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Traditional systems in a contemporary context - Livelihoods, biodiversity and global change in Portuguese cork oak woodlands

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@Artur Pastor – extração da cortiça/*cork extraction* [1950's]

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Abstract

Cork oak woodlands are a complex socio-ecological system which has been managed for centuries for different goods and uses. This woodlands are considered amongst the best preserved low intensity farming systems, and its persistence suggests a sustainable system that simultaneously generates environmental and social benefits. However, recent changes in socio-economic and climate conditions are threatening the woodlands equilibrium and the resources it was originally designed to provide. This study aimed to understand if cork oak woodlands can persist under current socio-economic and ecologic conditions and if so, to which extent the system will continue to maintain biodiversity while securing livelihoods of people that depend on it. To do so, I measured past and present interaction strength between the social and ecological component and how they are responding to ongoing changes. The results suggest that the cork oak woodlands are likely to persist as the system seems to be responding to changes by enhancing novel uses and goods of the system and that economically it is still profitable. However both traditional and new are increasingly benefiting outsiders, whilst locals turn to other sources of income. Further, the ecological system is being stressed by climate conditions and cork oak tree health and cork quality may be decreasing. Biodiversity values for the study area where lower than expected for multi-functional woodlands. Thus at the present, the system is not delivering synergies between its human and environmental components.

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Introduction

One of the most pressing challenges concerning today's society is on how to achieve sustainable outcomes that benefit both people and the environment (Kates *et al.* 2001). Simultaneously, there is a growing acknowledgment that some of the most biodiverse sites overlay with human-dominated landscapes (Myers *et al.* 2000), showing human interference is not inherently deleterious to nature. Many studies have since examined social-ecological systems (SES) and sought to identify features compatible with a sustainable development (e.g. Redman 1999; Folke *et al.* 2002; Ostrom 2009). Despite the scholars efforts, the complexity of SES hinders the understanding of outcomes of human-nature interactions (Liu *et al.* 2007), and pathways for synergies across multiple social and ecological goals remain unclear.

Traditional systems

Notoriously many European traditional farming systems, while managed to address societal needs, developed heterogeneous compositions that granted them richer biodiversity than their primitive states (Blondel 2006). Traditional systems are those that use traditional land use practices, which include "practices that have been out of fashion for many years and techniques that are not generally part of modern agriculture" (Bignal *et al.* 1996). Common traditional practices include multiple uses of the same land, such as polyculture or integration of forestry and agricultural practices, low mechanization, low input of nutrients and low yield per hectare (Bignal and McCracken 1996; Vos and Meekes 1999; Plieninger *et al.* 2006). These differ from postmodern agriculture, which usually relies on monocultures, use of agrochemicals and mechanization to achieve higher yields (Vos and Meekes 1999).

Low-intensity farming systems bear a significant role in Europe's biodiversity (Bignal and McCracken 1996; Plieninger *et al.* 2006), but such landscapes are disappearing. For example, streuobst, a system from temperate Europe which combines fruit trees with pastures and animals, has been gradually replaced by intensely managed orchards as traditional trees are replaced by fast growing species and increasing tree density to allow for mechanization (Herzog 1998; Eichhorn *et al.* 2006). Contrasting, other systems such as Mediterranean mountain areas, are being marginalized, leading to shrub encroachment under the lack of human interference (Lasanta *et al.* 2001). Thus, whilst the biodiversity value of traditional landscapes is widely recognized, current degradation trends raise questions on their sustainability (Moreno and Pulido 2009).

Cork oak woodlands: the system and its uses

Oak woodlands, called *montados* in Portuguese, cover around 3 million hectares within the Iberia Peninsula (Ribeiro *et al.* 2010) and are considered one of the best conserved low-intensity agroforestry systems (Bignal and McCracken 1996). The system is characterized by an uniform tree cover, that can vary between 20 and 120 trees.ha^{-1}, dominated by holm oaks (*Quercus ilex*) or cork oaks (*Q. suber*), depending on the region (Pinto-Correia 1993). Southern Portugal has the largest cover of cork oak stands and the country is the biggest producer of cork, which accounts for 757.8 million euros in national exports (INE 2016).

In cork oak woodlands, cork harvest is the main economic activity but other products, such as mushrooms, cereals or livestock, are also harvested (Berrahmouni *et al.* 2007). Best practices for cork harvest inflict no harm to the trees, and harvest can be done in cycles of 9-12 years (Pausas *et al.* 2009). The natural scrubland is usually cleared every 4-7 years, minimizing the chances of wildfire, allowing for pasture and agricultural activities, and reducing nutrient competition with the trees (Pinto-Correia 2000; Moreno *et al.* 2013). The resulting spatial and temporal variability creates heterogeneity, habitat that supports diverse animal and plant species, and offers diverse ecosystem services (Bugalho *et al.* 2011). The system is also acknowledged for its importance to regional identity, and aesthetic and cultural value (Costa *et al.* 2009; Pinto-Correia *et al.* 2011).

Cork oak woodlands under global change

Cork oak woodlands are known to be resilient, and able to adapt to societal demands, maintaining a dynamic equilibrium amongst its different components (Pinto-Correia and Godinho 2013). Still, alike other traditional agroforestry systems, the extent covered by cork oak woodlands has been diminishing over the past decades (Eichhorn *et al.* 2006; Pinto-Correia and Godinho 2013). This decline of the woodlands has been attributed to different factors including (i) the introduction of new technologies, complaisant with a more intensive and productive agriculture and abandonment of traditional practices (Pinto-Correia 2000; Costa *et al.* 2010), (ii) rural depopulation that deprived the system from abundant and cheap labour (Pinto-Correia and Godinho 2013), and (iii) bad management and practices (Pinto-Correia *et al.* 2011). These are mainly due to changes in market, policy, technology and socio-economic conditions (Pinto-Correia 1993; Pinto-Correia and Mascarenhas 1999; Schnabel 2004; Pinto-Correia *et al.* 2011).

Consequences of the aforementioned factors often translate into: (i) over-exploitation of the tree cover, as cork harvest and pruning happen in unbalanced terms which harms and weakens the trees (Pinto-Correia and Godinho 2013), (ii) intensification of activities in the understory, such as overgrazing and mechanized ploughing, that increase soil compaction and erosion risk and affect the trees' root system, weakening the trees and hindering natural regeneration (Pinto-Correia and Mascarenhas 1999, Bugalho *et al.* 2010), (iii) shrub encroachment in less intensely managed areas, which may lead to a higher regional (gamma) diversity (Pérez-Ramos *et al.* 2008; Pinto-Correia and Godinho 2013), but increases competition with trees (and potentially decreases cork production) and the risks of wildfire (Pinto-Correia and Mascarenhas 1999). Alternatively, new functions such as agro-tourism are emerging, and there is an increase in non-productive activities as hiking or photography. However, landowners in these areas still prefer agriculture and other productive practices (Surová and Pinto-Correia 2009).

In addition to changes in land management strategies, environmental hazards such as droughts and wildfires (Acácio *et al.* 2009), and the incidence of diseases (e.g. *Phytophthora cinnamomi*), increase stress factors and decrease cork oak productivity and ecosystem functioning (Moreira and Martins 2005; Camilo-Alves *et al.* 2013).

Sustainability in cork oak woodlands

The tight links between humans and nature in cork oak woodlands are widely recognized, and it is hard to address the system other than as a SES, where both dimensions are considered in tandem (Santos and Thorne 2010). Sustainability in this SES is dependent on the interaction strength between its social and ecological components and joint outcomes it can generate (Bugalho *et al.* 2011; Persha *et al.* 2011, figure 1). The persistence of this SES for over 12 centuries suggests a sustainable system that simultaneously generates environmental and social benefits. However, recent and rapid changes in socio-economic and climate conditions are affecting the SES equilibrium and the resources it was originally designed to provide (Pinto-Correia *et al.* 2011).

The continuous decrease of the woodlands seems to indicate that the system is responding to ongoing changes, however, pathways of development are not certain. Some authors see this as an opportunity to allow for natural succession to occur, culminating in the revival of extinct Mediterranean forests, arguing traditional systems do not represent best adaptations to present and future social and ecological conditions (Navarro and Pereira 2012; Henne *et al.* 2015). Contrasting, the resilience of the system, reinforced by protection measures, and its cultural relevance next to its ecologic and economic value suggest the system will be maintained (Bugalho *et al.* 2011; Pinto-Correia and Godinho 2013; Godinho *et al.* 2016). To understand possible future pathways it is needed to examine to which extent the woodlands are resilient to economic and climate changes, and if so to which extent the system can maintain its biodiversity while securing livelihoods of people that depend on it.

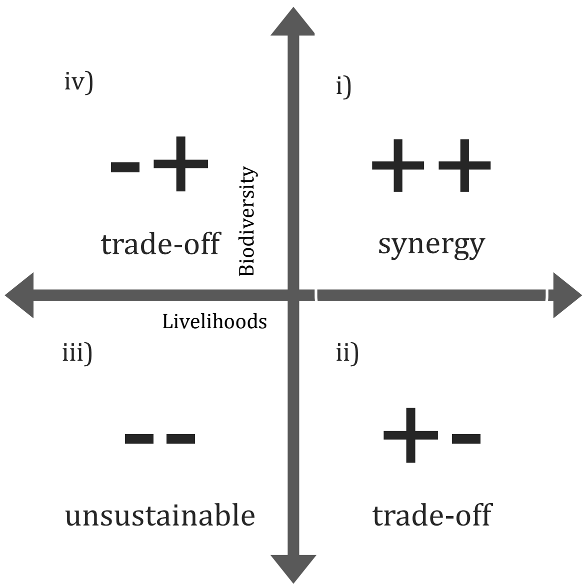


Figure 1. Graphic representation of possible joint outcomes between livelihoods and biodiversity. The X axis represent the human dimension, illustrated in this study through the use and collected goods from the woodlands; and the Y axis the environmental dimension, with understory diversity as a surrogate for biodiversity. The possible categories are i) synergy, when the system provides a significant contribution to the local community' livelihoods whilst maintaining its unique biodiversity; ii & iv) trade-offs, either when the woodlands have a positive contribution for local communities, but with consequences to the system's biodiversity, or when enforced measures to safeguard biodiversity hinder the contribution of the woodlands to the population livelihoods, and ii) negative-negative, when the system fails to provide positive outcomes to both its social and environmental dimension.

Aim & research questions

This study aims to examine the ability of Portuguese cork oak woodlands to persist considering current (and future) ecological and socioeconomic settings. The objective is to identify the contribution of the system to local livelihood as well as what is its biodiversity potential. There is also an emphasis in change, both of human use and in the resource system itself, to examine to each extent changes in the resource system are influencing the interaction strength between social and environmental components. From here arises the following research question:

Can cork oak woodlands persist under present social and ecological conditions and if so, can they benefit local livelihoods and biodiversity simultaneously?

- What is the relevance of cork oak woodlands and its products to local communities' livelihoods?

  Considering the increased mechanization of labour over the past decades, and trends of abandonment of the system (Pinto-Correia & Mascarenhas 1999), I expect to find that cork oak woodlands play a less important role on local population's income source as people moved away or focused on alternative sources of income to the traditional activities. This would mean that the non-commercial use of goods and services from cork oak woodlands could contribute to local livelihoods and therefore counteract the negative effects of loss of traditional uses of the system (Stryamets *et al.* 2012). As cork oak woodlands provide a wide array of products and ecosystem services, I expect households to use and benefit from them both currently and in the past although with a different and reduced contribution. Alternatively, novel uses may have emerged that do no longer link people to the cork oak woodlands, resulting in a reduction in value.

  Due to the decreasing market value of cork, mainly due to substitution for synthetic materials in wine stoppers (Aronson *et al.* 2009), and consequent decreased interest in exploring cork oaks I expect a decrease in harvested cork.

- What is the biodiversity potential of cork oak woodlands?

