Assessment of Mediterranean Evergreen Oak (*Quercus suber* L.) Woodlands Loss. Consequence of climate changes effects? A case study at South-Western Portugal

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Abstract — Mediterranean evergreen oak woodlands are scattered trees ecosystems threatened by global warming scenarios and experiencing processes of loss and fragmentation. In representative areas of oak evergreen woodlands, over a 50-year period (1958 - 2007), quantitative information on the woodland's shifting mosaic, comprising its three main patch-types: forest, farmland and shrubland, was obtained. This information included rates of: woodlands loss; core area loss and; edge high-contrast length expansion. Evergreen oak woodlands loss rates sharply increased in recent decades under current management systems. In some areas these ecosystems would be lost in approximately 90-180 years. However it was not clear if the loss of these ecosystems was sensitive to climate change, namely to extreme weather events like precipitation with enlarged below-mean values periods, as particular combinations of socio-economic factors and biophysical conditions seems to affect its dynamics, mainly impacting tree long-term persistence by natural regeneration failure and by shrubland encroachment. Also, the existing environmental financial support programmes for these landscapes, which focus on increasing recruitment, may not reverse this trend.
Perpetuating these ecosystems requires a strategy that keeps both, low tree mortality and tree recruitment, encompassing: i) the identification and protection of areas with natural regeneration; ii) the exploitation of soil conservation techniques for oak woodland recovery; and iii) considering the effects of different fragmentation patterns on the ecosystem functioning. Further work is been carried out, with a more precise approach, to have a more clear relationship between oak woodland patterns of loss and fragmentation and global warming extreme weather events.

Keywords — Annual precipitation, Land-use, Mediterranean evergreen oak woodlands, Quercus suber, Vegetation cover metrics

1 Introduction

Mediterranean dense evergreen oak forests were transformed into scattered trees or savannah-like ecosystems (called *montados* in Portugal, or *dehesas,* in Spain) in result of a long-term forest fragmentation by human-disturbances such as fire or grazing. Nowadays these woodlands are described as a kaleidoscopic landscape, given its spatial heterogeneity and the temporal variability of its mosaic pattern, including open oak woodlands, grasslands and shrublands [1, 2, 3].
Cork oak systems have a tree cover layer dominated by cork oak (*Quercus suber* L.) for the production of cork, with an herbaceous understory of pastures, annual crops or fallows [4]. The changes in evergreen oak woodlands were mainly related to stressing environmental conditions [5,6] and in some extent, to vulnerable agricultural economy.
These changes resulted in the polarization of the land use, between land intensification (e.g. exotic species plantation) and land abandonment (e.g. shrub encroachment). The multifunctional traditional landscapes were transformed into single function land use types and the forest loss and fragmentation may be critical to sustain many ecological processes [7, 8].
In this context, this study was developed in main representative areas of cork oak woodlands in southwestern Portugal hypothesizing that: i) recent changes in cork oak woodlands in Southwestern Portugal resulted in evergreen oak forest loss; ii) the occurrence of this loss impacted forest core and edge habitats and; iii) oak woodlands shifting patterns may be linked to landscape physic attributes (e.g. soil type), key factors on cork oak access to soil-water resources, sensitive to climate change effects.

2 Material and Methods

2.1 Study area

The study areas comprised two parishes in Southern Portugal: Ulme (UL), located in the Tagus basin,

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(39°23'N - 08°30'W and 39°16'N - 08°15'W) and S. Bartolomeu da Serra (SB), closest to the ocean (38°04'N - 08°40'W and 37°56'N - 08°34'W), with areas of 12179 and 6224 ha, respectively. The climate of the study areas is of Mediterranean type (Fig. 1) with some Atlantic influence. Rainfall mostly occurs from late autumn to early spring, with great yearly irregularities. Mean annual temperatures of 15.9 °C and annual rainfall of 715 mm were found for UL (1960-1990, Santarém), while 15.7 °C and 551 mm (1966-1990, mean values for Grândola and Sines) were found for SB.

