System Report: Cork Oak Silvopastoral Systems in Portugal

Project name	AGFORWARD (613520)
Work-package	2: High Nature and Cultural Value Agroforestry
Specific group	*Montado* in Portugal
Deliverable	Contribution to Deliverable 2.4 (2.1): Detailed system description of a case study system
Date of report	30 January 2016
Authors	Joana Amaral Paulo, Josep Crous-Duran, Paulo Neves Firmino, Sónia Pacheco Faias, João HN Palma
Contact	joanaap@isa.ulisboa.pt
Approved	Paul Burgess (7 April 2016)

Contents

AGFORWARD (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

1 Context

The AGFORWARD research project (January 2014-December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

This document reports to Deliverable 2.4, which aims at providing a "report describing the components, structure, ecosystem services, and economic value of selected high cultural and natural value agroforestry systems across Europe". The data included in this report will also inform the modelling activities being developed in WP6 of the project.

2 Background

In Portugal the main agroforestry system is a traditional system called *montado*, occupying a total area of 737.000 ha (ICNF 2013). It is characterized by low trees density values (average 66 trees ha^{-1} (AFN 2010)), combined with agriculture and/or pastoral activities (Pereira and Tomé 2004). Some areas, public or privately owned, are also managed concerning the provision of other services such as biodiversity protection, hunting activities, education and/or leisure activities.

The main tree species found in the *montado* is cork oak (*Quercus suber* L), a species characterized by the ability of production a thicker back layer (cork), which can be regenerated after it is extracted during an operation called debarking. The physical and chemical properties of the cork material allow this natural material to be used on a large and increasing number of products that go from the most simple handicraft or natural cork stoppers, to new products and applications such as bioabsorbents of heavy metals in aqueous solutions, composite materials, architecture and medical applications and pharmacy (Pereira 2007).

Montado was the main agroforesty system discussed by the farmers at the initial stakeholder's group meeting that took place on 24 July 2014, in Coruche, Portugal, under work-package 2 of the AGFORWARD project[1]. The list of knowledge gaps and innovations proposed during this meeting highlighted the importance of the system's ecological, economic and social characteristics. The importance of cork for the financial viability of farms raises concern regarding tree decay and mortality rates that have been observed since the beginning of the twentieth century (Natividade 1950; Cabral et al. 1992; Cadima et al. 1995; Costa et al. 2010). It also highlighted the need for research on the best agroforestry management practices that should be adopted to contribute to tree regeneration, increase cork quality, adequate selection of crop and pasture species, and ultimately to guarantee an economic and ecological sustainable management of the *montado* in Portugal.

[1] http://www.agforward.eu/index.php/en/*montado*-in-portugal.html

3 Description of the system components

3.1 Tree and cork components

The main tree species occurring in the *montado* is *Quercus suber* L, although associations in mixed stands with other tree species, namely *Quercus ilex* and *Pinus pinea*, may occur (see Section 2). The cork oak species grows in warm humid and sub-humid conditions up to 2000 m, but with optimum growth occurring up to 600 m of altitude. It is considered a semi-tolerant species, well adapted to mild climates, namely to the Mediterranean climates with Atlantic influence. Cork oak grows well with mean annual precipitations of 600-800 mm, but survives in years with very low precipitation under 400 mm. It can tolerate higher precipitations of up to 1700 mm, but is very sensitive to water logging. It is adapted to the Mediterranean type of climate with precipitation concentrated in the late autumn and winter (October-March) with minimal summer rain. The optimum mean annual temperature is considered to be 13-16°C, but the system also occurs where the mean temperature is 19°C. The mean temperature of the coldest month should not be below 4-5°C and the absolute minimum survival temperature is -12°C (APA 1984; Correia and Oliveira 2003; Serrada and Montero 2008).

The tree species is tolerant of most soil types with the exception of calcareous (Figure 1) and limestone substrates. It may grow on poor and shallow soils with low nitrogen and organic matter content, and it allows a pH range between 5 and 7. It occurs preferentially in siliceous and sandy soils (Figure 2), and prefers deep and well aerated and drained soils. It is very sensitive to compaction and water logging (Figure 1).

Figure 1. Soil with calcareous and compaction characteristics present in a young cork oak plantation (age 12 years) with low survival and growth rate of the trees. Photos: Joana Amaral Paulo.

Figure 2 Soil of sandy texture and approximate depth of 150 cm present in a young cork oak plantation (age 12 years) with survival rates of 90% and high growth rates of the trees. Photos: Joana Amaral Paulo.

Although a resilient and tolerant species, soil properties are known to affect cork oak tree growth (Paulo et al 2015a), root system development (David et al. 2013, Pinto et al. 2014), and ultimately tree survival (Costa et al. 2010; Castel-Branco 2014). David et al. (2013) were able to map the complete tree root system, both laterally and in depth, demonstrating that *Quercus suber* had a dimorphic root system with deep roots reaching groundwater and superficial roots that are linked to sinker roots (Figure 3). These descriptions highlight the species adaptation for prolonged dry summer season that characterizes the Mediterranean climate, and the importance of adequate management practices that protect the root system, particularly the superficial root systems, especially in locations with shallow soils, or where tillage is no longer a practice. Since the success of new cork oak plantations is relevant for future productivity, it is crucial to find where cork oak can grow while having good survival rates and better growing conditions.

Cork oaks are typically trees with a short stem and thick branches that rarely attain heights greater than 18 m (Paulo et al. 2011) and crown diameter greater than 15 m (Paulo et al 2015b) (Figure 4 and Figure 5). Paulo (2011) presents data on the number of main branches and stem height, highlighting average values for adult trees of 2 and 2.37 m respectively. However these average values may be misleading, since maximum values of 7 main branches and 11.20 m were also found for the two variables respectively.

The number of main branches and the crown shape is frequently determined by formation pruning operations, made around 10 years after tree plantation or regeneration, and again close to the first debarking operation, between 20 and 25 years (Costa and Pereira 2007). Formation pruning (Figure 6) is an operation also determined by stand management objectives. For the majority of the stands that are managed for cork and pastoral purposes it is made in order to guarantee the tree contribution for shade and acorn production, which are relevant for the pastoral and grazing activities of these agroforestry systems (e.g. Moreno 2008). However, uncertainty remains on the best tree stem conformation for the optimization of cork production, shade and acorn production. Controversy on this matter is related to the positive relationship between debarking surface and cork production (e.g. Ribeiro and Tomé 2002), simultaneously to the observed reduction of cork thickness (and consequently cork value) along stem height and in the branches (Montero and Vallejo 1992).