  The human use that led to the evolution of Mediterranean forests into cork oak woodlands, also lead to the design of a more complex landscape , with higher alpha and gamma diversity than its original format (Blondel 2006). The maintenance of the system's high biodiversity is dependent on human interference (Bugalho *et al.* 2011). Considering that extensification and abandonment are currently main trends to the system's management, I expect this to translate into a decrease in cork oak woodlands biodiversity.

- What is the interaction strength between livelihoods and biodiversity and to which extent is it responding to ongoing changes in the resource system?

  Interactions between humans and the ecosystem in cork oak woodlands have been forged over a long period of land management and thought to, through a dynamic equilibrium and evolving practices, benefit economic, social and environmental concerns simultaneously (Pinto-Correia *et al.* 2011). Nevertheless, current degradation trends of the system are raising questions on the sustainability of the woodlands, and I expect to find evidence that cork oak woodlands are not providing positive outcomes for both its social and natural components (figure 1). This unbalance of the system is often pinned on anthropogenic factors. However, cork oak woodlands are susceptible to environmental hazards and to climate extremes (Acácio *et al.* 2016), and our previous analysis showed changing trends in the resource system's primary productivity, hinting changes in the resource system (Santos *et al.* 2016). As so, I expect to find evidence that changes to cork oak woodlands dynamics can be, at least in part, explained by changes in the resource system.

Methods

The study area

The study area is located in Serra de Grândola (Alentejo, Portugal; Figure 2). The region is characterized by a matrix of cork oak (*Quercus suber*) woodland, with patches of holm oak woodland (*Q. ilex sub-spp. rotundifolia*), pastures, scrublands, gum tree plantations (*Eucalyptus globulus*) and urban settlements (Santos & Santos-Reis 2009). The topography is moderate, with gentle slopes and low altitude and the soil low in fertility and scarce in water. The climate is Mediterranean with Atlantic influence, mean annual precipitation of 500mm and maximum average daily temperatures ranging between 5˚ to 35˚C (Santos & Santos-Reis 2009).

The parish of Santa Margarida da Serra and the parish of Grândola were merged in 2013, under new terms of national administrative parish organization. The borders of the old parish of Santa Margarida da Serra where taken as guide lines to delimit the research area to a reasonable size, which enclose a surface of about 5240 ha. In the census of 2011 the parish of Santa Margarida da Serra had 177 inhabitants (INE 2011). Individual houses within the woodlands (*montes*, in Portuguese) used to be the most common form of residency. However, migration movements within the parish lead to a gradual transference of people from the periphery to the village, with the same name as the parish, where the majority of the population is now living (Santos 2004).

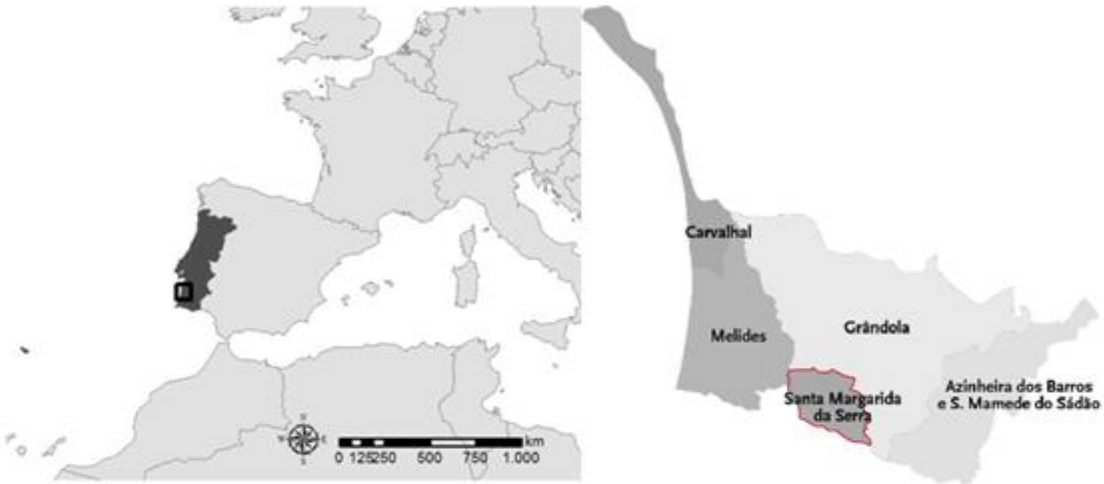


Figure 2. a) Location of the study area in Serra de Grândola, Portugal. b) Map of parishes of Grândola, and demarcation of Santa Margarida da Serra (in red).

Data collection

Interviews

To understand how the local community uses and perceives the woodlands, this study resorted to a participatory approach. Data was collected using a semi-structured interview approach as it allows to get quantitative data, relevant for a generalization of the population, but also qualitative data on perceptions of the system and quality of life (Bryman 2006). Residents of the parish were questioned on their income sources, harvested products and their use, harvest methods, perceived preservation state of the *montado,* and the easiness of access to certain services as indicators of life quality. The respondents were also asked to recall changes in their use of the *montado* and the motivations behind such changes, to have a comparison between past and present use. The interviews were guided by a script; however, interviewees were given freedom to talk about the subject. The interviews were not recorded, out of fear of hesitation in cooperating. Instead, notes of relevant points were taken and a more complete summary was written *a posteriori*. Table 1 presents a summary of the information gathered through interviews.

Interviews were conducted between March and May 2016. 22 participants in the study were selected using a nonprobability sample of residents in the community, i.e., no effort was made to sample each element of the population with a fixed probability. Within the village interviews were conducted in the cafes, with the people willing to participate. These comprised both residents and non-residents of the village. To include people living in *montes*, houses that appeared to be inhabited were visited and the willing inhabitants interviewed. It is important to note that respondents here designated as "outsiders" represent a rather diverse group which includes former inhabitants, living now abroad but frequent visitors, urban dwellers that own holiday houses in the village or *montes*; inhabitants of Grândola or neighbouring localities that work or have business in the parish, and a rural tourism establishment owner, located near, but outside the parish (figure 3).

Table 1. Summary of the data gathered during interviews, the variable it relates to, the information asked for, and how it was quantified for analytical purposes.

Variable	Information	Quantification
Reliance on the woodland		
As income source in the past	profession	none/additional/main
As income source at the present	profession	none/additional/main
For use	goods and uses	#uses, commercial/personal
Changes in use	goods and uses	stop/decrease/same/increase
Life quality		
Access to services	education, health, food, culture, Grândola, police, water, electricity	1-very hard, 2- hard, 3- nor easy nor hard, 4-easy, 5- very easy
Changes in access to services	education, health, food, culture, Grândola, police, water, electricity	harder/same/easier
Perception on woodlands and their change		
Changes	# trees, tree health, cork quality, air quality, rain, understory cover, animals, plants	decrease/same/increase
Perceptions	subsistence form, income source, recreational, cultural identity	
Conservation		agrees/disagrees

Field data

To collect data on land use, five transects with lengths between 2.5 and 3 kilometres each were set. The starting point and direction were randomly chosen, but the route was dependent on existing paths and tracks,, as they often pose as boundaries to different land uses.. Signs of human disturbance were registered by noting the following variables: presence of beehives, presence of livestock, cork harvesting intensity, and type of use.

Twenty-four nested plots were set alongside the transects. These included one ten meter circular plot, within which one nested 3 meter diameter plot was established, following the protocol of the International Forest Research Institute (IFRI) Field Manual (Ostrom, 2008) to characterize plant cover and species diversity. Within the 10 m plots I recorded signs of soil degradation (present/absent), fire damage (presence of fire scars) and hydric stress (dead branches and/or defoliation). I also recorded the number, species identity and perimeter at breast height (pbh, in cm) for trees and woody shrubs. For cork oaks, additional information on maximum harvesting height (hh, in meters) and year of harvest (yoh) was collected. Seedlings, saplings, and herbaceous cover were sampled within the smaller plot. Species were visually identified and unknown individuals where drawn, photographed and posteriorly identified with the help of field guide (Santos-Reis and Correia 1999)and the online platform of Portuguese flora *Flora-On* (found at *flora-on.pt*)

In addition to the oak stand within the plots, other oak stands were sampled at random locations within the study area, following the same procedures. This increased sample size and allowed for more representative data on cork oak stands and cork extraction,

Remote sensing data

Information on the system's primary productivity and phenologic evolution was gathered through remotely sensing the time series of the Enhanced Vegetation Index (EVI; Melaas *et al.* 2013) for the study area (Santos et al. 2016). EVI is particularly well suited for cork oak woodlands, because this vegetation index is generally less affected by the saturation of dense canopy covers characteristic of cork oak woodlands than the most commonly used Normalized Difference Vegetation Index (NDVI; Huete *et al.* 2002). EVI was calculated from a time series of Landsat images from 2000 to 2013. Within a previous work (Santos *et al.* 2016), all images were processed to surface reflectance values using the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS; Masek *et al.* 2006), and (b) masking all clouds and cloud shadows using Fmask (Zhu and Woodcock 2012). EVI was then calculated for each processed image as follows:

$$\mathrm{EVI} = \mathrm{G} \times \frac{\rho_{\mathrm{NIR}} - \rho_{\mathrm{R}}}{\rho_{\mathrm{NIR}} + \mathrm{C}_1 \times \rho_{\mathrm{R}} - \mathrm{C}_2 \times \rho_{\mathrm{B}} + \mathrm{L}}$$

Where ρ_x is the surface reflectance for band × (NIR = shortwave infrared band, R = red band, B = blue band), L is the canopy background adjustment, C1 and C2 are the coefficients of the aerosol resistance term, and G is the gain or scaling factor (Huete *et al.* 2002). The range of values for EVI is -1 to 1, where negative values indicate the presence of clouds, snow or water, and positive values are positively correlated to green vegetation density (Chen *et al.* 2006).

Data analysis

Social system

I first used descriptive statistics (mean, standard deviation) to describe the users and their living place, income sources and use of the woodlands and to understand who benefits mostly from the woodlands and for which uses.

I classified the uses of the woodlands in personal and commercial, and goods and uses. *Commercial* use happens if there is income generated either by revenues from sale or for harvesting work. If there no income is generated, and the user directly usufructs from the service or good it is considered for *personal* consumption. Tangible goods that can be collected or harvested are from hereafter referred to as *goods*, whereas the conditions and processes need to obtain such goods, or benefits either intangible or delivered over a period of time fall under the category of *uses*. Such classification scheme helps to have a better understanding on the contribution of the woodlands to its user's livelihoods. The contribution of the woodlands as income source was discriminated between main, when the interviewee profession is directly linked to the woodlands; additional, if the woodlands provide additional income next to job, and none, when no income (or negligible income) is derived from the woodlands.

To understand if living place or the income retrieved from the woodlands influences how the interviewees benefit from the system, I used chi-square tests to assess whether they differed in number of uses and use type (commercial or personal). The scores of easiness of access to services were averaged and differences in assess between user groups where tested through a Kruskal-Wallis test.

I calculated the proportion of interviewees with the same answers on the perceived changes to the woodlands, the drivers of such changes, conservation measures and on the perception of the woodlands, to detect if users are changing practices due to changes in the resource system. Chi-square tests were used to understand if answers differed amongst different groups of users.

Natural system

Land cover was classified according to the characteristics of both the canopy and understory as follows: dense cork oak woodlands with understory (DCoW), dense cork oak woodlands without understory (DCoWt), sparse cork oak woodlands with understory (SCoW), sparse cork oak woodlands without understory (SCoWt), riparian vegetation (RV), eucalyptus plantations (EP) and pine plantations (PP).