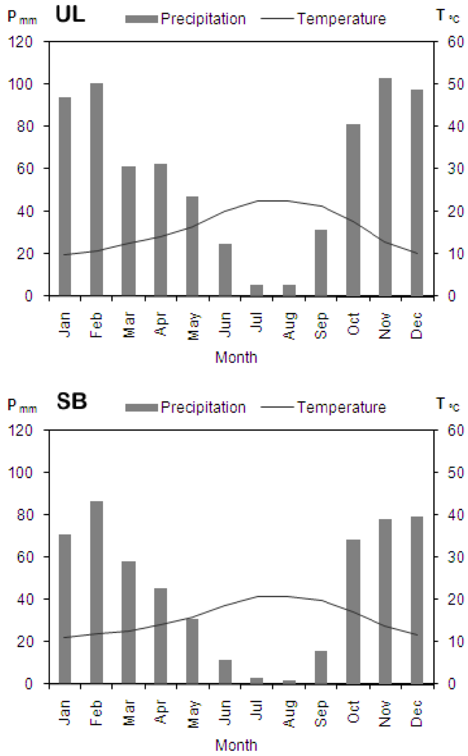

Fig. 1. Mean annual patterns of temperature and precipitation: UL (1960-1991, Santarém Meteorological Station); SB (1966-1990, Grândola and Sines Meteorological Stations).

In UL, only geologic sedimentary formations occur. Lithology is related to Miocene-Pliocene formations, mostly sandstones intercalated with clay beds. Geologic formations are densely incised by water lines, in some cases with active gullies. The land is flat in valley bottoms and on top of the Pliocenic terraces: soils in valleys are mostly Fluvisols (FL) and in flat tops are Stagnic Luvisols (LV). In the undulating steep areas, in Miocenic formations, soils are Regosols (RG) and Cambisols (CM) [9,10] (Fig. 2).

In SB, geological formations are related to schists (grauwakes, siltstones and carbonaceous schists) and sedimentary formations of the Plio-Plistocenic (sandstones and sands) only occur at small extent overlaying schist formations in the rounded flattened hilltops. Soils are mostly Haplic Leptosols (LPx) associated at low extent with Epileptic Luvisols (LVx) and Haplic Leptosols on sandstones (LPst) and Haplic Arenosols (AR)[10] (Fig. 2).

The study areas are dominated by cork oak (*Quercus suber* L.), traditionally dominated by a mosaic of open farmland areas and oak woodlands, representative of multifunctional agroforestry *montado* systems.

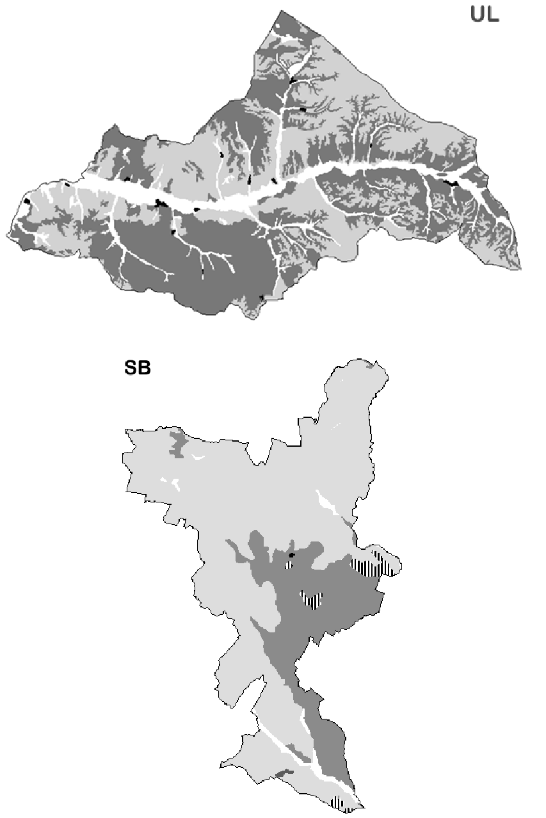

Fig. 2. Soils in the study areas. At UL and SB: FL, in white and Built up land and Water areas, in black. At UL: LV, in light grey; RG + CM, in dark grey. At SB: LPx, in light grey; LVx, in dark grey; LPst in darker grey; AR, in black & white vertical strikes. (Study areas without scaling)

2.2 Methodology

The landscape analysis of study areas was carried out for two dates: 1958 and 2007. The aerial photographs from 1958 and 2007 were projected onto the SHG73 System (based on Gauss Transverse Mercator projection, ellipsoid of Hayford and Local Datum73), according to the methodology described in [9].

