0.0
221																			0.0	0.0
223								28.1	8.4		29.1						91.8	5.4	162.8	0.2
231																37.0			37.0	0.0
242			5.7						12.3								36.6		54.6	0.1
243			19.0														199.9		218.9	0.3
244					11.5	2.6		4.6									232.5		251.3	0.3
311			7.2	6.8		67.2	5.8										17884.1	6.5	17977.7	22.6
312			17.5		36.6												45683.4		45737.5	57.5
313			4.7														837.3		842.0	1.1
321			1.9		6.1		28.8										117.8		154.6	0.2
322			27.1																27.1	0.0
323							24.7				242.6						367.7		635.0	0.8
324	22.7	87.7	6.9		7.6	10.6	64.5		21.2	14.2	42.1		4478.8	1562.2	404.1			27.9	6750.5	8.5
334													36.1				5921.4		5957.4	7.5
Sum	22.7	93.6	90.1	6.8	75.5	80.5	123.8	112.7	48.1	14.2	313.9	16.3	4545.3	1562.2	404.1	37.0	71983.2	46.2	79576.1	100.0
%	0.0	0.1	0.1	0.0	0.1	0.1	0.2	0.1	0.1	0.0	0.4	0.0	5.7	2.0	0.5	0.0	90.5	0.1	100.0	

CLC classes: 1. Artificial surfaces: 112 Discontinuous urban fabric, 121 Industrial or commercial units, 122 Road and rail networks and associated land, 132 Dump sites, 133 Construction sites, 142 Sport and leisure facilities; 2. Agricultural areas: 211 Non-irrigated arable land, 212 Permanently irrigated land, 221 Vineyards, 223 Olive groves, 231 Pastures, 242 Complex cultivation patterns, 243 Land principally occupied by agriculture, with significant areas of natural vegetation, 244 Agro-forestry areas; 3. Forests and semi-natural areas: 311 Broad-leaved forest, 312 Coniferous forest, 313 Mixed forest, 321 Natural grasslands, 322 Moors and heathland, 323 Sclerophyllous vegetation, 324 Open forests, cuts and new plantations, 334 Burnt areas; 5. Water bodies: 512 Water bodies.

Table 3
Afforestation projects (3363 ha) – biophysical and stand establishment characterisation.

Code	Previous Land Cover	Area (%)	Soil Type	Area (%)	Soil Depth	Area (%)	Altitude class	Area (%)	Species	Area (%)	Com-Position	Area (%)	Site Preparation	Area (%)	Seedlings Protection	Area (%)	Animal Damage	Area (%)
1	OG	5	Sa	5	S	62	B	60	Pp	1.6	P	67	MCRB	35.7	W	34.2	N	21
2	NIA	25	Sc	71	M	32	sM	39	Pn	3.8	M	33	RB	39.5	P	38.4	Y	69
3	NG	67	Gr	24	D	2	M	2	Qr	5			RP	7.5	F	15.2		
4	F	3							Qs	54.2			MCP	0.1	PF	12.2		
5									B	2.4			MCB	1.9				
6									PnQs/PnQr	20			MCS	0.4				
7									PpQ	0.1			S	11.3				
8									QsPp/QsCu	2.9			MCHP	0.2				
9									QsQr	8.6			SMC	3.4				
10									BB	1.4								