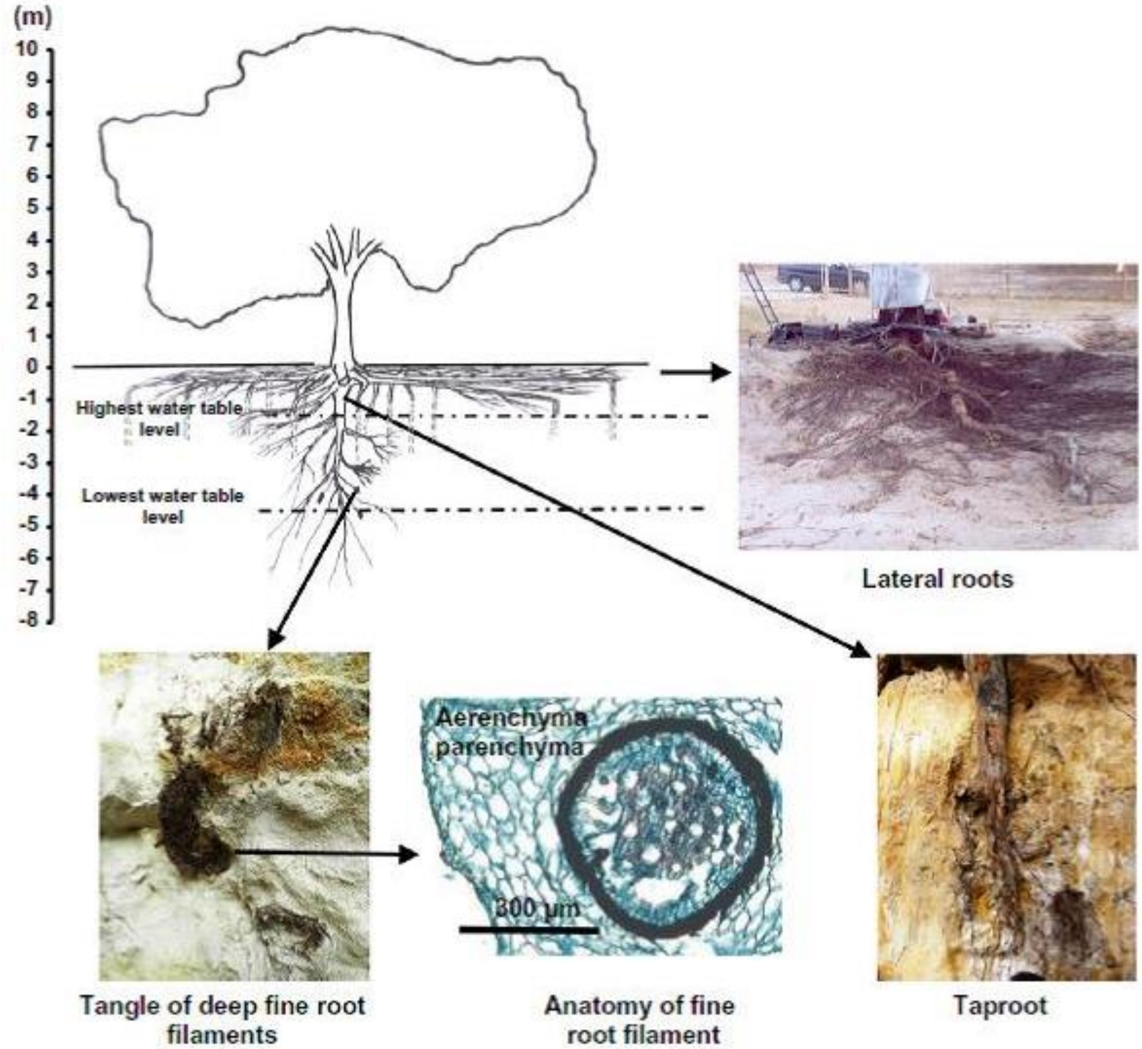


Figure 3. Scheme and photographs of the *Quercus suber* root system (superficial lateral roots at stem base, sinker roots, taproot sections at two depths and tangle of deep fine root filaments) Source: David et al. (2013).

Figure 4. Cork oak tree stem presenting two main branches and two distinct debarking years. Numbers indicate the year of the last debarking (2013 and 2015). Photo: Joana Amaral Paulo

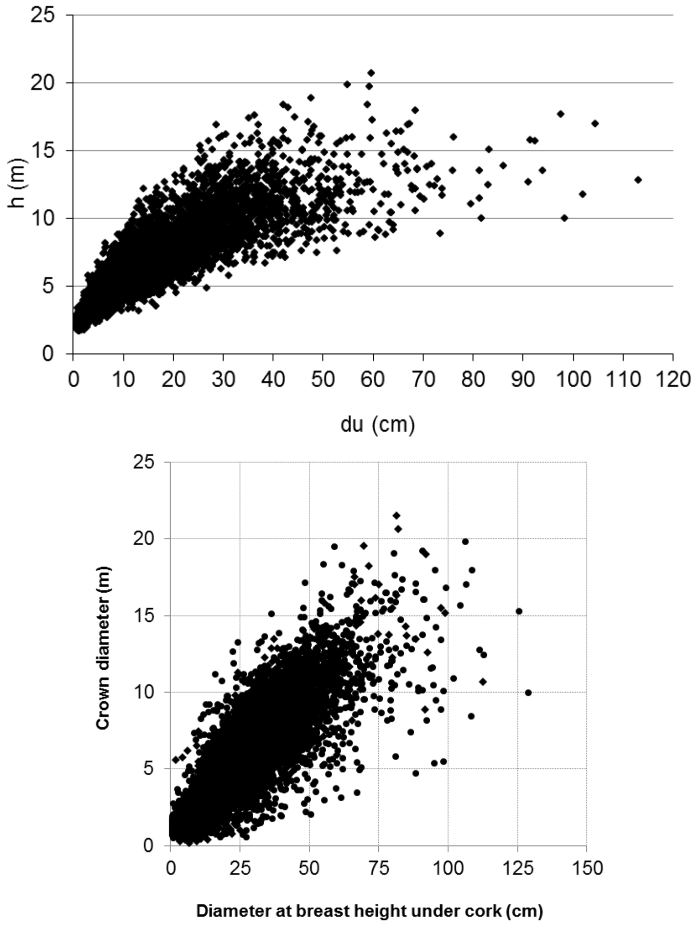


Figure 5. Relationship of diameter at breast height – du – and total height – h – (Source: Paulo et al 2011) and crown diameter – cw – (Adapted from Paulo et al. 2015b).

Figure 6. Formation pruning operation in a juvenile cork oak stand managed for cork and game production. Photo: Joana Amaral Paulo

The tree can be easily differentiated from others due to the presence of a thick bark (cork). The first cork is called the virgin cork (Figure 7). Virgin cork is characterized by deep fractures and cracks that extend irregularly, but mostly longitudinally, due to the rapid radial growth of wood in young trees. The removal of the cork layer exposes the phellogen, causing this layer to consequently die. As a response, a new periderm (the traumatic periderm) is formed in order to protect the living tissues that were exposed to the environment. The unprotected tissues that dry out and die during this process fracture easily due to the radial growth of the new periderm that follows and that originates mature cork (Figure 8). These layers form the external part of the new cork layer and are called the cork back (Pereira 2007). Internally to the cork back, seasonal cork rings develop until the next cork extraction takes place, forming the tissue of mature cork (first mature cork is designated as secondary cork). Only mature cork may be used for cork stopper production, and even when certain limits of cork thickness and porosity are found (e.g. Costa and Pereira 2006). These product features, associated to the low growth rates that characterize the tree species, imply that cork production economic return is only obtained around 35 to 45 years after tree plantations (depending on site characteristics).

Although the relation between cork annual growth and climate is well established, in particular with precipitation and temperature (Caritat et al 1996, Sánchez-González et al 2007, Pizzurro et al 2010), questions remain regarding the influence of several tree, soil, stand and management practices on cork thickness and even more on cork quality (Paulo et al submitted).

The experimental work carried out in the AGFORWARD project under the scope of work-package 2 contributes to the clarification of some of these questions, in particular on the effect of lupin pasture and shrub encroachment on cork growth[2]. It is expected that Yield-SAFE, an agroforestry process-based growth model that considers competition between tree and crop for water and light (van der

[2] http://www.agforward.eu/index.php/en/*montado*-in-portugal.html

Werf et al 2007), can contribute to the understanding of the impact of tree density on tree growth, in the context of current and climate change scenarios.