Species diversity within the sampling plots was calculated using the Shannon-Weaver (H') and Simpson (D) indices. Both are fairly simple and widely used to measure biological diversity (Clergue *et al.* 2005. The Shannon index is sensitive to rare species and the Simpson index gives more weight to common species, the use of both allows for a more accurate characterization of diversity (Nagendra 2002):

$$H' = -\sum_{i=1}^{S} pi \times \ln(pi)$$

Where, S = total number of species, pi = proportion of individuals of species i, i.e. number of individuals of species i divided by the total amount of individuals found in the plot (N) (ni/N) (Shannon and Weaver 1949). In addition, the index also measures maximum diversity (Hmax) and evenness (E),

$$H_{max} = \ln(S)$$

$$E_H = \frac{H}{H_{max}}$$

Inverting the Simpson original index (D'=1/D) makes the index increase as diversity increases, making it more intuitive to interpret (Morris *et al.* 2014),

$$D' = \frac{1}{\sum_{i=1}^{S} pi^2}$$

$$D_{max} = S$$

$$E_D = \frac{D'}{D_{max}}$$

Shannon index values generally vary between 1.5 and 3.5, and high value indicates high diversity. Inverted Simpson index varies between 1 and the maximum number of found species. Maximum diversity is the highest value the index can score and describes a situation where pi is the same for every species, meaning all species have equal abundance. Evenness ranges between 0 and 1, and represents the degree to which individuals are split among species, with low values indicating one or few species dominate and 1 representing equal abundance, i.e, maximum diversity (Morris *et al.* 2014).

As they give information at species level, these indices are usually used to measure alpha diversity. However, they can be adapted to reflect landscape diversity, and thus provide information on gamma diversity (Nagendra 2002). Land cover type diversity was calculated using the same indices, using the different land cover types and their proportion along the transects. The land cover was not always the same on both sides of the transects. Thus in addition to calculate diversity indices, also discrepancies were registered to have a better perception on land cover variability and on human use boundaries.

To examine how accessibility affects plant diversity, I used a Kendall's tau to look for correlations between plot's diversity and distance to human settlements. The influence of soil degradation, fire damage and hydric stress on plant's diversity was calculated using a Mann-Whitney test.

Interaction strength

Joint outcomes - Interactions between the social and the natural system where assessed based on joint outcomes between the contribution of the woodlands to the local population and its biodiversity. The outcomes for each component where considered to be positive or negative, and the joint outcome placed within one of the four quadrants of figure 1. Outcomes for the social component where considered positive if the system was favouring local livelihoods over non-local. Outcomes for the natural component where considered positive if the system was able to deliver the characteristic high alpha and gamma diversity values of cork oak woodlands (Blondel 2006; Santos and Thorne 2010).

To examine if changes in the resource system are affecting interactions strength within the woodlands I looked for connections between EVI and (i) cork extraction, (ii) changes in interviewees using behaviour and (iii) plot diversity.

EVI trends - Changes in the resource system were examined through the variability in EVI. Trends of change within the EVI time series were calculated using a Kendall's tau, a common test to detect trends in time series (e.g., Santos et al. 2016).

EVI was computed for random locations within the study area to provide a proportional representation of each land cover, and prior to the field work. For this study, only points that had an influence area where oak stands, plots or interview places fell within were considered. To define the influence areas, I delineated Thiessen Polygons (for examples see Manies and Mladenoff 2000; Gutiérrez and García-Palomares 2008), as these polygons are designed by assigning each data point the geographic area that is closest to that point relative to all other points (Brassel and Reif 1979).

Cork extraction - The harvest surface (hs; cm^2) offers a good indicator of cork production, balancing precision and applicability (Ferreira and Carvalho Oliveira 1991). Its calculation is derived from the perimeter of a cylinder, and can be derived from the perimeter at breast height (pbh; cm) and harvesting height (hh; cm):

$hs = pbh \times hh$ (Costa et al., 2002).

Years since harvest (ysh) were calculated assuming a 10 year cycle, where for a tree stripped in 2015 it has been one year since harvest, and for a tree stripped in 2006 is has been ten years since harvest.

Changes in use – Differences between past and present income derived from the woodlands were analysed using Wilcoxon Signed rank test. This test allows to find significant differences between paired, non-parametric variables (Demšar 2006). The significance of the reported changes in use where calculated using chi-square tests.

Plot diversity – I used a Kendal's tau to look for correlations between understory diversity and EVI. Further, I used plot information to assess if environmental factors are affecting primary productivity. Differences in EVI between plots that showed evidence of soil degradation, fire damage and hydric stress and plots that did not, where calculated using a Mann-Whitney test.

Results

Local community and the woodlands

In total 22 interviews were conducted. Finding interviewees revealed to be more difficult than anticipated, as the people found in the cafes were often the same and a large amount of *montes* was either abandoned or made into weekend-houses, and empty at the time of the research. The interviewees can be labelled according to their living situation: village (n=6), *montes* (n=8), and outside the parish of Santa Margarida da Serra (n=8). Except for 2 interviews that were actively selected and took place in Grândola and in João Mendes, the remaining interviews took place in the village where the interviewees could be found (figure 3).

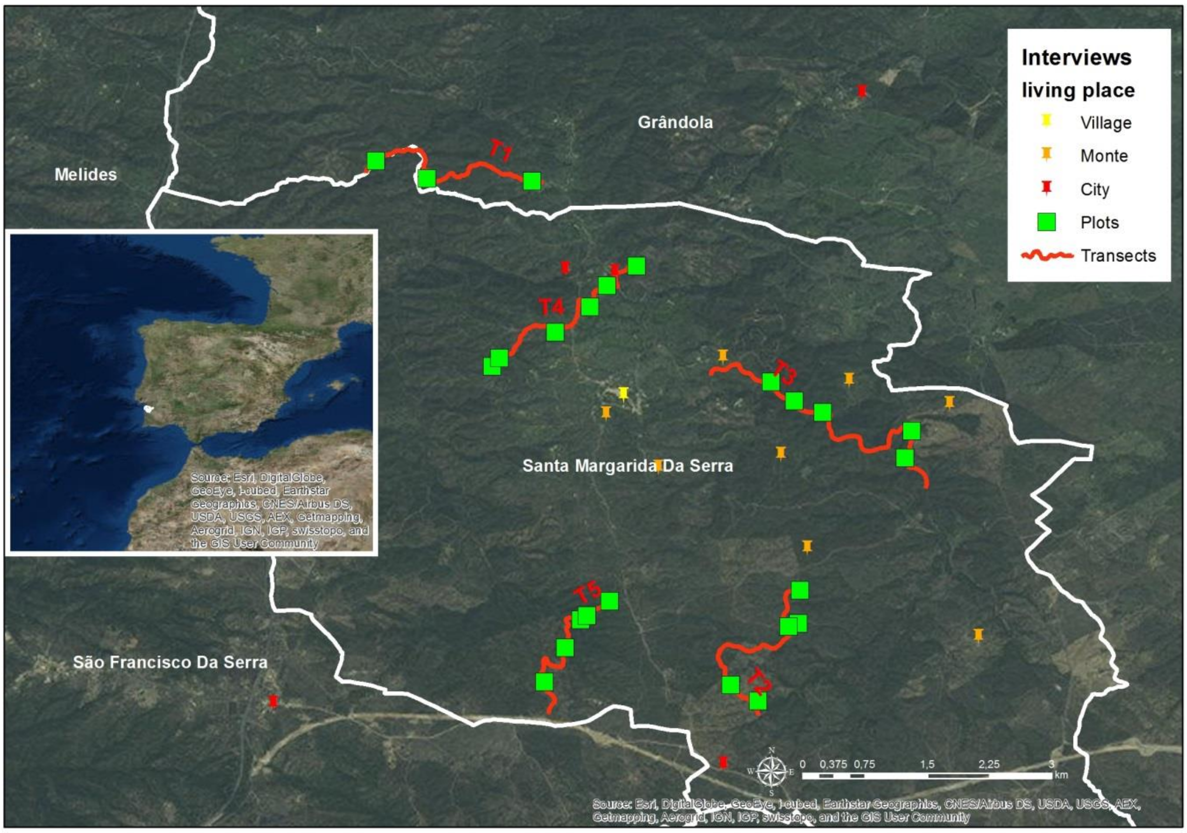


Figure 3. Representation of plots, interview sites and transects

Collected goods and uses

All but one of the interviewees claimed to use or collect at least one good from the *montado*. Firewood and orchards were the most common collected good and use, respectively (table 2). Cork extraction was the second most frequent extracted good alongside with game, which is in line with recreation being the second most important use. Recreation includes walks, photography and cycling.

Table 2. Uses of the *montado* ranked by their frequency in the interviews.

Collected Goods or Uses	Type	# Interviewees
Goods	Firewood	18
	Cork	10
	Game	8
	Mushrooms	5
	Aromatics	3
	Strawberry tree	3
	Honey	1
Uses	Orchards	15
	Recreation	6
	Livestock	4
	Oliveyard	3

Differences in uses

Sixty four percent of the interviewees (14 out of 22) said to use the woodlands for at least one commercial purpose, being cork the most common commercial good (n=10; figure 4). Nonetheless, the majority (n=56) were personal uses.

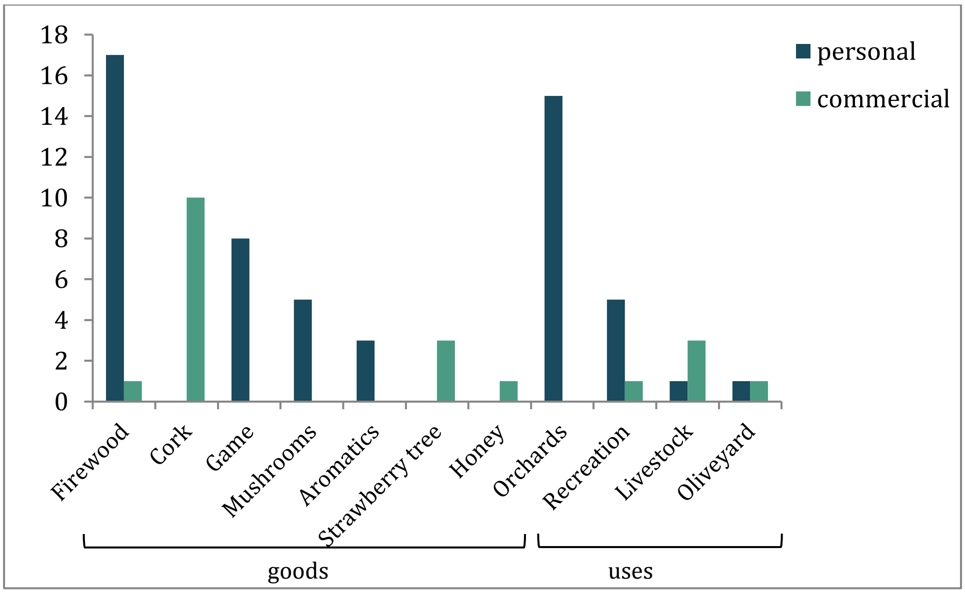


Figure 4. Number of interviewees that benefits from the woodlands at a personal and commercial level. The X axis discriminates between the different goods and uses, whereas the Y axis indicates the frequency the goods and uses are indicated by the interviewees. Each interviewee could have indicated more than one good or use.

Six interviewees work directly in the woodlands, with jobs including: shepherd (n=2), bee keeper, working housekeeper, machine operator, and partner in a *montado* management business. Amongst them, their income derives from livestock production (sheep and cattle), honey production, cork harvest and production of strawberry tree's fruit and derived products (figure 5). In addition, seven other interviewees said to obtain part of their income from the woodlands as a complement to their job. This additional source of income is mainly derived from cork harvesting, either by removing cork for others (n=4) or for having cork removed from their own land (n=3). I found no significant differences in commercial vs personal uses per income type (main, additional or none; Chi-square=2.383, P-value=0.304).

The dependence on *montado* as source of income or number of uses is independent of living in the village, *montes* or outside the parish, as no significant difference was found (Chi-square=3.125, P-value=0.210) or for the number of uses in the different living places (Chi-square=3.125, P-value=0.210). However, collection of aromatics and honey and production of livestock are exclusive to people living in *montes* (figure 5).