OG – olive groves, NIA – non-irrigated arable land, NG – natural grassland, F – forests; Sa – sandstone, Sc – schist, Gr – granite; S – superficial, M – medium, D – deep; B – basal (0–400 m), sM – sub-montane (400–700 m), M – montane (700–1000 m); Pp – *Pinus pinaster*, Pn – *Pinus pinea*, Qr – *Quercus rotundifolia*, Qs – *Quercus suber*, B – other wood broadleaves, PnQs – *Pinus pinea* × *Quercus suber*, PnQr – *Pinus pinea* × *Quercus rotundifolia*, PpQ – *Pinus pinaster* × *Quercus* sp., QsPp – *Quercus suber* × *Pinus pinaster*, QsCu – *Quercus suber* × *Cupressus* sp., QsQr – *Quercus suber* × *Quercus rotundifolia*, BB – mixed of wood broadleaves; P – pure, M – mixed; MCRB – mechanical clearing, ripping and bedding, RB – ripping and bedding, RP – ripping and plowing, MCP – mechanical clearing and plowing, MCB – mechanical clearing and bedding, MCS – mechanical clearing and subsoiling, S – subsoiling, MCHP – manual clearing and hole plantation, SMC – stand manual clearing; W – without seedlings protection, P – individual tree protection, F – fences, PF – individual tree protection and fences; Y – yes, N – no.

(0.817) and seedlings protection (0.615) have positive loadings, while animal damage (−0.259) is negative. At the 2nd component, the variables altitude level (0.695) and previous land cover (0.626) have positive loadings by contrast to soil type (−0.614) and soil depth (−0.493) that have negative loadings. Higher values in the positive loadings component than in the negative loadings component were observed. Moving to the CATPCA results for the irregular status samples due to lack of minimum stand density ($n = 29$) (Fig. 5b) internal consistencies of 0.722 and 0.534 were observed respectively, for the 1st and 2nd components. Eigenvalues of 2.790 and 1.904 were observed, respectively. The two components also explain around 52% of data variability (1st component 31% and 2nd component 21%). Looking at the 1st component, previous land cover (0.808), site preparation (0.772) and animal damage (0.213) have positive loadings, while species (−0.918) and composition (−0.646) are negative. At the 2nd component, the variables soil type (0.712) and seedlings protection (0.518) have positive loadings.

Finally, the analysis of regular status samples ($n = 111$) against irregular status samples due to lack of minimum stand density ($n = 29$) (Fig. 6) proved that the incidence of physical individual tree protection was higher in regular samples (69% of samples) than in irregular samples (45% of samples), whereas the animal damage was lower in regular samples (66% of samples) than in irregular samples (86% of samples). Samples in which individual tree protection was used, a regular status was found in all of them (100%). Samples where individual tree protection and fences were combined (PF) or just fences (F) were used an increasing rate of irregular status was verified (3% and 10%, respectively). Still, a high rate of animal damage was observed in regular samples (66%) which may be related to the existence of several important hunting reserves in the study area. Lastly, both cork oak stands and cork oak mixtures (e.g. PnQs – *Pinus pinea*× *Quercus suber*, QsPp – *Quercus suber*× *Pinus pinaster*, QsCu – *Quercus suber* × *Cupressus* sp., QsQr – *Quercus suber* × *Quercus rotundifolia*) were the ones where a higher incidence of physical individual tree protection was observed.

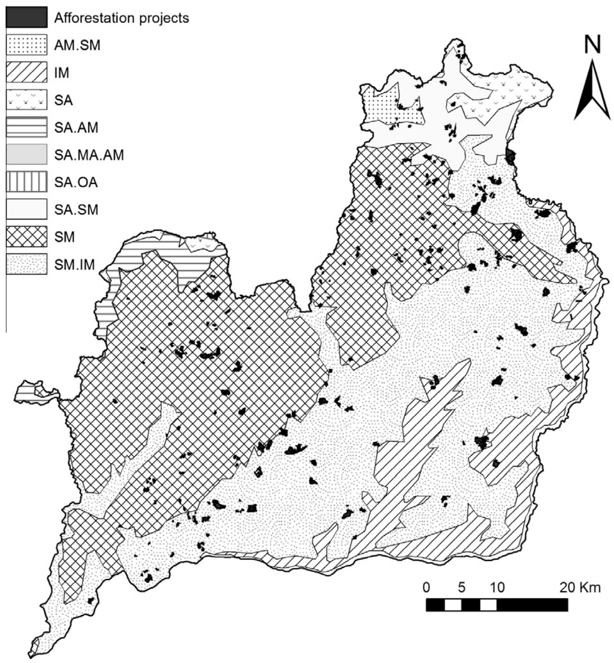


Fig. 3. BIS region ecological zoning and RURIS-AAL afforestation projects (2002–2007).