The analysis of land cover change was based on a total of eight cover classes described in [9] including: water areas, built up land, open farmland, shrubland and four forest classes. These forest classes, were defined by a minimum tree density [5]: i) Cork oak woodlands; ii) Eucalyptus plantation; iii) Other broad-leaved forest; and iv) Coniferous forest. The cork oak woodlands comprised a mosaic of three patch-types: oak forest, oak farmland and oak shrubland. In oak farmland and oak shrubland, oaks have densities up to 20 trees per ha, with underlying natural grasslands or legumes for fodder, occasionally cultivated for cereal crops in the former and with encroaching shrub species in the latter. In the oak forest, cork oak is the dominant species, with densities over 20 trees per ha, and with no tree mortality. This forest was classified by: i) canopy cover, in three classes of tree crown area percentage of total area: open: <25%; typical: 25-50%; dense: >50% and ii) by understory, in two classes of dominant vegetation underlying the trees (herbaceous class: dominated by cultivated (bi)annual herbaceous plant communities in pastures alternating with fallow years and; shrubby class: with an increase of woody plant cover, dominated by encroaching shrub species).

For each study area, the annual precipitation time series (1960-2006) was built to detect changes in the rainfall patterns. Readings of annual rainfall data from the five nearest Meteorological Stations, in UL and SB, were considered in this study.

The cork oak woodlands areas discriminated by patch-types will be crossed with reference soil groups within each study areas in a spatial database using GIS (Geographical Information System).

The landscape mosaic characteristics of each study area were analyzed based on vegetation cover metrics calculated by FRAGSTATS vs.3.3 [11]. For this purpose, digital maps of land cover for each year (1958 and 2007) were rasterized according to methodology followed in [9].

To assess the process of change of land use within the landscape vegetation cover class areas were separately computed to quantify and compare change rates in the considered 50-year period. However, transitions matrix were built considering water areas, built up land, other broad-leaved and coniferous forests grouped in one class called Other. Selected metrics at patch level within cork oak woodlands vegetation class were also computed to characterize the fragmentation patterns: number of patches (NP); mean patch area (AWMPS); core area (AWCORE) and; edge contrast with open farmland and shrubland (ECON) (*see* definitions in [11]).

3 Results

3.1 Annual precipitation patterns

In the last 50 years the annual precipitation varied between consecutive years similarly in the two study areas, Periods with enlarged below-mean values were noticed since 1970 (Fig. 3).

Observing the annual precipitation in each 10-years period in the two study areas, were noticed great similarities: i) within the 60's and the 70's only one year (1964) had less than 80% of the mean annual precipitation; ii) the 80's had two years with about half of the mean annual precipitation (1980 and 1982); the 90's were mostly dry (four years with annual bellow-mean rainfall); and 2004 was the driest year of the analyzed time-series, with only 44% and 37% of mean annual precipitation, respectively for UL and SB.