Figure 7. Virgin cork debarking (left) and virgin cork in detail (right). Photos: Joana Amaral Paulo


Figure 8. Mature cork debarking (left) and cork samples showing annual cork rings (right). Photos: Joana Amaral Paulo (left) and Sónia P. Faias (right).

3.2 Crops and understory components

Agriculture, typically cereal production, has been a common practice since the 13th century even in areas recognized for their low productivity. The incentives given by kings and politicians for this activity were based on the need to cope with increasing population in this region at that time (Fonseca 2008). In the 20th century, mainly as a result of the European common agricultural policy (CAP), cereal production decreased and pastoral activities became dominant (e.g. Borges et al. 2010; Fragoso et al. 2011), resulting in the increase of areas dominated by natural or improved pastures, forages or fallow (Figure 9). Pastoral activities are known to affect species composition and evolution of the understory, with contrasting effects depending on the site characteristics, animal species, the number of animals by grazed area and management practices that characterize each farm. These include adequate frequency and equipment selection for mechanical operations, and adequate livestock stocking rates.

Figure 9. Young cork oak stand with lupine pasture (top left), adult stand with improved pasture (top right), adult stand with fallow and sheep (lower left) and adult stand with fallow and wild cows. Photos: Joana Amaral Paulo

Research shows different relationships between the understory and other systems components, in particular the cork oak tree, both beneficial and damaging depending on the species that are present. For example, the understory is known to contribute to the tree canopy facilitation in the recruitment of cork oak tree seedlings (Caldeira et al. 2014) and to promote the abundance of wild animal species such as reptiles in *montado* (Godinho et al. 2010), but when developed as a result of land abandonment practices, shrub invasion, in association to extreme drought, is recognized to reduce ecosystem functioning and resilience with particular impacts in tree survival and growth rates (Caldeira et al. 2015). Lack of research persists on the effects of understory management practices, composition and grazing regimes on cork growth.

Godinho et al. (2010) suggests livestock stocking rates should be maintained at a sustainable level of 0.2–0.4 livestock units per hectare, but it is known that this value varies greatly between farms and even in different years, depending on market prices of meat and forage as well as political measures and subsidies resulting from the CAP reforms implementations. The lack of information at national level regarding the understory management and grazing regimes of *montado* areas hampers a clear classification and quantification of the areas occupied by the different systems.

Areas where natural pastures or fallow prevail (Figure 11) are characterized by a complex mosaic of semi-deciduous and evergreen shrubs herbaceous and fungi species, reaching up to 60 - 100 flowering plant species identified per 0.1 hectare (Pinto-Correia et al. 2011b).

Figure 10. Cork oak with nature pasture. Photo: Joana Amaral Paulo

Figure 11. General morphology of the three most abundant plants in a *montado* stand in the Coruche region (upper photo: Alexandra Correia): *Ulex airensis*, *Cistus crispus*, *Cistus salvifolius*. Source: Correia et al (2013).

The species composition and structure is many times associated to site specific conditions (e.g. Otieno et al. 2011; Correia et al. 2013), management practices (Caldeira et al. 2015), and annual climate conditions (e.g. Jongen et al. 2013). Correia et al. (2013) was able to demonstrate the contrasting strategies adopted by different shrub species in order to overcome summer drought, suggesting an efficient mosaic exploitation of seasonal environmental resources (Figure 11).

Many of the species present in the *montado* understory are also valued as non-timber forest products for human use, many of them with aromatic, culinary or medicinal properties. These shrubs contribute about 17% of the total ecosystem CO_2 uptake (Correia et al. 2013), suggesting the importance of considering this ecosystem component when defining management operations as a way of promoting its positive effect in carbon balance.

4 Description of the system structure

In this section the characterization of the *montado* system will refer to the following variables: area of distribution, stand crown cover, tree species composition and classification of the system structures.

The area covered by the cork oak species in Portugal has been increasing since 1965, having expanded 6.44% between 1995 and 2010 (Figure 12) (UNAC, 2013). It is now extends to 737,000 ha according to the latest forest inventory (ICNF 2013) results. This area is distributed mainly in the south of Portugal; the Alentejo region contains 87% of the stands (Figure 13). The increase of the area between 1995 and 2010 has been boosted by an increase of 46,815 hectares of new cork oak plantations (AFN 2010), representing 8% of the cork oak area in Portugal. These new plantations have been mainly established on agricultural land, and are distributed in the Alentejo and Central regions of the country, linked in part to an increased interest by farmers of the Central region in the species. This interest regarding the *montado*, in such regions, is increasing the need of tools that can help knowledge exchange regarding system characteristics, opportunities, limitations and best agroforestry management practices. By contrast, in the Algarve region, where severe fire events and extreme drought conditions have been observed in recent decades, the area of cork oak plantations is low.

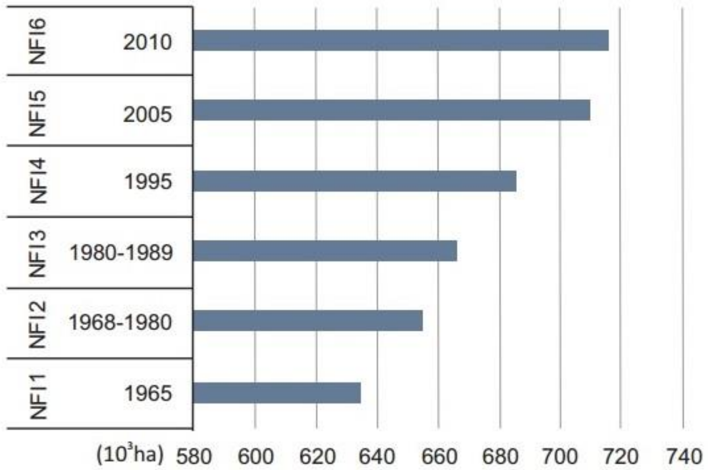


Figure 12. Cork oak area (10^3ha) evolutions according to the six National Forest Inventories (NFI) made in Portugal (Adapted from UNAC, 2013).

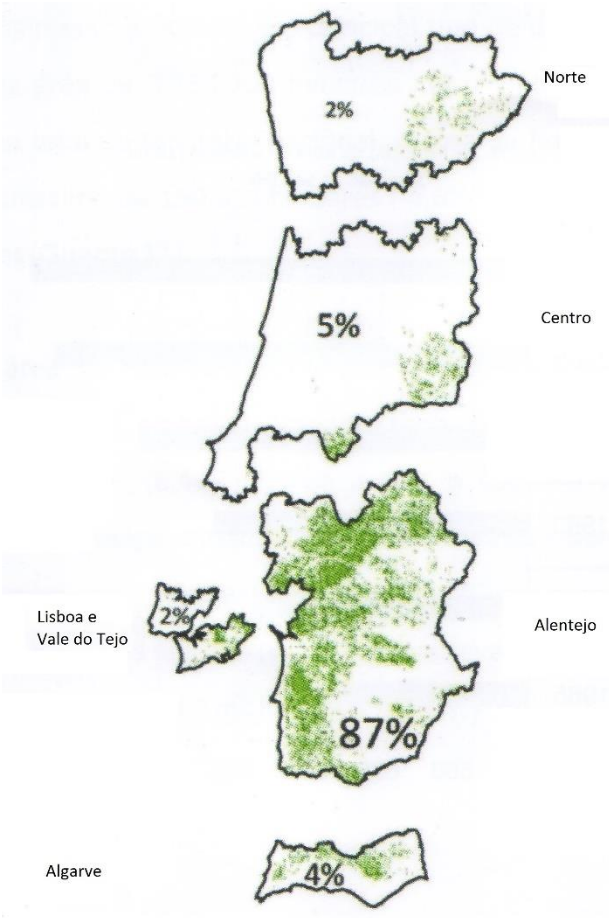


Figure 13. Cork oak percentage distribution by region (Adapted from UNAC, 2013).