4. Discussion

During the past two decades (1990–2006) agricultural areas decreased (−1.5%; 5674 ha) in relation to the increase of forests and semi-natural areas (+1.1%; 4256 ha) in the BIS region. Land cover change from 2000 until 2006 was mainly due to forest fires. As a result, a decrease in forest areas as opposed to an increase of open forests, cuts and new plantations areas was observed. The impact of the RURIS–AAL programme on agricultural area loss was found to be very weak (−0.6%) since only 1009 ha were afforested in both non-irrigated arable land and olive groves, the remaining 2354 ha were in natural grassland and in naturally forested areas. In addition, the RURIS–AAL programme was very positive in recovering oak forest areas (mainly, pure cork oak and mixtures of cork oak and holm oak; 2892 ha; 86%). According to BIS RFMP, a decrease in both maritime pine area (36–17%) and eucalyptus area (33–13%) is recommended. While, an increase in both cork oak area (14–28%) and holm oak area (15–27%) should be promoted (DGRF, 2006b). Therefore, efforts to recovering Portuguese native oak species referred to above must continue. Furthermore, afforestation using other coniferous and broadleaves, either in pure or mixed stands, should also be encouraged for landscape diversification. However, it should be stressed that the observed land cover change from 1990 to 2006 has already resulted in some landscape fragmentation and heterogeneity (Galego, 2012) which may have a positive role in forest fire prevention.

The species used in the afforestation projects were well selected in relation to their ecological zoning as confirmed by GIS spatial analysis. During the period in analysis the RURIS–AAL afforestation projects levels of success were proven as being high, with 76% of the afforested area considered as having a regular status. The statistical analysis through CATPCA showed that around 52% of data variability could be explained, in which the 1st component resumes the variables related to stand establishment and the 2nd component to the variables related to biophysical conditions. According to Johnson (1998), the use of the two first components when reaching more than 50% of the total variance explained is quite satisfactory in environmental studies. These results proved that the combination of the necessary biophysical conditions for each species together with the most appropriated procedures for stand establishment were verified in RURIS–AAL projects. The importance of using either individual tree protection (P) or individual tree protection and fences combined (PF) to provide physical tree protection especially against animal damage, was highlighted in the 1st component of CATPCA. However, variables related to the plant itself and to climate may help to explain the rest of data variability. According to Dey et al. (2010) successful afforestation requires a commitment to implementing general principles and practices that are well known and available in local management guides. However, despite selecting the appropriate of the species to be used in an afforestation, its success depends ultimately on the correct landowner choices regarding root stock and size (age) of seedlings, the time and method of planting, and the protection of seedlings from competition and predators (Sweeney et al., 2007).

The lowest success rates (<40%) were mainly observed in areas of pure stands of maritime pine (Pp), umbrella pine (Pn) and holm oak (Qr) which is reinforced by the CATPCA analysis that pointed towards the importance of seedling protection (2nd component) to explain the irregular status samples due to lack of minimum stand density. In effect, more than 50% of these species samples had no seedling protection and a high rate of animal damage (>75%).

The importance of site preparation was also highlighted in the 1st component of CATPCA. In fact, intense site preparation (e.g. MCRB and RB) was used in the majority of the RURIS–AAL