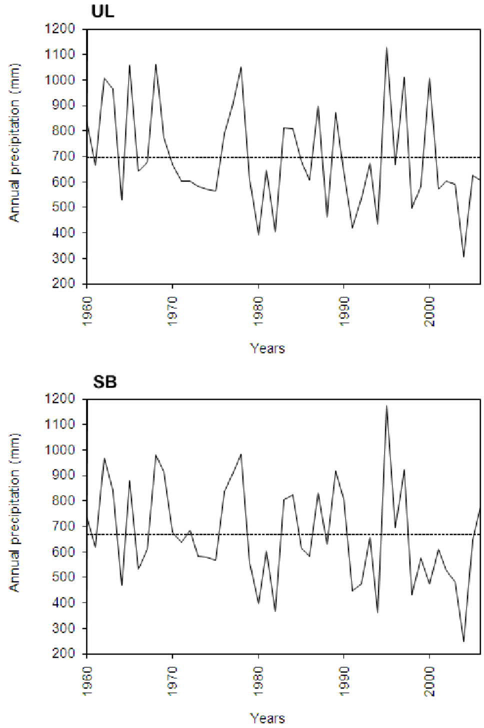

Fig. 3. Annual precipitation time series (1960-2006) in UL and SB. Straight line is the time series mean annual rainfall, 695 mm and 669 mm at UL and SB, respectively.

3.2 Cork oak woodlands loss

In the 1958-2007 period the cork oak woodlands area decreased at UL and SB (Table 1).

Table 1. Cork oak woodlands area discriminated by patch-types canopy cover and understory, in UL and SB, at the initial (1958) and final (2007) years of the study period.

Patch-types	UL Area (ha) 1958	UL Area (ha) 2007	UL Mean annual loss (%)	SB Area (ha) 1958	SB Area (ha) 2007	SB Mean annual loss (%)
Cork oak woodland	4819	3121	-0.7	4697	4110	-0.3
Oak farmland	623	345	-0.9	462	581	0.5
Oak shrubland	171	630	5.5	34	88	3.3
Oak forest	4024	2147	-1.0	4201	3441	-0.4
Open						
herbaceous	368	279	-0.5	917	448	-1.0
shrubby	347	266	-0.5	35	126	5.3
Typical						
herbaceous	297	244	-0.4	1070	705	-0.7
shrubby	249	215	-0.3	77	187	2.9
Dense						
herbaceous	1727	820	-1.1	2040	1784	-0.3
shrubby	1036	324	-1.4	63	192	4.2

This decrease was mostly noticed at UL, with an annual loss of 35 ha corresponding to a reduction of 0.7% in relation to initial area. At SB the mean annual loss was only 12 ha, corresponding to a reduction of 0.3% in relation to initial area, about half of the one in UL.
In both study areas, cork oak woodlands were mostly dense stands. Also, in both areas the oak shrubland was the only patch-type with an area increase for the considered period (oak shrubland increased annually 5.5% at UL and 3.3% at SB).
At SB, between 1958 and 2007, the shrub encroachment was also noticed in the oak forest with shrubby understory patch-types where the area sharply increased, in contrast with the oak forest with herbaceous understory area.

3.3 Cork oak woodlands fragmentation patterns

In the study areas the cork oak woodlands loss was accompanied by a forest fragmentation, i.e. increase of NP and decrease of AWMPS (Table 2).

Table 2. Fragmentation variables (NP-number of patches and AWMPS-mean patch size) at the initial (1958) and final (2007) years of the study period for cork oak woodlands of UL and SB discriminated by patch-types and canopy cover classes.

Patch-types	UL				SB			
	NP (#)		AWMPS (ha)		NP (#)		AWMPS (ha)	
	1958	2007	1958	2007	1958	2007	1958	2007
Oak farmland	108	83	17	12	141	255	10	7
Oak shrubland	50	65	7	35	16	62	3	3
Oak forest								
Open	102	73	24	21	222	225	19	8
Typical	72	71	17	13	214	314	20	8
Dense	145	138	190	41	164	281	77	55
Cork oak woodland	142	184	323	109	61	217	1619	720

The decrease of oak woodland patch area (AWMPS) was noticed mainly at UL (in correspondence with the highest oak woodlands loss, Table 1). At UL, the dense oak forest patches also decreased its mean area to less than a quarter of the initial area (AWMPS of 190 ha and of 41 ha, respectively in 1958 and in 2007).
The oak shrubland showed different fragmentation patterns in both study areas. At UL, was the mean patch size that strongly increased (five-times higher in 2007), for a small increase of the number of patches. At SB, was the opposite, the number of patches strongly increased (four-times higher in 2007), maintaining the average size.
Despite showing similar number of oak shrubland patches in 2007, mean patch size was strongly higher at UL (35 ha at UL against 3 ha at SB).