In addition to an increase of the total distribution area, mature *montado* areas have also been facing a decrease of tree density (Figure 14) and tree crown cover (Figure 15). Tree crown cover percentage is one of the variables traditionally referenced for silvopastoral cork oak stands management. A cover of 48% is recommended for the silvopastoral management of mature and cork productive stands (Natividade 1950, Serrada and Montero 2008), which is a much higher cover that presently observed in Portuguese stands. Paulo et al. (2015b) has developed a model that allows the estimation of this variable using data from national forest inventories (NFI). Considering the two last NFI's (DGF 2001; AFN 2010), the authors estimated a decrease from 28.0% to 26.5% of the average crown cover values in the period of 10 years that separated the two inventories. Moreover, the authors also demonstrated an increase of the frequency of lower crown cover classes (< 20%) and a decrease of the frequency of higher crown cover classes (20% to 40%) (Figure 15). It is a current concern that the low stocking of mature stands may lead to a decrease in the cork production and to an increase of landscape fragmentation as cork oak woodlands undergo degradation processes that result from the action of several biotic and abiotic disturbance variables (Costa et al. 2014). These results highlight the importance of supporting measures to protect stands and to increase stand density by natural or artificial tree regeneration.

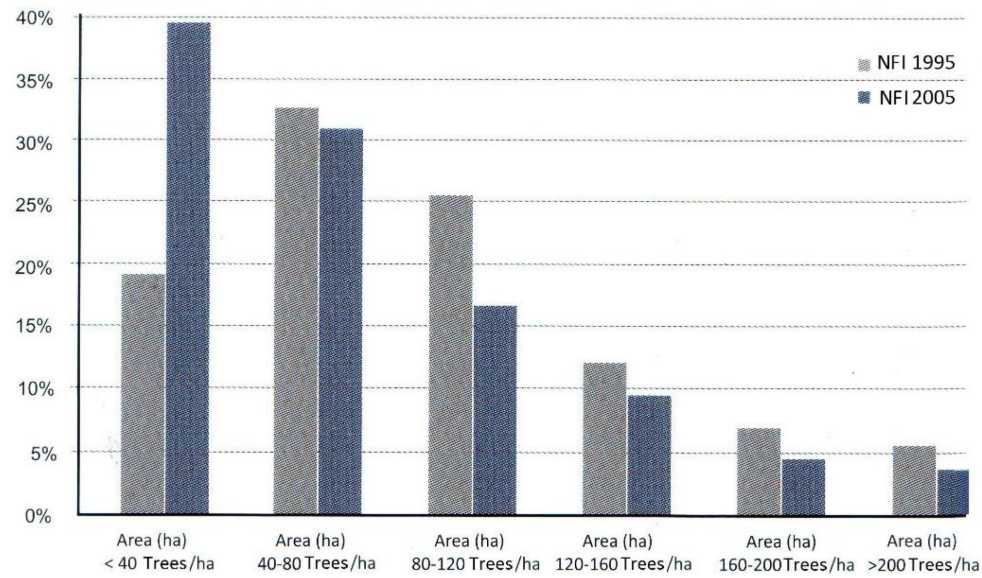


Figure 14. Proportion of cork oak stand in terms of area categorised according to tree density classes (Adapted from UNAC, 2013). NFI1995 (DGF 2001) NFI2005 (AFN 2010).

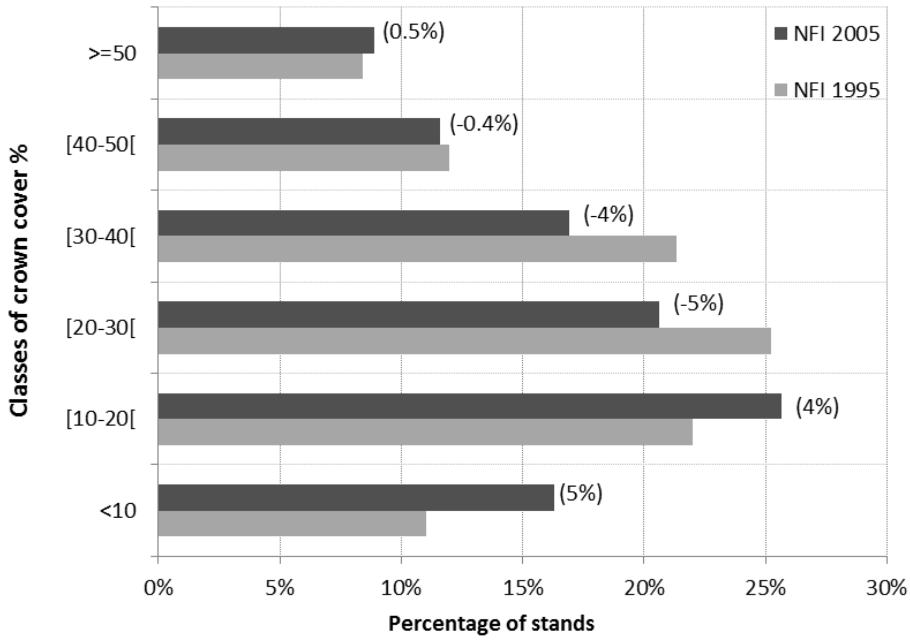


Figure 15. Proportion of cork oak stands in term of area categorised according to crown cover percentage classes. Inside brackets the difference between the two NFI's. NFI1995 (DGF 2001) NFI2005 (AFN 2010). (Source: Paulo et al 2015b)

The *Montado* landscape does not only include pure stands of cork oak species. An area of 206,783 hectares is identified in AFN (2010) as presenting a mixed stand structure (Bravo-Oviedo et al. 2014), where the species is mixed with holm oak, stone pine or maritime pine species. These areas are receiving increased interest from farmers since they allow a diversification of products and services, reducing risk when dealing with market prices fluctuations and other risk variables such as extreme climate events, forest fires, and disease. The distribution of new plantations, pure and mixed cork oak stands in Portugal is presented in Figure 16.

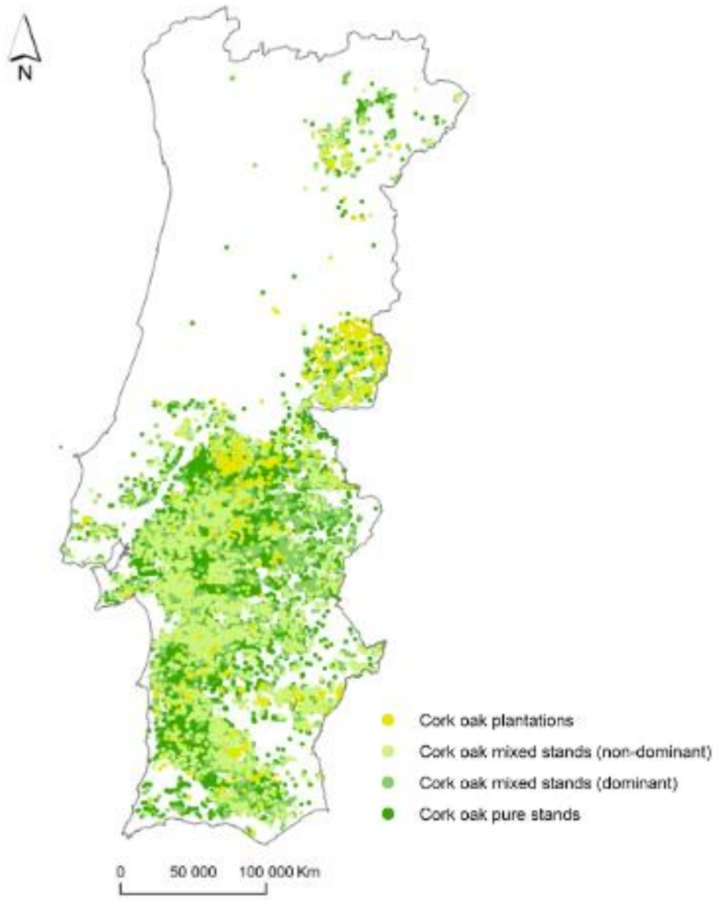


Figure 16. Distribution of new plantations, pure and mixed (dominant and non-dominant) cork oak stands in Portugal (Adapted from UNAC, 2013).