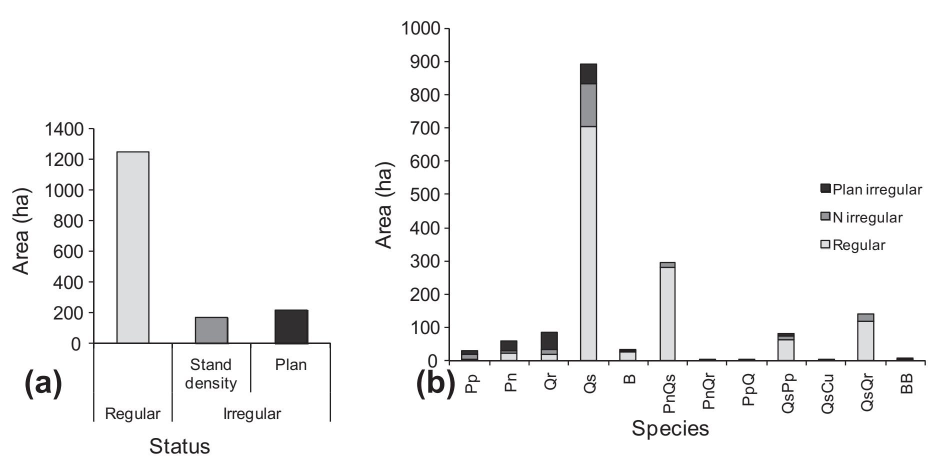
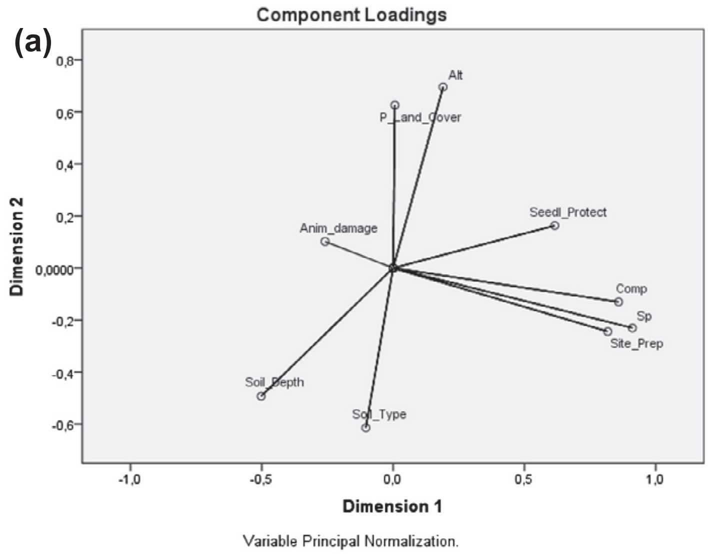
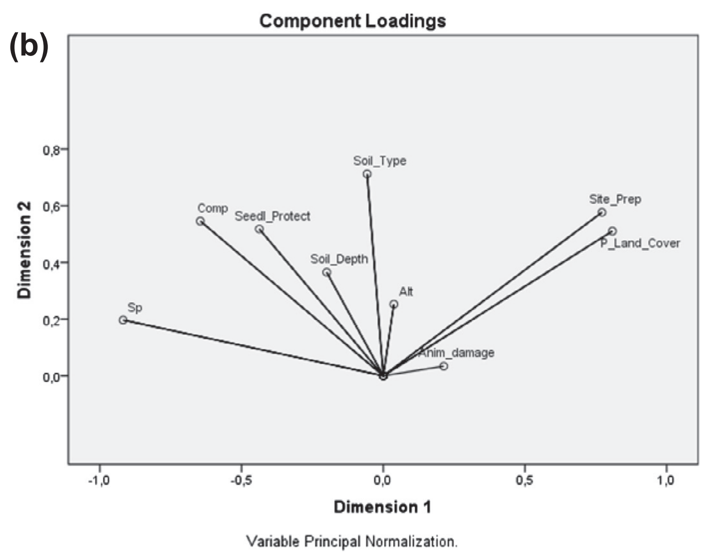


Fig. 4. Afforestation projects status (2007–2011): (a) Global and (b) species.