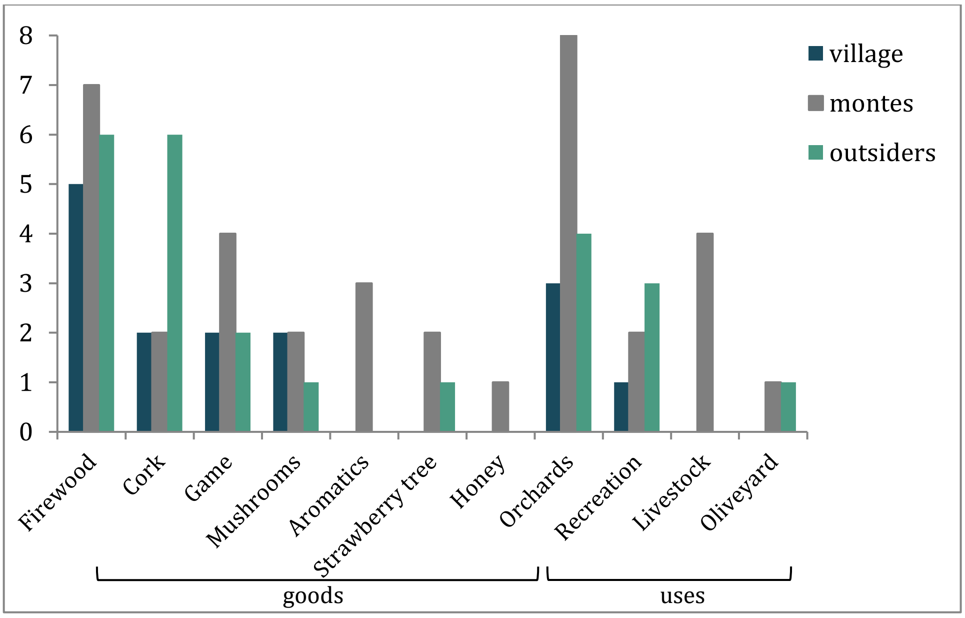


Figure 5. **Number of interviewees per living situation that benefits from goods and uses from the woodlands**. The X axis shows the different goods and uses, whereas the Y axis indicates the number of interviewees that indicated its use. Each interviewee could have indicated more than one good or use.

Easiness of access to services

Interviewees identified easiest access to Grândola (4.6), food (4.65), and water (4.7) (figure 6). On the other hand, education (3.125), health (3.35) and culture (3.3) had the lowest access, although all variables scored on average above 3 indicating neither hard, nor easy access.

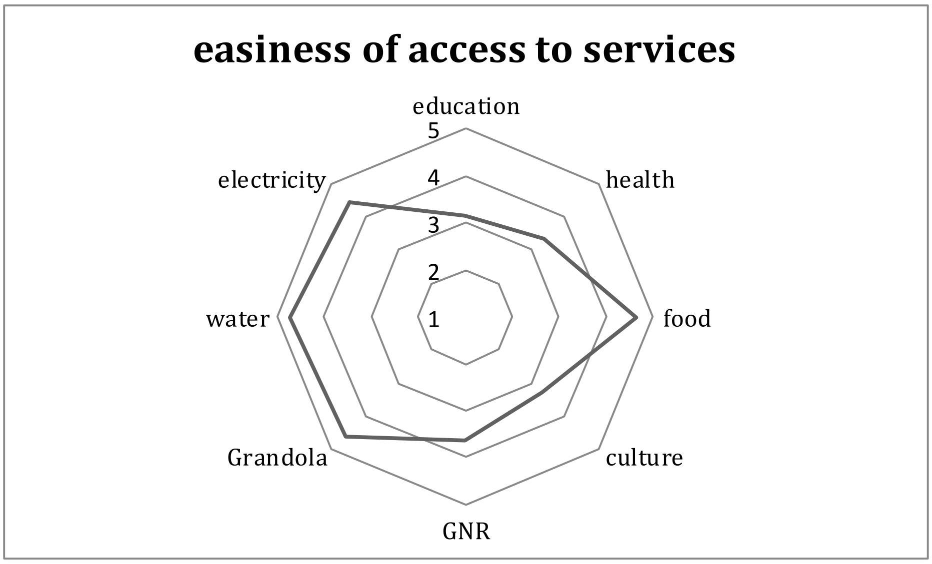


Figure 6. Average rank of easiness of access to basic services. Where Grândola is the nearest town and GNR is the national gendarmerie.

No significant differences were found in the easiness of access to services between interviewees from different living places (figure 7). However, people living in *montes* have slightly lower accessibility to services, except for food, and in particular to health care (Chi-square=5.671, P-value=0.059).

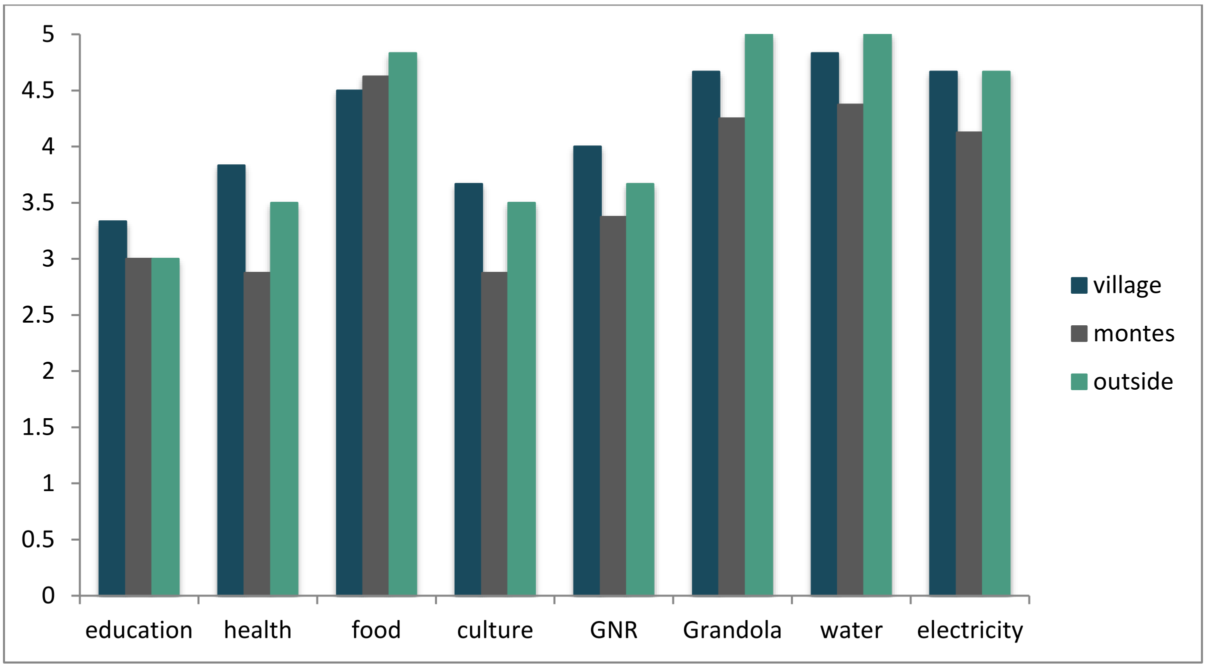


Figure 7. Average rank of easiness of access to services per living situation. No significant differences were found, (P-value in order of appearance in the Figure 7: 0.783, **0.059**, 0.503, 0.107, 0.160, 0.134, 0.093 & 0.223)

Biodiversity

Land cover

The total length of transects was 11.37 km, and they transversed several land cover types. Both Shannon and inverted Simpson indices show a low land cover diversity, with transect 3 being an outlier with higher diversity values (table 3). H values range between 1.03 and 1.55, with an average of 1.32 and Hmax was never higher than 2. D' values vary around half Dmax. $Evenness_H$ varies between 0.64 and 0.84, with an average of 0.75. Evenness values are lower for the Simpson index, varying between 0.44 and 0.65 and an average of 0.54. Table 3 shows the scores of each transect for both used diversity indices.

Species diversity and evenness

Cork oaks heavily dominate the canopy of the woodlands, and other tree species were seldom registered. Even including shrubs with more than 1m height, canopy richness had a maximum of 6, and average of 2. Average diversity scores where H=0.42 (Hmax=0.515, E_H=0.34) and D'=1.26 (Dmax=2, E_D=0.37). A list of observed tree species can found in the appendix (table i). Understorey vegetation had more species present in different numbers, ranging between 6 and 34. A list of the observed species can be found on table ii in the appendix.

Table 3. **Land cover diversity.** The variability in land cover across each transect is presented through the Shannon (H) and inverse Simpson (D') indices and respective maximum diversity and evenness, as well length across which there is a mismatch in land cover between the two sides of the transect.

Transect	Length (m)	Mismatches between left and right		H	H_{max}	E_H	D'	D_{max}	E_D
		Length (m)	%						
1	2178.13	549.86	25.24	1.18	1.79	0.66	2.63	6	0.44
2	2223.30	462.08	20.78	1.35	1.61	0.84	3.26	5	0.65
3	3085.69	2082.17	67.48	1.55	1.95	0.80	3.35	7	0.48
4	2133.58	491.41	23.03	1.11	1.61	0.69	2.57	5	0.51
5	1754.69	592.59	33.77	1.03	1.61	0.64	2.40	5	0.48
Sum	11375.39	4178,11	36,72	1.68	1.95	0.86	4.69	7	0.67
Average				1,32	1,75	0,75	3,15	5,83	0,54

Understorey plant diversity scored an average of 1.96 with the Shannon index, being DCoWt (H=2.39), PP (H=2.64), SCoWt (H=1.95) and DCoWt (H=1.91) the land cover types that scored higher understorey plant diversity, and RV (H=1.21) and SCoW (H=1.65) the land covers that scored the lowest understorey plant diversity. H values tend to differ of about 1 point from Hmax that averages on 2.89. Evenness is quite variable with a minimum of 0.42 (RV), maximum of 0.83 (PP) and an average of 0.68. DCoWt (D'=10.01) and PP (D'=9.22) also score the highest with the Simpson index, and RV (D'=1.82) and SCoW (D'=3.9) the lowest. The biggest difference in rank is found in SCoWt that scores D' values well below half their respective Dmax, being average D' 5.80 and average Dmax 19.29. Evenness in D is lower than with H, ranging between 0.1 and 0.38 and with an average of 0.32 (table 4).

I found no significant differences in species diversity between plots with different land cover types for either index (H - F=1620, P-value=0.202; D'- Chi-square=6.916, P-value=0.329). However, plots with understorey (DCoW & SCoW) have significantly higher diversity that plots without understorey (DCoWt & SCoWt) (Hmax – F=1.353, P-value=0.045, Dmax – F=0.273, P-value=0.44)

Table 4- Species diversity per land cover type. Plots with the same land cover where considered together to calculate understory diversity using the Shannon (H) and inverse Simpson (D') indices and respective maximum diversity and evenness.

land cover	# plots	H	H_{max}	Evenness	D'	D_{max}	Evenness
DCoW	7	1.91	2.65	0.73	5.3	15.71	0.39
DCoWt	5	2.39	3.21	0.74	10.01	25.2	0.39
SCoW	5	1.65	2.88	0.58	3.9	18.4	0.24
SCoWt	4	1.95	2.95	0.66	4.4	19.5	0.24
EP	1	1.88	2.71	0.69	4.02	15	0.27
PP	1	2.64	3.18	0.83	9.22	24	0.38
RV	1	1.21	2.89	0.42	1.82	18	0.1
average	24	1.96	2.89	0.68	5.80	19.29	0.32

I found no correlation between diversity and soil degradation, hydric stress and fire damage. Diversity, maximum diversity or evenness was not significantly correlated with soil degradation (H – Z=-1.026, P-value=0.383, D' – Z=-0.570, P-value=0.5.69), hydric stress (H – Z=-0.156, P-value=0.876, D' – Z=-0.311, P-value=0.755), or fire damage (H – Z=-5.79, P-value=0.595, D' – Z=-0.507, P-value=0.717).