Cork oak is heavily concentrated in the southwestern and centre regions of Portugal. UNAC (2013) differentiate three distinct systems structures for *montado* areas on the basis of soil characteristics and orography (Figure 17):

- ***Montado* from the Tejo and Sado rivers basins** – this represents the cork oak *montado* area located in sandstone derivate soils, with depth depending on the existence of consolidated clay horizons, with reduced hydric retention and low fertilities, on altitude levels less than 400 m and in several orographies.
- ***Montado* of the Alentejo region** – present in wide plains, occupying soils of metamorphic or eruptive origin, normally more fertile and deep, at altitude levels less than 200 m and light slopes.
- ***Montado* in mountain regions** – presence of cork oak in mountains with essentially shale derived soils which can support tree growth, in altitude levels greater than 200 m or lower levels but with higher slopes. *Montado*s from Serra de São Mamede, Ossa, Grândola, Portel, Caldeirão and Monchique belong on this region.

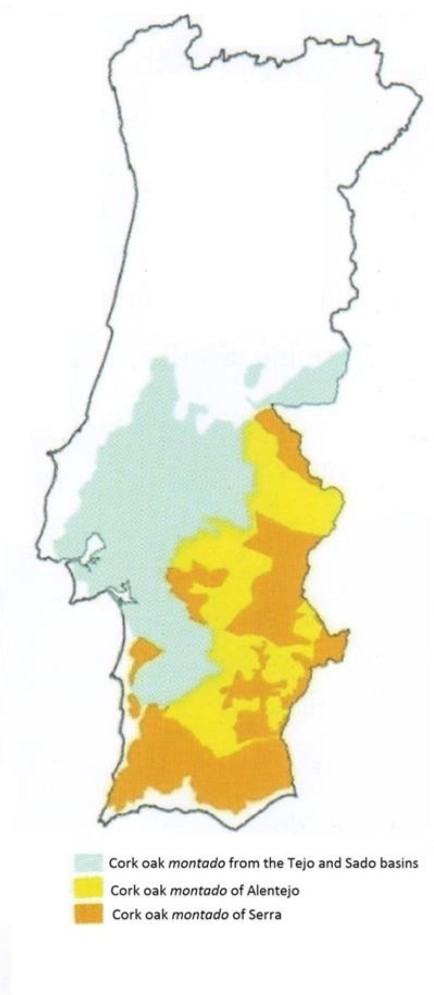


Figure 17. Distribution of three types of *montado* (Adapted from UNAC, 2013)

5 Description of ecosystems services

The structure of the *Montado*, integrating woody vegetation with crop and/or animal systems, benefits from the resulting ecological and economic interactions and is considered as a good example of sustainable land use practice combining food and fibre production and other ecosystem services for the whole society (Ramachandran Nair et al. 2010). The concept of ecosystem services appeared in the scientific literature during the 1990s (Daily 1997; Costanza et al. 1997) and gained importance in 2003 with the Millennium Ecosystem Assessment (MEA) where the concept was better defined and several classifications presented. Following the European Environmental Agency (EEA), ecosystem services can be divided into three main categories that directly offer final services to society (Haines-Young and Potschin 2013):

- Provisioning services which considers food, materials or energy outputs from ecosystems
- Regulating services which include services where ecosystems act as regulators on water, soil or air quality control
- Cultural services including aspects related to the recreation and appreciation services offered by the ecosystems.

A fourth category is also considered: supporting services which include the set of intermediate services to facilitate the other three categories.

In terms of provisioning ecosystem services, cork-oak *Montados* can be considered as a complex system whose complexity is related to the different activities practiced on the same area (Pinto-Correia et al. 2011a). The system can include forest, agricultural or pastoral production processes. Cork is a key source of income and Portugal is the largest global producer accounting for about 50% of world cork production (Pereira et al. 2007, Mendes and Graça 2009). However the system offers many other products derived from the combination of activities such as wood, charcoal, crops, fodder, meat, dairy products, honey, mushrooms and/or medicinal and aromatic plants (Gaspar et al. 2007; Pereira 2007; Pinto-Correia et al. 2011b).

The habitat heterogeneity in the *montado* improves the capacity of the system to host biodiversity (Bugalho et al. 2011), promoting plant diversity caused by shrub clearing (Canteiro et al. 2011), conditioning of the canopy cover on the macrofungal communities (Santos-Silva et al. 2011) and on the population density of wild ungulates, especially red deer (*Cervus elaphus hispanicus*) and wild boar (*Sus scrofa*). Other animals are abundant, including the endangered Cabrera vole (*Microtus cabrerae*) (Godinho et al. 2010; Pinto-Correia et al. 2011a).

Generally, information of regulating ecosystem services provided by *Montado* is scarce and the studies found are mainly based on:

1) the capacity of the system for carbon sequestration (Pereira et al. 2007, Hussain et al. 2009, Coelho et al. 2012; Palma et al. 2014)
2) the estimate of carbon balance of the system (Crous-Duran et al. 2014)
3) its capacity to improve water infiltration and prevent soil erosion (Pausas et al. 2009; Guerra and Pinto- Correia 2016).

Crous-Duran et al. (2015) applied the ESAT-A tool (Tsonkova et al. 2014) to compare the *montado* and two of its land-use alternatives (wheat agriculture and dense forestry) in terms of carbon sequestration, water and wind soil erosion. The ESAT-A tool was developed for the alley cropping systems in Germany, and facilitates the comparison of ecosystem service supply for different management options (tree densities) while offers an assessment for five regulation services: carbon sequestration, soil fertility, erosion control, water regulation and water quality and one supporting service: habitat provision.

The *montado* is widely recognised for its capacity to support recreation activities and its aesthetic appreciation (Pinto-Correia and Vos, 2004, Barroso et al. 2012). However research is needed in methodological approaches to relate public preferences and perceptions to the different types of *Montado* resulted from different management options (Pinto-Correia et al. 2011a) so that detailed information can be used in decision support systems (Borges et al. 2010).

6 Economic value and sustainability

6.1 Cork price evolution

In this section we focus on the evolution of cork prices. Cork prices are referred in €/@, where @ designates 'arroba', the most used weight unit in the cork industry and is equivalent to 15 kg. There have been large fluctuations in cork prices since 1959 (Figure 18) with maximum values of 55.8€/@ obtained between 1999 and 2001. After 2001, a general reduction of prices has been noticed, resulting in an average decrease of 6% per year, with a low value of around 24€/@ being found in 2012. In 2013, cork was valued at 26€/@ (UNAC, 2013).

The changes in cork price has affected farms in different ways, since cork price is differentiated between regions, farms, and even inside the farm if different plots are managed for cork production. Currently farmer owners associations are trying to clarify cork prices by encouraging farmers to carry out forest cork inventories before cork debarking (Almeida and Tomé 2010), allowing the collection of cork samples that can be classified for quality and thickness.