3.4 Cork oak woodlands core and edge habitats

The cork oak woodlands fragmentation at UL and SB impacted forest core and edge habitats (Table 3A and 3B).
With the exception of oak shrubland patch-type, in all oak woodland area the core area decreased in both study areas. At UL, where the loss and fragmentation of oak woodlands were higher, the core habitat area decrease was mostly noticed.

Table 3A. Core area (AWCORE) and edge contrast (ECON) with open farmland and shrubland at the initial (1958) and final (2007) years of the study period for cork oak woodlands at UL discriminated by patch-types and canopy cover classes.

Patch-types	AWCORE (ha)		ECON (%)			
			Open farmland		Shrubland	
	1958	2007	1958	2007	1958	2007
Oak farmland	10	6	52	12	10	22
Oak shrubland	3	19	40	7	25	34
Oak forest						
Open	14	12	49	14	13	32
Typical	9	7	52	15	5	2
Dense	132	24	60	14	14	20
Cork oak woodland	239	73	76	16	21	35

Table 3B. Core area (AWCORE) and edge contrast (ECON) with open farmland and shrubland at the initial (1958) and final (2007) years of the study period for cork oak woodlands at SB discriminated by patch-types and canopy cover classes.

Patch-types	AWCORE (ha)		ECON (%)			
			Open farmland		Shrubland	
	1958	2007	1958	2007	1958	2007
Oak farmland	5	2	32	27	2	7
Oak shrubland	1	1	10	19	3	22
Oak forest						
Open	11	2	22	24	2	13
Typical	10	3	22	26	2	3
Dense	50	34	26	27	1	10
Cork oak woodland	1328	521	76	57	5	25

The cork oak woodland edges habitat changed along the study period. Oak woodland edges with open farmland decreased while with shrubland increased. In fact, in 1958 cork oak woodland in average had 76% edge length with open farmland in both areas. This length drastically reduced to 16% at UL and to only 57% at SB. In contrast, oak woodland edge length with shrubland increased noticeably at SB (five-times) while at UL increased only from 21% (1958) to 35% (2007), the highest value for edge length percentage with shrubland.

3.5 Cork oak woodlands in relation to soil-types

At UL the cork oak woodlands were mostly located in the undulating steep areas (where Regosols (RG), and Cambisols (CM) are dominant), more than 50% of total oak woodlands area for the study-years, 1958 and 2007 (Table 4A). Dense oak forest showed a clear decreasing trend of its distribution in the flat tops of the Pliocenic terraces and a correspondent increase of occupation of the steep undulating areas of the Miocenic formations with Regosols. On the other hand, oak farmland accentuated its dominance in the flat tops in the former sedimentary formations, in 1958, 46% of oak farmland area was located on Sagnic Luvisols (LV) (289 ha of 623 ha) and in 2007 were 61% (210 ha of 345 ha).
Oak shrubland seems to proportionally increase in LV (from 41% to 46%, respectively in 1958 and in 2007) while decreased in RG and CM (from 57% to 51%, respectively in 1958 and in 2007).

Table 4A. Cork oak woodlands area (ha) discriminated by patch-types and canopy cover classes in relation to representative Reference Soil Groups in UL: Fluvisols (FL), Stagnic Luvisols (LV) and Regosols (RG) and Cambisols (CM).

Patch-types	FL		LV		RG + CM	
	1958	2007	1958	2007	1958	2007
Oak farmland	53	14	289	210	281	120
Oak shrubland	4	19	70	290	98	320
Oak forest						
Open	47	23	314	256	354	266
Typical	40	42	244	206	262	211
Dense	209	105	1000	348	1553	690

Table 4B. Cork oak woodlands area (ha) discriminated by patch-types and canopy cover classes in relation to representative Reference Soil Groups in SB: Fluvisols (FL), Haplic Leptosols (LPx) Epileptic Luvisols (LVx) and Haplic Arenosols (AR).