Understorey plant diversity is independent of proximity to human settlements. There is no significant correlation between diversity and distance to village (H- Tau=-0.171, P-value=0.277, D' – Tau =-0.2, P-value=0.205), Grândola (H- Tau =-0.086, P-value=0.587, D' – Tau=-0.019, P-value=0.904), roads (H - Tau=-0.143, P-value=0.365, D' – Tau=0.038, P-value=0.809) or number of inhabited houses in a 1km distance (H – Tau=0.129, P-value=0.440, D' – Tau=0.160, P-value=0.338).

Interaction strength

Changes in use

Income type at the present does not significantly differ from the past. Half of the interviewees reported changes in the income they derive from the cork oak woodlands. Eight interviewees reported decreased derived income and 3 interviewees reported increased income (figure 8), but these differences were not significant (Z = -1.069, P-value = 0.285).

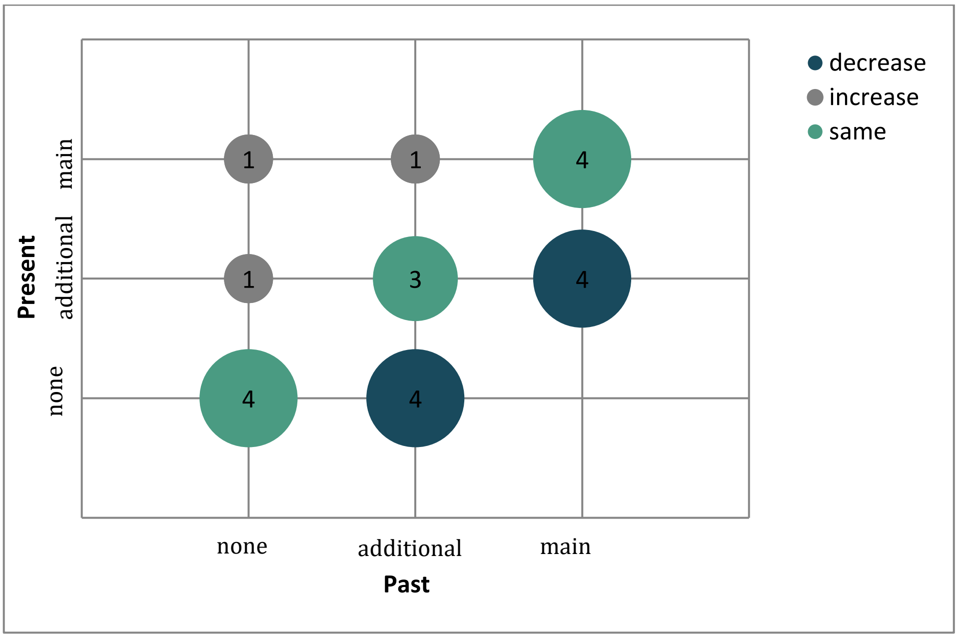
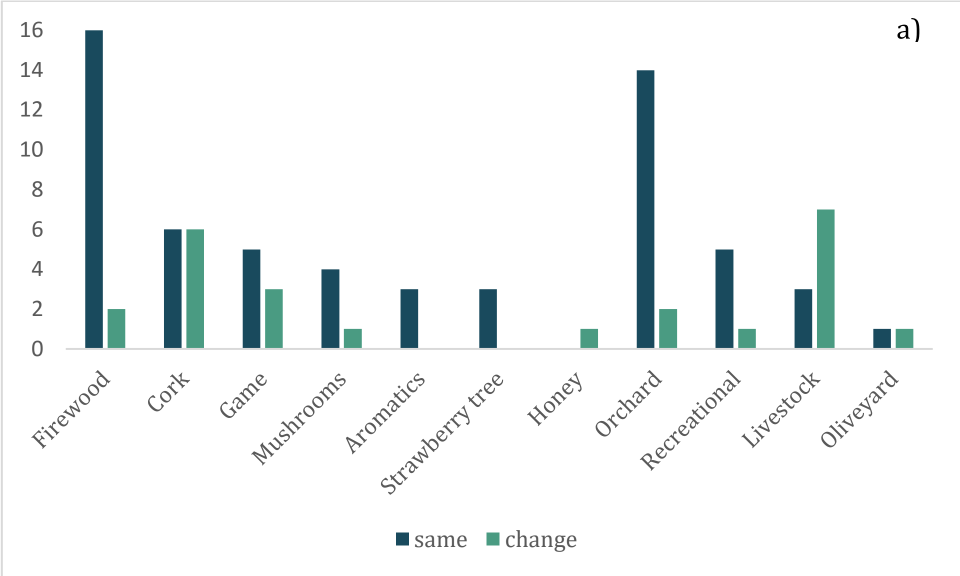


Figure 8. Relation between income type in the past and at the present. The different income categories (none, additional, main) are shown in both axis**,** where the Y axis represents the present situation and the X axis the past situation. The numbers in the bubbles represent the number of interviewees with the same answers. From the 11 respondents that changed their income type, 3 increased and 8 decreased the derived income.

There was not a significant change in use habits. Accounting for all the mentions to collected goods and uses from all interviewees (n=84), only 24 changes were claimed. Of these, 11 interviewees indicated they have reduced or even stopped collecting a good or use, and 4 claimed to have increased or started to collect a new product (for example honey). Most of the reported changes were in cork and livestock (figure 9). Nonetheless, no significant differences were found (Chi-square=1.652, P-value=0.438).



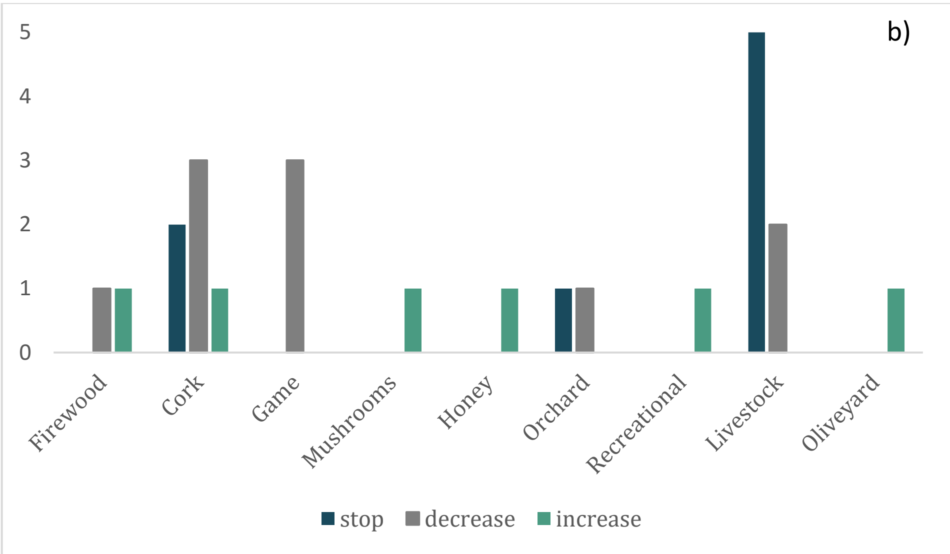


Figure 9. Changes in use habits. a. (above) shows the number of uses that remain the same and the number of reported changes. b (below) direction of change in use or good. In this figure the number of claimed changes is reported, and not the number of interviewees that claimed to have changed usage. The absence of certain goods means no changes in their consumption habits were reported.

The most common reasons of change in derived income and overall use were: retirement (n=4), changes in the resources (n=4), rise of new opportunities (n=3), desire of change (n=3), lack of work or broken business (n=3), changes in government subsidy schemes (n=2), and lack of time to harvest products (n=1). All the interviewees that said to have new opportunities (exploring village café are outsiders.

The relative contribution of the woodlands to local livelihoods is lower now than in the past. Despite the lack of significant differences in income and use changes found above, z-scores show that at the present income derived from the woodlands goes to outsiders more than to locals (figure 10). Locals make more use of the woodland's goods and uses than outsiders both in the past and at the present, but there has been an increase in non-locals use of the woodlands.

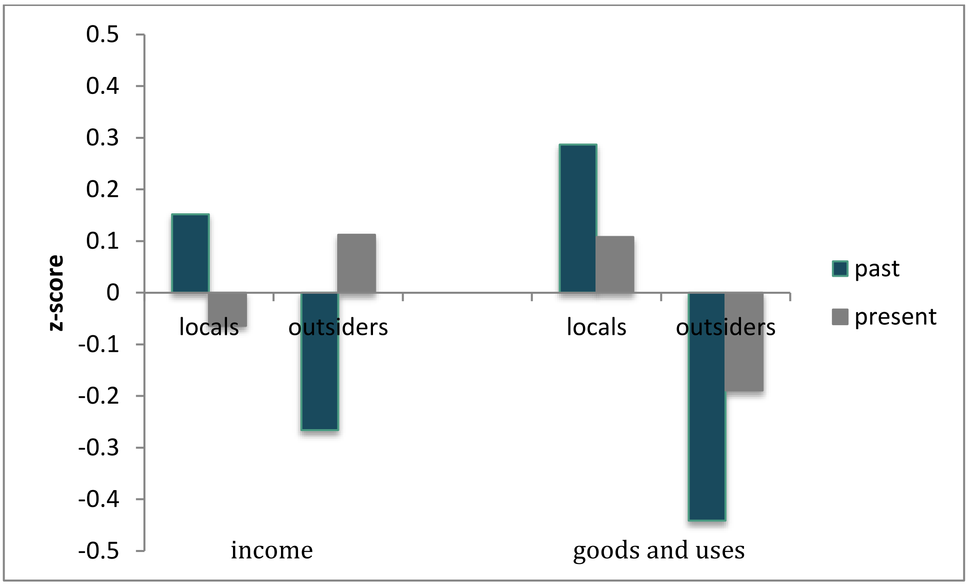


Figure 10. Contribution of the woodlands to local and non-local livelihoods as income source (on the left) and as good and uses provider (on the right), in the past and at the present. The woodlands used to be a more relevant income source to local livelihoods in the past, whereas at the present it is more relevant for non-locals. Similarly, outsiders are also using more goods and uses at the present that in the past, but locals still are the main usufructuaries.

Cork extraction

There is no clear pattern of change in harvested cork. There is a trend of, but no significant differences in harvest surface between 2006 and 2015 (Chi-square=16.846, P-value=0.051). Also, I found no correlation between harvest surface and time (Tau=0.057, P-value= 0.333, figure 11).

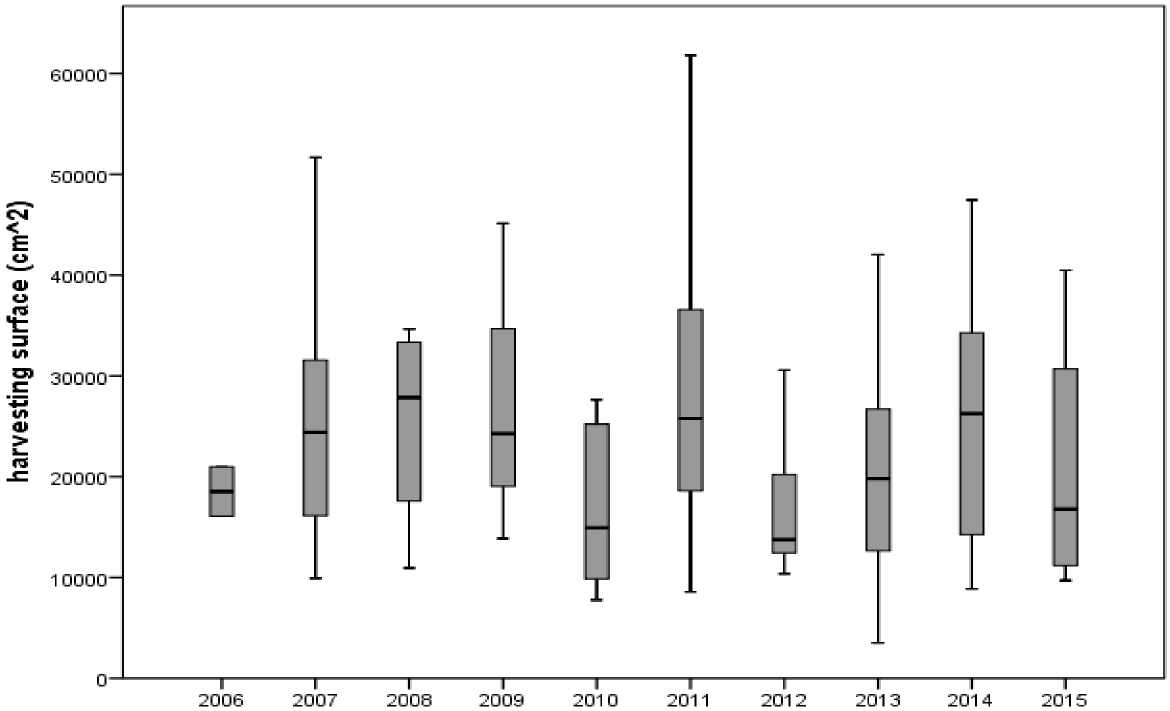


Figure 11. Harvested surface between 2006 and 2015. Variation in extracted cork between the different years is noticeable (Chi-square=16.846, P-value=0.051). However there no clear pattern of change is discernible.