Variables	Components	
	1	2
P_Land_Cover	0.007	0.626
Soil_Type	-0.104	-0.614
Soil_Depth	-0.502	-0.493
Alt	0.190	0.695
Sp	0.911	-0.230
Comp	0.858	-0.130
Site_Prep	0.817	-0.244
Seedl_Protect	0.615	0.163
Anim_damage	-0.259	0.102
Eigenvalue	2.980	1.661
% of Variance	33.113	18.460
Cronbach's Alpha	0.747	0.448



Variables	Components	
	1	2
P_Land_Cover	0.808	0.511
Soil_Type	-0.057	0.712
Soil_Depth	-0.200	0.365
Alt	0.037	0.252
Sp	-0.918	0.197
Comp	-0.646	0.546
Site_Prep	0.772	0.577
Seedl_Protect	-0.437	0.518
Anim_damage	0.213	0.034
Eigenvalue	2.790	1.904
% of Variance	31.000	21.156
Cronbach's Alpha	0.722	0.534



Legend – Previous land cover (P_Land_Cover); Soil type (Soil_Type); Soil depth (Soil_Depth); Altitude class (Alt); Species (Sp); Composition (Comp); Site preparation (Site_Prep); Seedling protection (Seedl_Protect); Animal damage (Anim_damage).

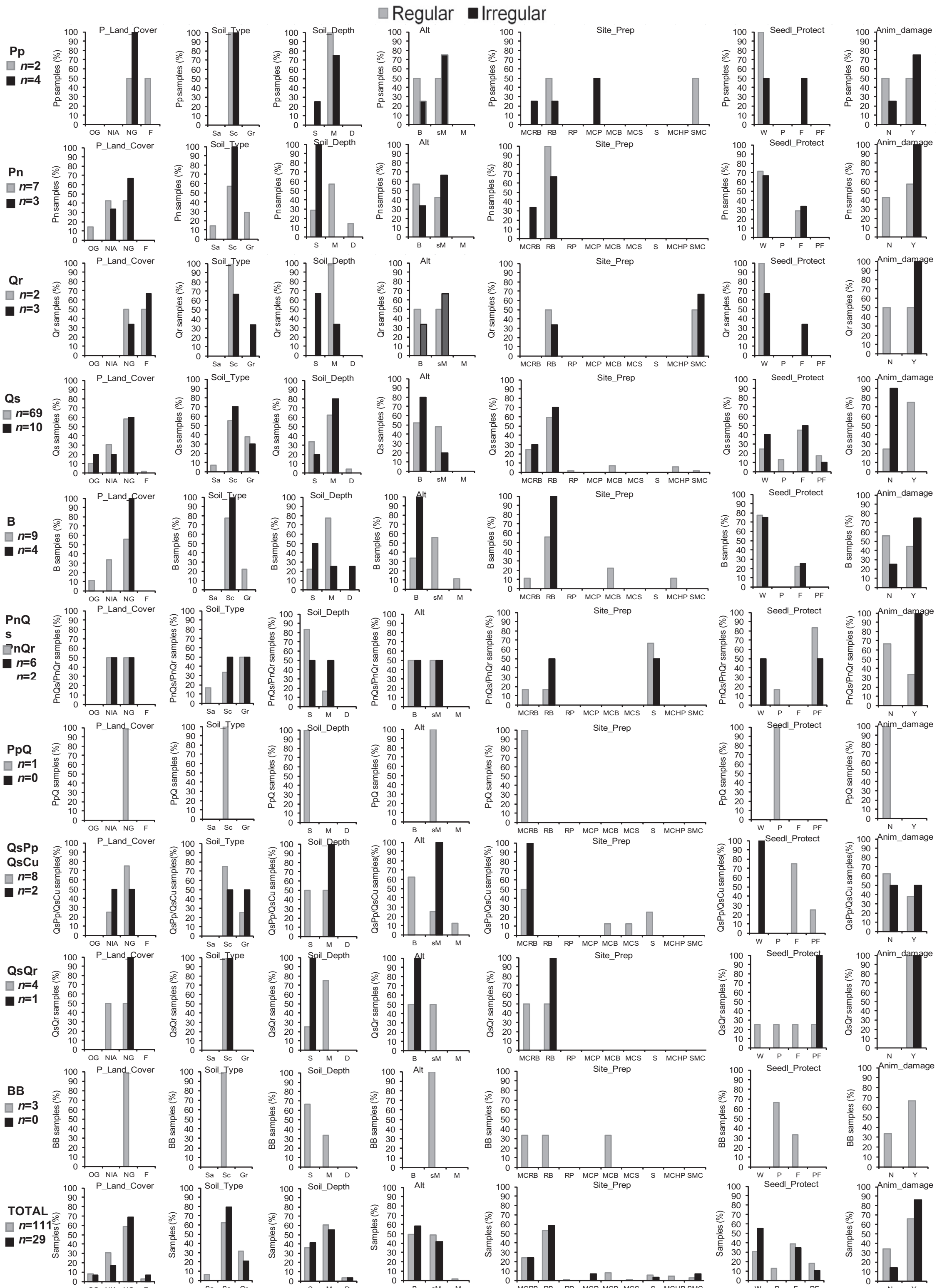
Fig. 5. CATPCA: (a) Field samples with regular status and (b) Field samples with irregular status due to lack of minimum stand density.