Patch-types	FL		LPx		LVx		AR	
	1958	2007	1958	2007	1958	2007	1958	2007
Oak farmland	10	5	402	370	48	188	2	18
Oak shrubland	0	1	34	84	0	4	0	0
Oak forest								
Open	7	2	759	487	171	81	11	4
Typical	7	4	868	702	250	168	21	15
Dense	10	5	1520	1559	512	366	57	46

In SB, cork oak woodlands were mostly located in the Leptosols developed on schists (LPx), almost 80% of total oak woodlands area, for both study-years, 1958 and 2007 (Table 4B). Also, in LPx was located the largest area of oak shrubland.
In LPx, dense oak forest maintained or showed a small increase of its area within the study period (from 1529 ha to 1559 ha, respectively in 1958 and 2007). In contrast, oak farmland area decreased in the LPx (from 87%, 402 ha of 462 ha, to 64%, 370 ha of 581 ha, respectively for 1958 and 2007) and showed a strong increase in the Luvisols on schists (LVx) (from 10%, 48 ha of 462 ha, to 32%, 188 ha of 581 ha, respectively for 1958 and 2007).

4 DISCUSSION

Considering the high annual mean loss rate of evergreen oak woodlands in UL, it is expected that this ecosystems will disappeared in this region within the next 100-year period.
Furthermore, these oak woodlands showed an intense fragmentation with a drastic reduction of core area (core area decreased about 70% of the initial area) and a complete change of edge habitats mainly in result of the introduction of new large afforestation areas with Eucalyptus [9], that replaced previous oak farmland areas and, in less extent, oak woodlands areas in Stagnic Luvisols (*see* Fig. 4A).

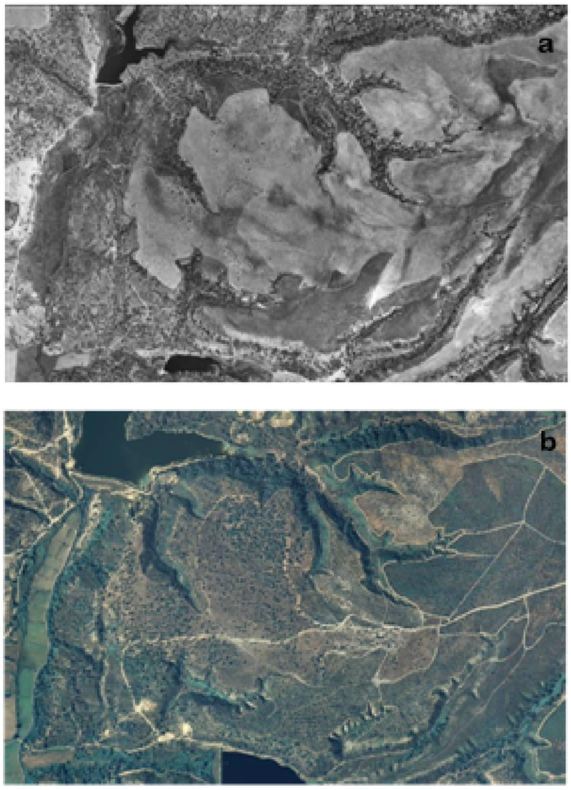

Fig. 4A. Aerial photographs of UL from 1958 (a) and 2007 (b) showing the landscape features and land cover changes, e.g. Pliocenic terraces with open farmland in 1958 that changed to Eucalyptus plantations in 2007. Cork oak woodlands maintained its location in steep slopes with shrub understory.

The dense oak forest maintained its main location in the steep undulating areas, some of them severely affected by erosion in active gullies, where farmland was not possible and where afforestation with Eucalyptus was avoided (*see* Fig. 4A).

These oak woodlands habitat dynamics and landscape structural changes (e.g. fragmentation and interspersion) may negatively affect oak system sustainability as regards the lack of natural tree regeneration hotspots and the occurrence of cork oak decline and mortality [6,13]. However, shrubland areas at UL were mostly fire-driven and can be considered a transitory successional path before cork oak woodlands [11, 15].