Trends in EVI

I found that during the study period (2000–2013) there is a small but significant downward trend in maximum EVI and a significant upward trend for minimum EVI. The increase in minimum EVI was slightly higher than the decrease in maximum EVI, with little correlation between maximum and minimum EVI (R2=0.203; Spearman's rho=0.211, table 5).

Table 5. Trends in, and correlations between, average, maximum, and minimum EVI per land-cover type and total from 2000 to 2013. Bold values show significant trends. Land-cover types: dense cork oak woodlands with understory (DCoW), dense cork oak woodlands without understory (DCoWt), sparse cork oak woodlands with understory (SCoW) and sparse cork oak woodlands without understory (SCoWt).

	Average/Date		Max/Date		Min/Date	
	Tau	**P-value**	**Tau**	**P-value**	**Tau**	**P-value**
DCoW	−0.16	0.686	−0.038	0.324	0.062	0.108
DCoWt	−0.037	0.338	−0.072	0.062	**0.112**	**0.003**
SCoW	−0.026	0.51	**−0.11**	**0.005**	0.067	0.088
SCoWt	−0.01	0.799	−0.008	0.828	0.03	0.432
All	−0.011	0.394	**−0.049**	**0.0001**	**0.059**	**0.0001**

Cork oak stands and EVI

There is an increase in average EVI over the 10 years of the harvesting cycle. EVI significantly increases with years after harvest (YAH, Tau =0.022, P-value =0.000). Contrasting, EVI decreases with dbh (Tau=-0.034, P-value=0.00), harvest height (Tau=-0.017, P-value=0.00) and harvest surface (Tau=-0.037, P-value=0.00). When including unharvested stands, however, the correlation between EVI and dbh is no longer significant (Tau= 0.005, P-value = 0.221).

Plant diversity and EVI

Understorey plant diversity showed no effect in EVI (H - Tau=-0.11, P-value=0.496; D´ - Tau=0.008, P-value=0.624). Anthropogenic disturbances, however, affected EVI in different directions. EVI of plots where soil degradation was present was significantly lower (Z=-4.645, P-value=0.00), while EVI was significantly higher in plots with fire damage (Z=-8.890, P-value=0.00) or hydric stress (Z=-3.911, P-value=0.00).

Interview sites and EVI

On average EVI was higher in areas where the interviewees indicated having decreased the income derived from the woodlands than in areas where income increased (Chi-square=17.294, P-value=0.00, figure 12). However, EVI was also significantly higher (average EVI=0.323) in areas where interviewees reported an increase in uses and goods (average EVI=0.317; Z=-2.638, P-value=0.008) than in areas where change in use and goods was not reported.

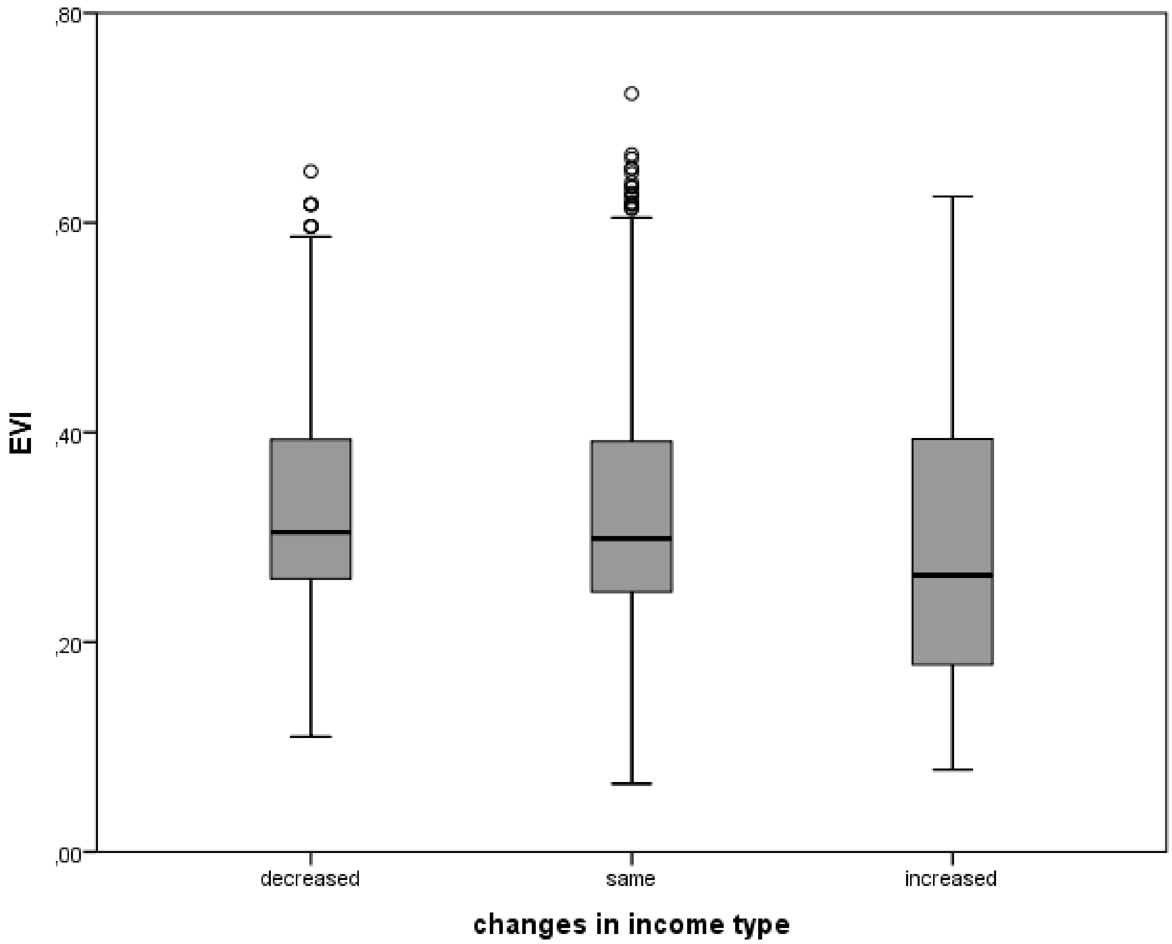


Figure 12. Differences in EVI amongst interview sites where interviewees reported a decrease, increase or same income derived from the woodlands. Sites where interviewees claimed to have increase the importance of the derived income have lower EVI.

Interviewees' perceptions

All interviewees agreed that the woodlands have changed over the last 15 years, and that this change has been mostly negative. All interviewees pointed out that tree health has deteriorated and that understorey cover has increased over the past years (figure 14). All participants agreed that *montado* is worth of and in need of protection. Most agreed with restricted cork oak cutting (n=21) and with designated hunting areas (n=17). However, some showed disbelief on the effectiveness of subsidies for afforestation of oak stands (n=4), claiming that nurseries are bond to dry out and be abandoned.

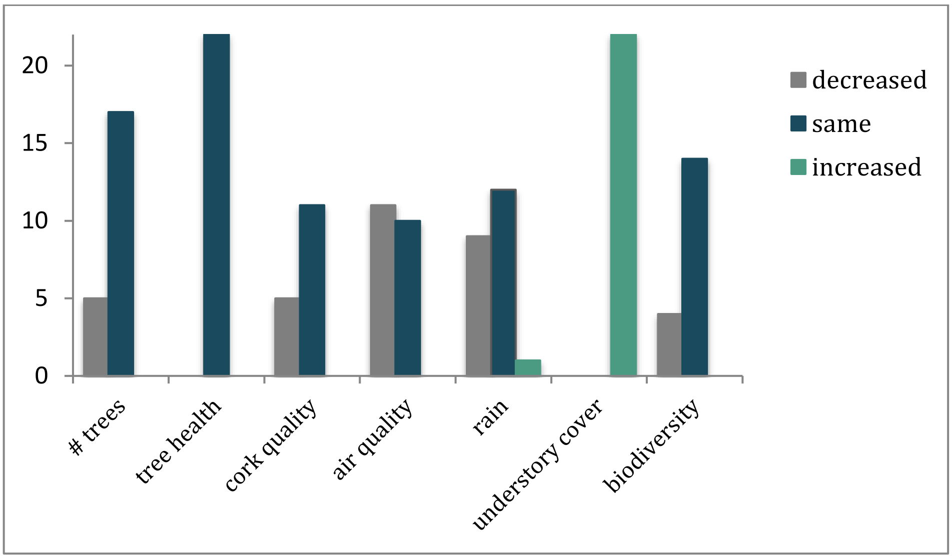


Figure 13. Interviewee's perceptions on changes to the woodlands. Interviewees were asked to comment on the change (decreased, increased or remains the same) of features of the environmental system disclaimed on the X axis.

Most interviewees perceived that major changes occurred in management strategies including abandonment (n=11), bad practices, such as over or lack of pruning, (n=6), use of heavy machines (n=5), lack of understory clearing (n=4), and lack of work (n=2). Also external factors (such as aging population, lack of governmental support, decrease of cork market value and pollution) were commonly mentioned, whereas environmental factors (e.g., disease, changes in rain patterns or lack of regeneration) were not generally perceived as the most important threats (figure 14).

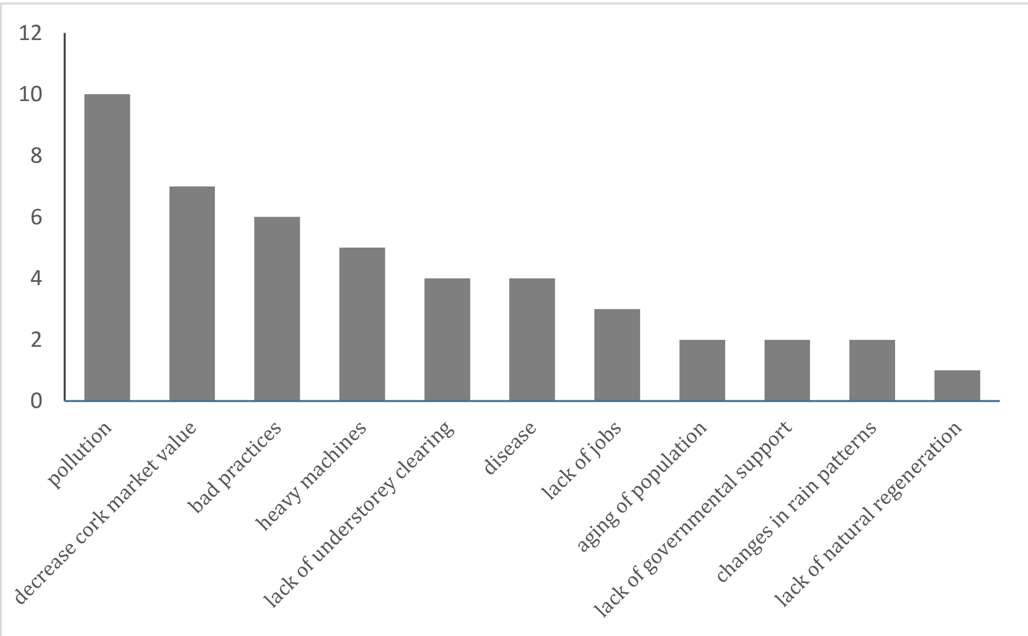


Figure 14. Most commonly mentioned drivers of change of the woodlands.