projects (76%) given that in Mediterranean environments, the success of forest plantations is greatly limited by poor soil conditions, namely a low root support capacity, which has negative effects on the amount of available water and nutrients. Therefore, soil preparation operations are required to increase soil depth, as well as water and nutrient availability, and, so to improve soil conditions for plant growth (Querejeta et al., 2001). For instance, Fonseca et al. (2011) observed that mortality after planting was affected by the soil preparation technique, in which higher mortality rates were reported on the less intense treatments.

High afforestation success rates were obtained for both pure cork oak stands area (Qs; 79%) and mixed stands of cork oak area (PnQs, QsPn, QsCu and QsQr; 89%), namely mixed umbrella pine and cork oak stands (PnQs; 95%). In fact, both these two species (Pn and Qs) thrive very well in the same ecological zones which may explain the good success rates.

Both, cork oak and umbrella pine forests offer non-wood products (cork and cone) of high market value which will improve farm's multi-functionality and provide extra incomes in the long-term. Umbrella pine is a very well adapted species to the Mediterranean climate, which has high temperatures and regular summer droughts (Raddi et al., 2009) and due to its ecological plasticity can grow well even in poor and degraded soils (Gonçalves and Pommerening, 2012). Cork oak is considered an important species for the socio-economical development of some European regions due to its potential use in sustainable forestry, as it provides a wide range of important goods and ecosystem services (FAO, 2013). Furthermore, cork oak forests are ecosystems of high conservation value and the species is a very good candidate for reforestation plans in the Mediterranean area due its efficient and rapid post-fire regeneration capacity (Pausas, 1997; Pons and Pausas, 2006).

The results obtained in this study are important guidelines for successful afforestation in future programmes either in this region or in other similar Mediterranean regions, since forests management costs are high and are carried over for decades until harvest revenues are earned.



Legend – Previous land cover (P_Land_Cover): OG – olive groves, NIA – non-irrigated arable land, NG – natural grassland, F – forests; Soil type (Soil_Type): Sa – sandstone, Sc – schist, Gr – granite; Soil depth (Soil_Depth): S – superficial, M – medium, D – deep; Altitude class (Alt): B - basal (0-400 m), sM – sub-montane (400-700 m), M – montane (700-1000 m); Site preparation (Site_Prep): MCRB – mechanical clearing, ripping and bedding, RB – ripping and bedding, RP – ripping and plowing, MCP – mechanical clearing and plowing, MCB – mechanical clearing and bedding, MCS – mechanical clearing and subsoiling, S – subsoiling, MCHP – manual clearing and hole plantation, SMC – stand manual clearing; Seedling protection (Seedl_Protect): W – without seedlings protection, P – individual tree protection, F – fences, PF – individual tree protection and fences; Animal damage (Anim_damage): Y – yes, N – no.

Fig. 6. Percentage distribution of field samples by species and status (regular versus irregular due to lack of minimum stand density) in relation to biophysical and stand establishment conditions.

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