In Mediterranean areas, under high annual rainfall irregularities, in, a scenario of increasing drought periods, the soil properties like nature of parent material or soil depth, more directly and strongly influence the tree growth [5]. In fact, soil-site relationships are clear: soils with high profile depth and/or with unconsolidated or fractured parent material that would allow the tree deep-rooting and consequently the access to deep soil water, the reliable source of water for oak trees in summer, would allow the tree growth; in contrast, shallow soils or/and compacted parent material would negatively affect the survival of the trees.

At UL, dense oak forest was strongly reduced at Stagnic Luvisols, mainly by the pressure of Eucalyptus plantations. On the other hand, the reduction of area of this patch-type at Regosols and Cambisols (over Miocenic formations) in steep slope areas (to less than half) may be linked to the fact that these soils are mostly developed on consolidated materials, close to the surface, determining a reduced soil depth, with low nutrient and moisture supplies.

Despite socioeconomic drivers of oak woodlands loss [9], the cork oak montado sustainability at UL may be also threatened by site biophysical characteristics that differently promote the oak growth, in scenarios of increasing drought periods, as verified since the latest 1970's.

A restoration strategy for the oak woodlands conservation at UL should therefore include the preservation of natural oak regeneration areas, by protecting saplings and young regeneration trees with individual fences or by making some grazing management adjustmens, e.g creating temporary non-grazing areas allowing regeneration[9]. In fact, according to [14] a 20-year period is needed to allow tree recruitment.

At SB, based on the loss rates found, it is expected that this ecosystems will prevail for next three centuries. However this area has been considered as an endangered region regarding cork oak decline [12]. The shrub overgrowth and the consequent invasion and interspersion of oak woodlands by sclerophylous species (e.g. Cistus spp.), better adapted to stronger soil and climate constrains, could corroborate previous comments referring that shrub encroachment could hindered the oak trees growth, especially in this scenario of increasing dryer years [5].

In addition, in schists landscapes, the deeper soils LVx mainly located in gentle slopes, showed strong pressure of grazing and livestock (*see* Fig. 4B) may hinder oak forest recovery. In contrast, shallow soils located in steeper slopes (LPx), but with a vertical fracturation of parent material, may allow the tree deep-root and the tree growth (with low grazing pressure).

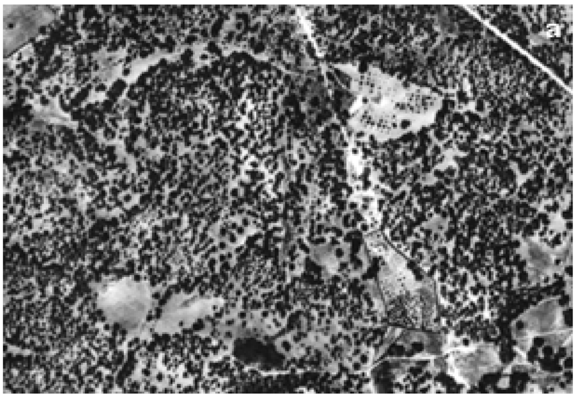

Fig. 4B. Aerial photographs of SB from 1958 (a) and 2007 (b) showing the landscape features and land cover changes, e.g. in Luvisols on schists, in gentle undulating areas, subjected to high grazing pressure (represented by the high number of ponds), cork oak woodlands clearance and thinning are visible.

The cork oak montado sustainability at SB is thus threatened by the increasing shrub encroachment, a direct consequence of lack of forest management (land use extensification), and by livestock (land use intensification). Conservation of this ecosytem implies the reduction of stocking rates and grazing pressure, within gentle slopes of LVx and the agri-environmental measures, promoting shrub management and afforestation, within LPx by future CAP policy tools.