People for whom cork is a source of income were more likely to claim a decrease in cork quality (n=8, Chi-square=8.360, P-value=0.015) and more likely to have found a decrease in biodiversity (n=9, Chi-square=6.011, P-value=0.050). Also a significant portion of people that use the woodlands as source of firewood claimed a decrease in cork quality (n=11, Chi-square=8.331, P-value=0.016). Most interviewees acknowledged the woodlands as multi-functional system with cultural, aesthetic, environmental and economic value (n=14). Some valued the woodlands mainly for its production (n=5), while others valued mainly its recreational potential (n=3).

Joint outcomes

At the present, the woodlands do not simultaneously benefit local livelihoods and biodiversity. Whilst income derived from the woodlands mainly benefits non-locals, goods and uses provided by the woodlands have a higher contribution to local livelihoods (figure 10). Depending on the importance given to one or the other, *montado*s classify either as positive (+) or negative (-) on its social component. Both gamma (H=1.32, D=3.15, table 3) and alpha (H=1.96, D=5.80, table 5) diversities are relatively low, thus the system scores negatively in biodiversity. Arising joint outcomes are then either unsustainable (--), or a trade-off between livelihoods and biodiversity (+-, figure 15b).

The woodland's contribution to local livelihoods was higher in the past and the system scores positive in the social component (figure 10). With little information on past biodiversity of the study system, it is not possible to comment on the biodiversity potential of the area, and classify it as positive or negative. However, two outcomes are possible: synergies or trade-offs (15a).

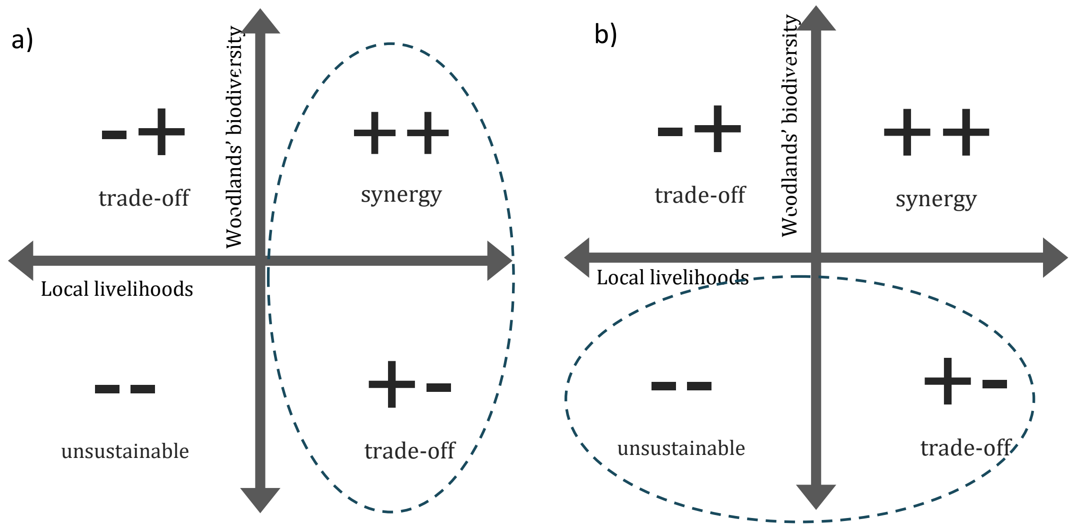


Figure 15. Joint outcomes between local livelihoods and biodiversity in the past (left) and at the present (right). The trace line outlines the quadrants where the system is expected to fall in. In the past, the woodlands favoured local livelihoods over non locals both in derived income and as render of goods and uses, thus scoring "positive" in the social axis. The lack of information on past biodiversity does not allow for a classification of negative or positive. At the present the low diversity scores, put the system in the "negative" as for biodiversity. The classification of human use is dependent on the importance given to the woodlands as source of income or as source of goods and income, as they favour different groups.

Discussion

The aim of this study was to assess if Portuguese cork oak woodlands can persist and simultaneously secure its high biodiversity and significantly contribute to local livelihoods under present social an ecological conditions. My results suggest that the cork oak woodlands are likely to persist as the system seems to be responding to changes by enhancing novel uses and goods of the system and that economically it is still profitable. Here I showed that the woodland's contribution to local livelihoods is decreasing and is smaller now than in the past, whilst growing in contribution to outsiders. The traditional income coming from cork harvest seems to mainly be benefiting landowners that do not live within the system, and while the contribution of the woodlands to the livelihoods of those more proximally connected to the systems may be decreasing, these livelihoods seem to be maintained. However, the ecological system is being stressed by climate conditions and cork oak tree health and cork quality may be decreasing. Biodiversity values are relatively small and disparate from the expected high alpha and gamma diversities of the system (Blondel 2006; Santos and Thorne 2010). Thus I considered the system is not delivering synergies between its human and environmental components under present conditions.

Pathways of development in cork oak woodlands are heavily dependent on the adopted management strategies. Main stakeholders determining such strategies are landowners, land managers, workers and users (either local or outsiders) (Barroso et al. 2012). Different groups have shown different preferences and expectations towards the system, being that landowners still prefer agriculture and other productive activities (Surová and Pinto-correia 2008; Surová and Pinto-Correia 2009). This study shows that cork extraction remains the main economic activity in the system, and that the amount harvested remained relatively stable over the past 10 years. And for as long as cork is still a profitable activity, cork oak woodlands are likely to persist. Nonetheless, there is a rise of "new activities" that indicate new links between people and the woodlands are being forged. Agro-tourism is a trending activity that, although capable of deriving income from the woodlands, does not guarantee the persistence of the system (Surová and Pinto-Correia 2009). An interesting development is the rise of businesses specialized in managing the system in the name of absent landowners. The specialized knowledge and resources allow for best practices and a better chance at perpetuating the system within its traditional settings. However, there is the risk this will further alienate those living within or in the proximities of the system, if specialized businesses with their own teams and equipment dominate the work opportunities related with the woodlands.

Trends of abandonment and extensification are diminishing available work related to the woodlands and consequently less people derive their main income from the woodlands. Labour associated with cork extraction is still relevant, but due to its seasonality it mainly constitutes an additional source of income for harvesters. Local communities used to constitute the main source of labour, and thus are also the most affected. Contrasting, locals seem to be increasing their use and production of other non-timber forest products such as honey and mushrooms, and prioritizing personal consumption. Socio-economic conditions were shown to influence the use of forest products, where these goods take an appreciated but not crucial role in the livelihoods of rural communities with a higher economic development (Stryamets *et al.* 2012). According to Navarro and Pereira (2012) traditional systems often do not provide a good life to the rural population dependent on them, so these results could be from an intentional decoupling of the local population from the woodlands, preferring other types of work. Nonetheless, a study with rural communities within cork oak woodlands showed that local agriculture plays an important role in their livelihoods, even if not economically (Surová *et al.* 2016). Other study reveals a desire of local communities to be engaged in the discussion of development pathways for agriculture in their region(McKee *et al.* 2014). Indeed, a common feeling through the interviews was of displease with the trajectory of the woodlands and a sense of community and identity with montados. It appears then, that there is a willingness to maintain ties and to be involved with future pathways of the system.

Consequences of recent management trends are also reflected in the natural system. Shrub encroachment is one of the most immediate changes to the landscape (Pinto-Correia 1993), and all interviewees could agree that understory cover had increased in the region over the past 15 years. Arising problems are an increased risk of wildfires, competition for nutrients with oak stands and loss of habitat heterogeneity (Bugalho *et al.* 2011; Moreno *et al.* 2013). Seeing that the area was once considered to have high plant diversity (Santos-Reis and Correia 1999), the found low scores in vegetation diversity in this study suggest a decrease in the system's biodiversity potential. Landscape richness tended to be higher than its evenness. These results are complacent with a landscape dominated by cork oaks, and only punctuated with other land cover types. Eucalyptus and pine plantations increased over the past decades as afforestation measures. However more recent policies, are favouring again the preference for cork oaks (Pinto-Correia and Godinho 2013). Intensity of human use has been connected to accessibility of the area (Acácio *et al.* 2016). In this study, distance to roads and human settlements did not determine plant diversity, suggesting accessibility is not a main factor determining human use.

The analysis of the area's productivity through an EVI time series suggest that cork oak woodland's productivity is dependent on both climate and anthropogenic factors (see also Santos *et al.* 2016). Soil degradation weakens the tree stands, hampering tree regeneration and increasing tree mortality (Bugalho *et al.* 2011). Modern shrub clearing methods such as soil mobilization and soil disking have been linked with an increase of soil degradation processes, and to damage oak roots further reinforcing hampering effects (Pinto-Correia and Godinho 2013). This explains the lower productivity in areas with evidence of soil degradation. Amongst the interviewees there was an awareness of the negative effects of the use of such practices. Nonetheless, most perceived such practices as the only alternative to hand clearing, which few are willing to do and to afford.

Contrasting, shrub encroachment is thought to aid in soil regeneration and to facilitate oak regeneration (Maestro *et al.* 2009, Moreno *et al.* 2013). However, shrub persistence is not favourable to stand functions, as it competes with trees for water and nutrients (Moreno *et al.* 2013). While shrub encroachment may lead to a decrease in productivity at the canopy level, productivity at the understory level increases. EVI is a vegetation index sensitive to canopy. While a good index to use in dense canopies in cork oak woodlands, it might lose in accuracy measuring understory primary productivity. This explains the lack of correlation between EVI and plot diversity within this study, as it mainly uses understory diversity. Nonetheless, if the rate of increase in understory productivity is higher than the rate of decrease in canopy's productivity, then EVI reflects positive trends. In addition to lack of clearing, also wildfires and dryer climate are thought to motivate the expansion of scrublands (Acácio *et al.* 2009). Seeing that EVI was higher in areas with evidence of fire damage and of hydric stress, this can be an indication of a shrub turnover in the area.

Best cork extraction practices are thought not to induce any harm to the tree, expect for a potentially higher vulnerability to fire (Pausas *et al.* 2009). My results are not in agreement with this, as the negative correlation between EVI and harvested surface seem to indicate that cork harvest is hindering the tree's productivity. Further, the increase in productivity the longer it has passed since harvest, also indicates a weakening of the stands, and consequent decrease in photosynthetic activity, after harvest. The inclusion of non-harvested stands in the analysis of the correlation between EVI and diameter at breast height, changes the results from a negative correlation, to non-significant. This means that in harvested stands, productivity tends to decrease with diameter growth, but the same trend is not true for unharvested stands. Differences between EVI trends in harvested and unharvested stands reinforce the sense, that cork harvest is affecting tree productivity. Oliveira and Costa (2012) point that oak resilience to current harvesting practices is not yet fully understood, as intensity and periodicity might have changed. Changes in practices may also affect cork quality, which is known to be improved by specific practices as formation pruning (Cañellas and Montero 2002). Amongst the interviewees, namely those who benefit from cork harvest at some level, was not an uncommon opinion that cork quality has decreased. Also, other factors, such as climate change, together with other anthropogenic stressors as pollution, or soil degradation, may be affecting both cork production and how the trees are responding to cork harvesting.

Ongoing changes in socio-economic and climate conditions are affecting the woodlands equilibrium and the resources it was originally designed to provide. Concomitantly, this is affecting how people use the resource system and interaction strengths within the system. At the present, the system seems unable to benefit local livelihoods whilst safeguarding its biodiversity. However, the system seems to be adapting to new conditions. The multifunctional character of the woodlands is highly appreciated and next to cork extraction, other products are being used. Firewood is the most commonly collected good, usually proceeding from pruning, and is collected year-round and stored to be used for heating purposes. Orchards are also a common practice, yet they do not allow self-sufficiency, and store bought food from commercial surfaces in the neighbouring towns is required to complement diets. There are no significant differences in the use of the woodlands between locals and non-locals. However, certain goods such as honey and aromatics were exclusively collected by people living within the system. In addition also recreational uses such as walks, photography and cycling are valued.