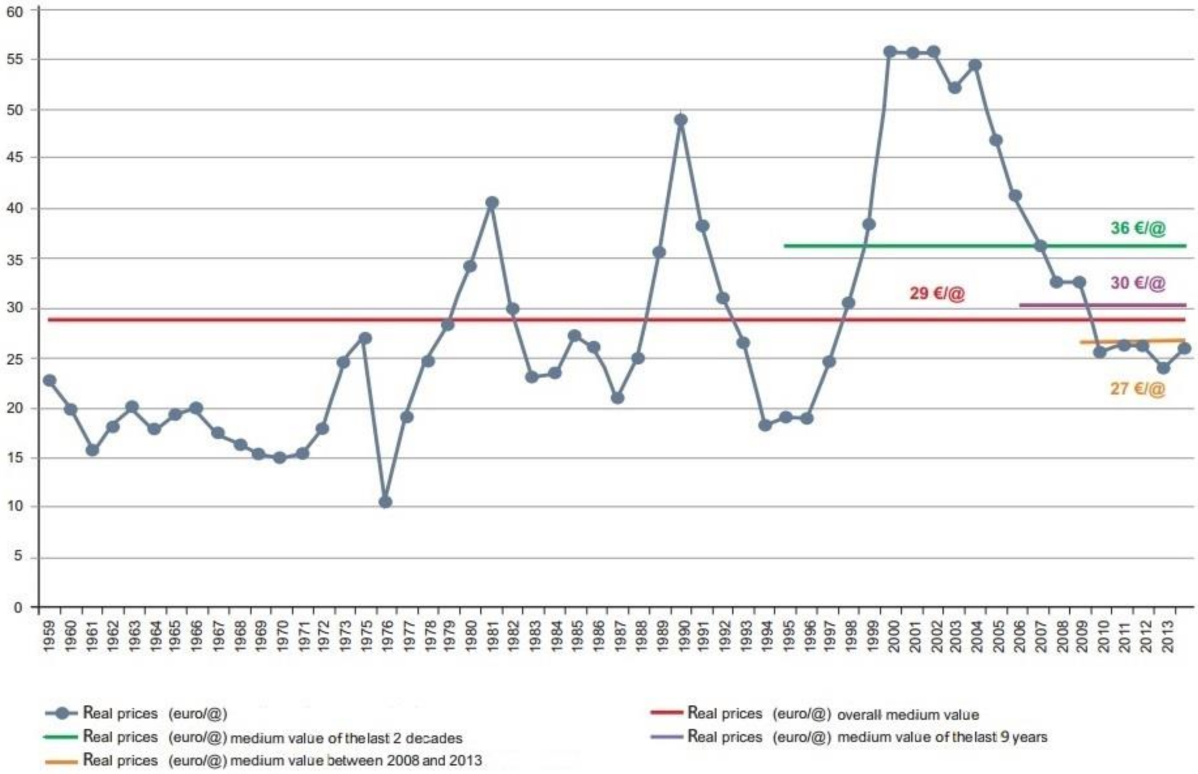


Figure 18. Evolution of real prices of cork (€/@) paid at production over the period of 1959-2013. Adapted from UNAC (2013).

Two features are important when defining the value of cork for the industry of cork stoppers: the thickness of the cork plank and the cork quality (Pereira 2007). Cork quality is visually evaluated by an operator that, considering the cork porosity and the presence of cork defects, classifies the cork in 7 classes, from quality class 1 (best quality) to quality class 7 or refuse (worst quality). The price of the cork extracted in one tree is defined by the combination of cork thickness, measured after boiling and classified in classes, and cork quality characteristics. Since different combinations of these two characteristics result in different prices, one may refer to a structure of cork prices when the presentation of these values is carried out. Cork price structure has changed in the last few years, generally showing a significant decrease in most of the cork assortments. It is important to notice that this price reduction was more significant in cork classified as poor and medium quality that in high quality classes. Table 1 and Table 2 present two real cork prices structures characterizing two distinct moments in the cork market in the last decades: the higher and lowest average cork prices, which occurred in the years 2000 and 2009, respectively. These market fluctuations have been driven by the evolution of the world wine market, the development of new cork applications, the increase of the amount of thinner and low quality cork in opposition to thicker and higher quality cork available for the industry, and the improvement of conservation methods of the raw material in the industry in order to cope with the fluctuations of material supply. It is important to notice that although the classification of the cork is made by the industry considering 5 thickness classes and 7 quality classes, cork prices are not differentiated for the resulting 35 combinations. For example, cork quality classes 1, 2 and 3 are typical attributed the same price, as the usage given to this cork material is generally the same (Pereira et al. 1994; Oliveira et al. 2012).

Table 1. Cork price structure (€ $@^{-1}$) characterizing a 'high cork price moment'. (Cork prices for the year of 2000). 1@ = 15 kg. Values already include the costs from the debarking operation. Source: APFC (personal communication).

<table>
<tr><th rowspan="2">Cork thickness class (mm)</th><th colspan="7">Quality class</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><td>< 18</td><td colspan="3" rowspan="2">36.39</td><td colspan="3">11.91</td><td rowspan="5"></td></tr>
<tr><td>18 – 23</td><td colspan="2">21.43</td><td>12.45</td></tr>
<tr><td>23 – 27</td><td colspan="5">44.62</td><td>15.44</td></tr>
<tr><td>27 – 41</td><td colspan="5">64.82</td><td>21.43</td></tr>
<tr><td>> 41</td><td colspan="6">32.65</td></tr>
</table>

Table 2. Cork price structure (€ $@^{-1}$) characterizing a 'low cork price moment'. (Cork prices for the year of 2009). 1@ = 15 kg. Values already include the costs from the debarking operation. Source: APFC (personal communication).

<table>
<tr><th rowspan="2">Cork thickness class (mm)</th><th colspan="7">Quality class</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th></tr>
<tr><td>< 18</td><td colspan="3" rowspan="3">11.75</td><td colspan="3">0.70</td><td rowspan="5"></td></tr>
<tr><td>18 – 23</td><td rowspan="2">11.65</td><td colspan="2" rowspan="4">6.50</td></tr>
<tr><td>23 – 27</td></tr>
<tr><td>27 – 41</td><td colspan="3" rowspan="2">88.25</td><td rowspan="2">51.50</td></tr>
<tr><td>> 41</td></tr>
</table>

6.2 Management costs for different agroforest management models

Reference values for minimum, average and maximum costs are provided by CAOF (Comissão de Acompanhamento das Operações Florestais – available @ http://www.anefa.pt/). Table 3 shows values for the main operations presented by UNAC (2013), where separately for each one of the three systems structures of *montado* (see section 3): *montado* from the Tejo and Sado rivers basins; *montado* of the Alentejo region and *montado* in mountain regions.

The main difference between farms primarily arises due to management options and the frequency of their application, generally designated as agroforest management alternatives. UNAC (2013) proposed two distinct agroforest management models to characterize *montado* management in Portugal:

- Sustainable management model: here the aim is the perpetuation of cork oak *montado* on a medium-long term. This model includes operations required for tree regeneration promotion and improvement of soil fertility levels, with a resulting increase of associated labour costs.
- Minimal management model: here the aim is the reduction of costs by practicing a minimal intervention on the *montado*. This model does not include operations required to guarantee tree regeneration, and the improvement of soil fertility levels, and therefore presents lower values associated to labour costs.