In both study areas, the soil-site characteristics determining the access of the tree to below ground water during summer drought have an important role on cork oak woodlands loss. Also, a long-term absence of land use may lead to a significant increase in competition for soil water and nutrients between trees and shrubs and therefore to a potential cork oak decline

5 CONCLUSIONS

This study, made at landscape level, over a large 50-year time span, was a first approach to site soil-water availability to cork oak woodlands under stressing climate conditions, namely increasing dryer years (with below-mean enlarged periods).
The results achieved regarding sensitive soil groups or shrub overgrowth, in relation to available soi-water resources, were conclusive and in accordance to results obtained by other authors.
In addition to socioeconomic drivers, typical of a cultural traditional system like *montados,* and to different biophysical conditions, namely relatively low, highly seasonal and uncertain rainfall and reduced buffering against meteorological extremes (e.g. shallow soils or steep slopes), the cork oak woodlands dynamics may be enhanced by a global warming scenario, with increasing drought periods. Further work is needed and a more precise approach should be carried out to have a more clear and precise relationship between climate change effects and cork oak decline.

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REFERENCES

[1] R.Vallejo, J. Aronson, J.G. Pausas and J. Cortina, “Restorarion of Mediterranean woodlands”, *Restoration ecology: The new frontier*, J. Van Andel and J. Aranson, eds., Oxford, UK: Blackwell Science, pp. 193-207, 2006.
[2] R. Joffre, S. Rambal and J.P. Ratte, “The dehesa system of southern Spain and Portugal as a natural ecosystem mimic”, Agroforest Syst, vol. 45, pp. 57-79,1999.
[3] T. Plieninger, F.J. Pulido and W. Konold, ”Effects of land-use history on size structure of holm oak stands in Spanish dehesas: implications for conservation and restoration”, Environ Conserv, vol. 30(1), pp. 61-70, 2003.
[4] R. Joffre and S. Rambal, “Tree-grass interactions in the south-western Iberian Peninsula dehesas and montados”, Secheresse vol. 17(1-2), pp. 340-342, 2006.
[5] A. Costa, M. Madeira, A.C. Oliveira, “The relationship between cork oak growth patterns and soil, slope and drainage in a cork oak woodland in Southern Portugal”, For Ecol Manag, vol. 255, pp. 1525-1535, 2008.
[6] A. Costa, H. Pereira and M. Madeira, “Analysis of spatial patterns of oak decline in cork oak woodlands in Mediterranean conditions”, Ann For Sci, vol. 67(2), DOI: 10.1051/forest/2009097, 2010.
[7] L. Cayuela, D.J. Golicher, J.M.R. Benayas, M. Gonzalez-Espinosa and N. Ramirez-Marcial, “Fragmentation, disturbance and tree diversity conservation in tropical montane forests”, J Appl Ecol, vol. 43, pp. 1172-1181, 2006.
[8] M.L. Cadenasso, S.T.A. Pickett, K.C. Weathers and C.G. Jones, “A framework for a theory of ecological boundaries”, BioScience, vol. 53(8), pp. 750-758, 2003.
[9] A. Costa, M. Madeira, J. Lima Santos and A. Oliveira, “Change and Dynamics in Mediterranean evergreen oak woodlands landscapes of South-western Iberian Peninsula”, Landscape and Urban Planning, in press, 2011.
[10] World reference base for soil resources. A framework for international classification, correlation and communication, World Soil Reports, vol. 103, Rome: FAO, 2006.
[11] K. McGarigal, S.A. Cushman, M.C. Neel and E. Ene, “FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps”, Computer software program produced by the authors at the University of Massachusetts, Amherst, 2002.
[12] A. Costa, H. Pereira and M. Madeira, “Landscape dynamics in endangered cork oak woodlands in Southwestern Portugal(1958-2005)”, Agroforest Syst, vol. 77(2), pp. 83-96, 2009.
[13] A. Costa, M. Madeira, J. Lima Santos and J. Seixas, “Loss, clearance and fragmentation processes in evergreen oak woodlands of South-western Iberia”, Landscape Ecol, *submitted for publication*, 2011.
[14] J.A. Ramírez and M. Díaz, “The role of temporal shrub encroachment for the maintenance of Spanish holm oak *Quercus ilex* dehesas”, For Ecol Manage, vol. 255, pp. 1976-1983, 2008.
[15] T. Plieninger, V. Rolo and G. Moreno, “Large-scale patterns of Quercus ilex, Quercus suber, and Quercus pyrenaica regeneration in Central-Western Spain”, Ecosystems, vol. 13, pp. 644-660, 2010.