It is important to remember, that cork oak woodlands went through reorganizations in the past (Pinto-Correia and Fonseca 2009). And although the lack of synergies between social and ecological components indicate that the system is not sustainable at the present, it could be it is in a transition phase and still adapting to the current conditions. There is increasing societal pressure for more socially sensitive management, and most landowners are receptive to that (Surová and Pinto-Correia 2009) and local livelihoods, despite decreasing its dependence on the woodlands seem to be maintained. The findings of this study are in agreement with the hypothesis that land management is the main driver of change in the woodlands, despite vulnerability to climate change (Acácio *et al.* 2009, 2016; Godinho *et al.* 2016). Further cork oak woodlands are resilient systems and there are ongoing policies and subsidies to ensure the system's persistence (Pinto-Correia and Godinho 2013). The introduction on new stakeholders and new uses may renovate the incentive to clear the understory, increasing (or restoring) the biodiversity potential of the system. However, it should also be noted that traditional systems and its associated landscapes are dynamic and change is one of their properties (Antrop 2005). Thus it should not be expected that as it adapts to present and future conditions, cork oak woodlands will retain the exact same characteristics of the past.

Finding interviewees revealed to be more difficult than anticipated. The people met in the village were often the same and the visited montes often had been converted into holiday houses and empty at the time of the research or even abandoned. Although an indicator of the low density of resident population within the system, the relatively small sampled population (N=22), might induce some bias on the research. On the other hand, this difficulty led to the inclusion of a broader range of users than initially planned, which contributed to a better representation of the diversity of stakeholders. The interviews were guided by a questioning script designed for a fluid but meaningful conversation, and I avoided taking notes during the interviews, writing a posterior summary instead. Not having an audio record or a transcript of the interviews may have resulted in a loss of information. Nonetheless the "informal tone" of the interviews allowed to captivate interviewees and to create a comfortable environment for the participants to share information that otherwise might not have been possible in such a tight community.

Although it was intended to have a stratified sampling on plant diversity, I reckon having 1 plot per each of the three less dominant land covers, does not allow for a proper representation of their diversity. Faced with a lack of time for a more exhaustive sampling scheme, I focused the research effort into having more accurate representation on each of the four types of cork oak cover, which dominate the system.

A limitation of this study is the lack of coordination between remote sensing data and field data (including interviews, plant diversity plots, and cork oak stands). Because they happened independently, data points did not always overlay, reducing the available data to examine productivity trends. Still, it was possible to find trends of change and evidence of anthropogenic stressors.

Traditional systems are appreciated for their potential of having agricultural production whilst retaining high biodiversity. However, recent changes to socioeconomic and climate conditions are threatening the equilibrium and persistence of these systems. Despite ongoing changes, Portuguese cork oak woodlands showed to remain economically viable and likely to persist as long as cork remains profitable. My results indicate the ecological system is under stress by both climate and anthropogenic stressors, and the system unable to deliver synergies. This shows that persistence is not synonymous with sustainability. An important development seems to be the integration of new stakeholders and new uses which might be able to restore the system's biodiversity value.

Although pathways for synergies remain uncertain, the tandem analysis of social and ecological concerns seems to be an adequate way of addressing such complex social-ecological systems. A good understanding of the stakeholders, their use as well as their expectations of the system is an important point in dealing with working landscapes, as sustainable outcomes are dependent on the ability of the system to benefit those that depend or rely on it.

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Appendix

Table i. Descriptive data on variables of the social system

Variable description	N	Mean	SD	Median
# of interviewees that derive their total or partial income from the woodlands (0=none, 1= additional 2=main)				
Past	22	1,091	0,811	1
Present	22	0,909	0,811	0
change (- decrease in derived income, + increase in derived income)	22	-0,227	0,812	0
use of goods and services (0=no use, 1= use)				
Firewood	22	0,818	0,395	1
Cork	22	0,455	0,509	0
Game	22	0,364	0,492	0
Mushrooms	22	0,227	0,429	0
Aromatics	22	0,136	0,351	0
strawberry tree	22	0,136	0,351	0
Honey	22	0,045	0,213	0
Orchards	22	0,682	0,477	1
Recreational	22	0,273	0,456	0
Livestock	22	0,182	0,395	0
Oliveyard	22	0,090	0,294	0
changes in use (0=stop, 1=decrease, 2=same, 3=increase)				
Firewood	22	2	0,343	2
Cork	22	1,5	0,905	2
Game	22	1,625	0,518	2
Mushrooms	22	2,2	0,447	2
Aromatics	22	2	0	2
Strawberry tree	22	2	0	2
Honey	22	3	0	3
Orchards	22	1,813	0,544	2
Recreational	22	2	0	2
Livestock	22	0,8	0,919	0,5
Oliveyard	22	2,5	0,707	2,5
access to services (1- very hard, 5- very easy)				
Education	22	3,125	0,885	3
Health	22	3,35	0,745	3,5
Food	22	4,65	0,587	5
Culture	22	3,3	0,732	3
Grândola	22	4,6	0,754	5
GNR	22	3,65	0,671	4
Water	22	4,7	0,571	5
Electricity	22	4,45	0,826	5
Change in access to services (0=harder, 1=same, 2=easier)				
Education	22	0,8	0,789	1
Health	22	1,625	0,619	2
Food	22	1,7	0,657	2
Culture	22	1,462	0,660	2
Grândola	22	1,571	0,598	2

GNR	22	1,313	0,479	1
Water	22	1,524	0,679	2
Electricity	22	1,619	0,589	2
condition woodlands (0=decreased, 1=same, 2=increased)				
# trees	22	0,227	0,429	0
tree health	22	0	0	0
cork quality	22	0,313	0,479	0
air quality	22	0,524	0,512	1
rain	22	0,5	0,598	0
understory cover	22	2	0	2
animals and plants	22	0,222	0,428	0

Table ii. Descriptive data on variables of the natural system

Variable description	N	Mean	SD	Median	Min	max
Trees						
diameter at breast height (dbh)	207	30,95	15,34	30,57	1,592	85,15
years since harvest	207	4,38	2,446	3	2	9
harvested (0=N, 1=Y)	207	0,715	0,453	1	0	1
harvesting height (hh)	207	204,24	82,36	178	23	511
harvesting surface (hs)	207	12039,51	13402,24	4386	15	71955
vegetation diversity						
Understory diversity	24	19,33	6,48	19	6	35
Canopy diversity	24	2	1.58	1	0	6
Environmental factors						
fire damage (0=N, 1=Y)	24	0,333	0,482	0	0	1
hydric stress (0=N, 1=Y)	24	0,708	0,464	1	0	1
evidence of lifestock (0=N, 1=Y)	24	0,042	0,204	10	0	1
primary productivity						
EVI	2368	0,308	0,104	0,299	0,039	0,883
& trees	147	0,323	0,083	0,321	0,046	0,723
& interview sites	15	0,321	0,107	0,302	0,065	0,723
& plots	10	0,312	0,094	0,309	0,046	0,723

Table iii. List of tree species found within the plots.

English name	Scientific name
Cork oak	*Quercus suber*
Portuguese oak	*Quercus faginea*
Olive trees	*Olea europaea*
Eucalyptus	*Eucalyptus globulus*
Maritime pine (or cluster pine)	*Pinus pinaster*
Stone pine	*Pinus pinea*

Table iv. Non-exhaustive list of plant species found within the plots (excluding trees).

English name	Scientific name
Strawberry tree	*Arbutus unedo*
Rock-rose	*Cistus ladanifer*
Topped lavender	*Lavandula stoechas*
Sage-leaved rock-rose	*Cistus salviifolius*
	Cistus crispus
Sea squill	*Urginea maritima*
	Crepis vesicaria
	Sherardia arvensis
	Brixa maxima
	Branchypodium distachyon
	Galactites tomentosus
	Stachys arvensis
	Genista triacanthos
	Anagallis arvensis
Field clover	*Trofolium campestre*
	Urospermum picroides
annual rock-rose	*Tuberaria guttata*
	Omithopus compressus
	Foeninculum vulgarre
	Thymus mastichina
	Silene gallica
	Scirpoides holoschoenus
Crossworts	*Crucianella angustifolia*
Starry clover	*Trifolium stellatum*
	Asterolinon verrucosa
	Umbilicus rupestris
	Lithodora prostrata
	Briza minor
	Daphne gnidium

Common smilax	*Smilax aspera*
	Geranium purpureum
Common sowthistle	*Sonchus oleraceus*
Wild oat	*Avena barbata subsp. lusitanica*
Stone clove	*Trifolium arvense*

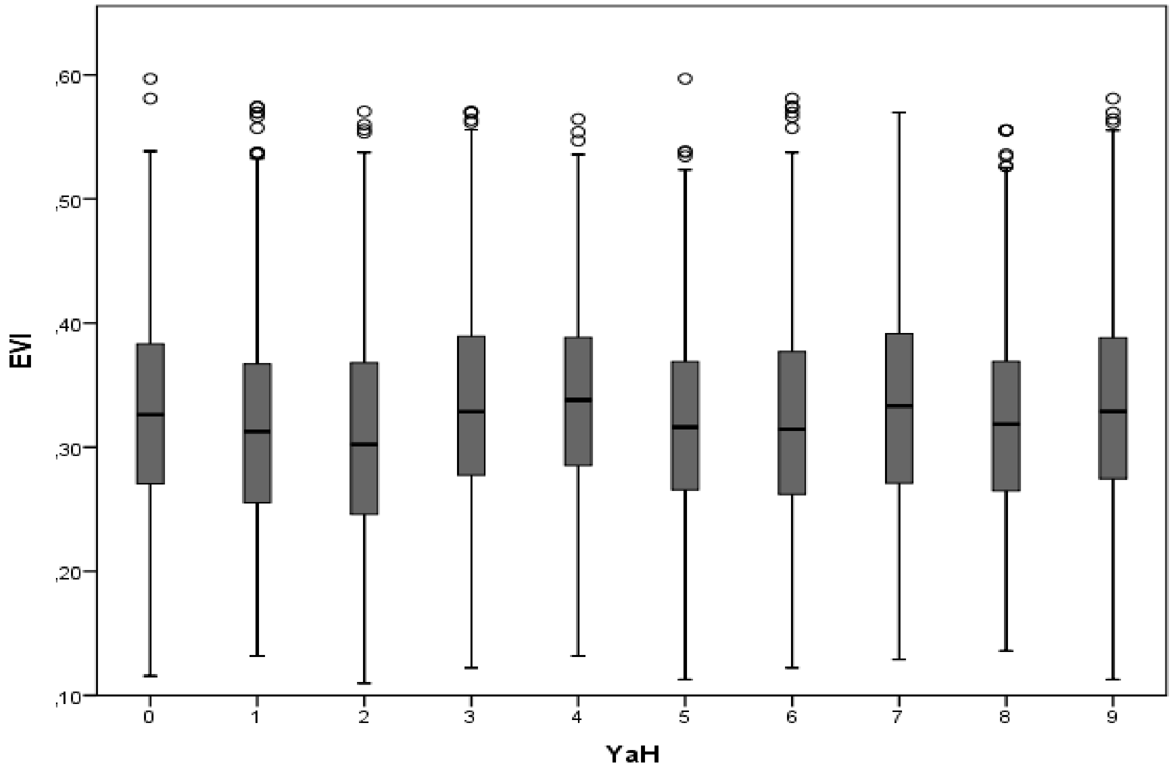

Figure i. EVI progression over 10 year harvest cycle, where 0 is the year of harvest. Although weak (Tau =0.022, P-value =0.000) there is a trend of increasing EVI the longer it has been since harvest. (YaH= year after harvest).