The chronograms associated to each of the two agroforest management models are presented in Annex A and B, separately for each of the three systems structures of *montado* areas presented in Section 3. For each one of these systems, installation, maintenance costs are presented in Table 3.

Table 3. Estimated installation, maintenance and total costs associated to *montado* systems. Adapted from UNAC (2013).

System structures of *montado*	Agroforest management model	Installation costs (€/@)	Maintenance costs (€/@)	Total costs (€/@)
Montado from the Tejo and Sado rivers basins	Minimal	10.45	19.63	30.08
	Sustainable	7.93	23.16	31.09
Montado of the Alentejo region	Minimal	11.52	19.96	31.48
	Sustainable	8.74	25.02	33.76
Montado in mountain	Minimal	20.62	20.05	40.67
	Sustainable	16.24	35.64	51.88

6.3 State of the art regarding the profitability of *montado* farms

The financial return associated to farms including *montado* areas is mainly dependent of cork, meat price and land use policy incentives. Other products such as acorns, wild mushrooms or even wood are a small fraction of the farmer revenue, and are mainly used for self-consuming or not commercialized by the farmer. Although published research on profitability is found for the case of *dehesas* (e.g. Campos et al. 2001, Campos et al. 2008), less information is available regarding *montado* farms were cork is one of the main products. Presently there is no existing agroforestry accounting systems that includes a cork production module that would allow research on:

- the impact of different debarking rotation periods (CDR) on the economic value and profitability of *montado,*
- the differences in economic value and profitability from farms characterized by different cork quality, and
- the impact of different cork prices structures on the economic value and profitability of the farms.

It is demonstrated that decoupling of CAP payments leads production decisions and resources allocation to be more dependent on market prices and competitive advantages, which in the case of cork have suffered a severe reduction in recent decades, with consequent negative economic effects on agricultural activities and resource use (Fragoso et al. 2011). Despite these results, and even considering six differentiated *montado* agro-forestry production systems, Fragoso et al. (2011) does not include cork price as an input variable on the research, compromising the differentiation of the results for different farms characterized by different cork quality features.

Paulo (2011) and UNAC (2013), although considering different methodologies, include the impact of cork quality and cork price on the farm profitability, but they do not consider the revenue associated with livestock, cereals and other crop production. Paulo et al. (2011) used the growth and yield SUBER model, which runs for a time step of one year and for a simulation unit of the individual tree, and computes both net present value (NPV) and equivalent annuity values associated with each simulation. Each simulation considers input information on agroforestry management operations calendar, associated costs, revenues resulting from cork production differentiated by cork quality class, and information on cork quality based on cork forest inventory or default values at regional level.

Paulo (2011) results on long-term simulations, for nine young stands with varying site indexes (Paulo et al 2015a) and cork quality characteristics, and considering cork debarking rotations (CDR) from 9 to 14 years, allowed the author to demonstrate that, for discount rates of 2%, the impact of the variation of the CDR on the equivalent annuity value is clear. CDR of 9 and 11 years are associated to similar annuity values, in stands characterized by high or average site index values, and high or medium quality cork characteristics. Variation of the CDR in stands representing low site index values or low quality cork characteristics did not had a relevant impact on annuity values, revealing the economic dependence of such systems on other products and services associated to the silvopastoral or silvoarable management practices and on CAP measures. For the simulations carried out with a discount rate of 5% the annuity value decreases with the increase of CDR, indicating that the minimum 9 years interval of CDR is adequate. Results also demonstrate that the recent decline in cork prices reduced the annuity value with increased risks for farm profitability. The annuity estimates computed for farms characterized by a production of low quality cork and considering 2009 cork prices (Table 2) result in negative values (0 to -30 €), in line with the values computed for the *dehesa* systems.

In summary, it is clear that both the *dehesa* and the *montado* are highly complex and labour intensive systems, with low and often negative profitability. The inclusion of cork production modules in existing agroforestry accounting systems, or economic models, that allow the input of information on cork production and cork quality characterizing the farm, is essential to allow further research to improve our knowledge on the impact of cork quality and cork prices on the profitability of *montado* farms.

7 Acknowledgements

The AGFORWARD project (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD, Theme 2 - Biotechnologies, Agriculture & Food. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

8 References

AFN (2010). Inventário Florestal Nacional Portugal Continental IFN5, 2005 - 2006. Autoridade Florestal Nacional, Lisboa, 209 pp. (http://www.icnf.pt/portal/florestas/ifn). [In Portuguese].

Almeida A, Tomé M (2010). Field sampling of cork value before extraction in Portuguese '*montados*'. Agroforest Systems 79: 419–430. http://dx.doi.org/10.1007/s10457-009-9260-8

APA (1984). Carta Ecológica de Portugal - Atlas Digital de Portugal. Agencia Portuguesa do Ambiente, Lisboa. [In Portuguese].

Barroso FL, Pinto-Correia T, Ramos IL, Surová D, Menezes H (2012). Dealing with landscape fuzziness in user preference studies: Photo-based questionnaires in the Mediterranean context. Landscape and Urban Planning 104: 329-342. http://dx.doi.org/10.1016/j.landurbplan.2011.11.005

Borges PF, Fragoso R, Garcia-Gonzalo J, Borges JG, Marques S, Lucas MR (2010). Assessing impacts of Common Agricultural Policy changes on regional land use patterns with a decision support system. An application in Southern Portugal. Forest Policy and Economics 12: 111-120. http://dx.doi.org/10.1016/j.forpol.2009.09.002

Bravo-Oviedo A, Pretzsch H, Ammer C, Andenmatten E, Barbati A, Barreiro S, Brang P, Bravo F, Coll L, Corona P, Ouden J, Ducey MJ, Forrester DI, Giergiczny M, Jacobsen JB, Lesinski J, Löf, M, Mason B, Matovic B, Metslaid M, Morneau F, Motiejunaite J, O'Reilly C, Pach M, Ponette Q, del Rio, M, Short I, Skovsgaard JP, Soliño M, Spathelf P, Sterba H, Stojanovic D, Strelcova K, Svoboda M, Verheyen K, von Lüpke N, Zlatanov T (2014). European Mixed Forests: definition and research perspectives Forest Systems, 23(3): 518-533. http://dx.doi.org/10.5424/fs/2014233-06256

Bugalho MN, Caldeira MC, Pereira JS, Aronson JA, Pausas J (2011). Mediterranean oak savannas require human use to sustain biodiversity and ecosystem services. Frontiers in Ecology and the Environment 5: 278-286 http://dx.doi.org/10.2307/23034413

Cabral MT, Ferreira MC, Moreira T, Carvalho EC, Diniz AC (1992). Diagnóstico das causas da anormal mortalidade dos sobreiros a Sul do Tejo. Scientia gerundensis 18: 205–214. [In Portuguese].

Cadima ISP, Capelo J, Gomes AA (1995). Relação entre variáveis ambientais, tipos de condução dos povoamentos e a mortalidade do sobreiro nos concelhos de Sines, Grândola e Santiago do Cacém. Silva Lusitana 3(1): 85–107. [In Portuguese].

Caldeira MC, Ibáñez I, Nogueira C, Bugalho MN, Lecomte X, Moreira A, Pereira, JS (2014). Direct and indirect effects of tree canopy facilitation in the recruitment of Mediterranean oaks. Journal of Applied Ecology 51(2): 1365-2664. http://dx.doi.org/10.1111/1365-2664.12189

Caldeira MC, Lecomte X, David TS, Pinto JG, Bugalho MN, Werner C (2015). Synergy of extreme drought and shrub invasion reduce ecosystem functioning and resilience in water-limited climates. Scientific Reports 5: 15110. http://dx.doi.org/10.1038/srep15110

Campos PP, Caparrós GS, Rodríguez JY (2001). Towards the dehesa total income accounting: theory and operative Monfragüe study cases. Investigación agraria. Sistemas y recursos forestales 10(1): 43-68. http://hdl.handle.net/10261/10285

Campos P, Ovando P, Montero G (2008). Does private income support sustainable agroforestry in Spanish dehesa? Land Use Policy 25(4): 510–522. http://dx.doi.org/10.1016/j.landusepol.2007.11.005

Canteiro C, Pinto-Cruz C, Simões MP, Gazarini L (2011). Conservation of Mediterranean oak woodlands: understorey dynamics under different shrub management. Agroforest Systems 82(2): 161-171 http://dx.doi.org/10.1007/s10457-011-9375-6

Caritat A, Molinas M, Gutierrez E (1996). Annual cork-ring width variability of Quercus suber L. in relation temperature and precipitation (Extremadura, southwestern Spain). Forest Ecology and Management 86: 113-120. http://dx.doi.org/10.1016/S0378-1127(96)03787-5

Castel-Branco D (2014). Analysis of mortality rates in young cork oak plantations (Quercus suber L.) and relation to site quality. Master thesis. Universidade de Lisboa, Instituto Superior de Agronomia, Lisboa, Portugal, 53 pp. http://hdl.handle.net/10400.5/7066 [In Portuguese].

Coelho MB, Paulo JA, Palma JHN, Tomé M (2012). Contribution of cork oak plantations installed after 1990 in Portugal to the Kyoto commitments and to the landowners economy. Forest Policy and Economics 17: 59-68. http://dx.doi.org/10.1016/j.forpol.2011.10.005

Correia A, Silva FC, Correia A, Hussain MZ, Rodrigues AP, David JS, Pereira JS (2013). Carbon sink strength of a Mediterranean cork oak understorey: How do semi-deciduous and evergreen shrubs face summer drought? Journal of Vegetation Science 25(2): 411–426. http://dx.doi.org/10.1111/jvs.12102

Correia AV, Oliveira AC (2003). Principais espécies florestais com interesse para Portugal – zonas de influência atlântica. Estudos e Informação nº 322, Direcção Geral das Florestas, Lisboa, 187 pp. [In Portuguese].

Costa A, Madeira M, Plieningerd T (2014). Cork oak woodlands patchiness: A signature of imminent deforestation? Applied Geography 54: 18–26. http://dx.doi.org/10.1016/j.apgeog.2014.07.006

Costa A, Pereira C (2007). Manual de Instalação de Novos Povoamentos com Sobreiro. Aplicação de Boas Práticas nas Regiões da Chamusca e de Alcácer do Sal. ISA, ERENA, ANSUB, ACHAR, Lisboa, Portugal, 30 pp. http://www.achar.pt/UserFiles/Image/ACHAR/MINPS-final.pdf [In Portuguese].

Costa A, Pereira H (2006). Decision Rules for Computer-Vision Quality Classification of Wine Natural Cork Stoppers. American Journal of Enology and Viticulture 57 (2): 210-219.

Costa A, Pereira H, Madeira M (2010). Analysis of spatial patterns of oak decline in cork oak woodlands in Mediterranean conditions. Ann. For. Sci. 67(2): 204-204. http://dx.doi.org/10.1051/forest/2009097

Costanza R, d'Arge R, de Groot R (1997). The value of the world's ecosystem services and natural capital. Nature 387: 253–260. http://dx.doi.org/10.1038/387253a0

Crous-Duran J, Paulo JA, Palma J (2014) Carbon balance estimation for agroforestry land use alternatives in Portugal. 2nd Agroforestry Conference – Integrating Science and Policy to Promote Agroforestry in Practice – Book of Abstracts. Palma JHN & Chalmin A (Eds), Cottbus, Germany 153-156 pp 4360. http://www.repository.utl.pt//handle/10400.5/6764

Crous-Duran J, T sonkova P, Freese D, Palma JHN (2015). Development of a methodological approach for evaluating provision of ecosystem from cork oak agroforestry systems. Report for STSM-FP1203- 24121. Available: http://www.nwfps.eu/wp-content/uploads/2012/07/josep-crous-duran-call3.pdf

Daily, G (1997). Nature's services. Societal dependence on natural ecosystems. Island Press, Washington, DC. 392 pp. ISBN 1-55963-475-8.

David TS, Pinto CA, Nadezhdina N, Kurz-Bessonc C, Henriquesd MO, Quilhó T, Cermak J, Chaves MM, Pereira JS, David JS (2013). Root functioning, tree water use and hydraulic redistribution in Quercus suber trees: A modeling approach based on root sap flow. Forest Ecology and Management 307: 136-146. http://dx.doi.org/10.1016/j.foreco.2013.07.012

DGF (2001). Inventário Florestal Nacional. 3ª Revisão. 1995-1998. [National Forest Inventory. 3rd revision. 1995-1998]. Direcção Geral das Florestas. Lisboa. 233 pp. [In Portuguese].

Fonseca A (2008). O *Montado* no Alentejo. Edições Colibri, Lisboa, Portugal, 158 pp. [In Portuguese].

Fragoso R, Marques C, Lucas MR, Martins MB, Jorge R (2011). The economic effects of common agricultural policy on Mediterranean *montado/dehesa* ecosystem. Journal of Policy Modeling 33 (2): 311–327. http://dx.doi.org/10.1016/j.jpolmod.2010.12.007

Gaspar P, Mesías FJ, Escribano M, Rodriguez de Ledesma A, Pulido F (2007). Economic and management characterization of dehesa farms: implications for their sustainability. Agroforestry Systems 71(3): 151-162. http://dx.doi.org/10.1007/s10457-007-9081-6

Godinho S, Santos AP, Sá-Sousa P (2010). Montado management effects on the abundance and conservation of reptiles in Alentejo, Southern Portugal. Agroforestry Systems 82 (2): 197-207. http://dx.doi.org/10.1007/s10457-010-9346-3

Guerra C, Pinto-Correia T (2016). Linking farm management and ecosystem service provision: Challenges and opportunities for soil erosion prevention in Mediterranean silvo-pastoral systems. Land Use Policy 51: 54–65 http://dx.doi.org/10.1016/j.landusepol.2015.10.028

Haines-Young R, Potschin M (2013). Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012. EEA Framework Contract No EEA/IEA/09/003 (Download at www.cices.eu or www.nottingham.ac.uk/cem)

Hussain MZ, Otieno, DO, Mirzae H, Li YL, Schmidt, MWT, Siebke L, Foken T, Ribeiro NA, Pereira JS, Tenhunen, JD (2009). CO2 exchange and biomass development of the herbaceous vegetation in the Portuguese *montado* ecosystem during spring. Agriculture, Ecosystems and Environment, 132(1-2): 143–152 http://www.repository.utl.pt//handle/10400.5/9017

ICNF (2013). 6º Inventário Florestal Nacional Portugal Continental. Resultados preliminares. Instituto da conservação da natureza e das florestas. (http://www.icnf.pt/portal/florestas/ifn/resource/ficheiros/ifn/ifn6-res-prelimv1-1). [In Portuguese].

Jongen M, Lecomte X, Unger S, Pintó-Marijuan M, Pereira JS (2013). The impact of changes in the timing of precipitation on the herbaceous understory of Mediterranean evergreen oak woodlands. Agricultural and Forest Meteorology 171–172: 163-173. http://dx.doi.org/10.1016/j.agrformet.2012.11.020

Mendes AMS, Graça JAR (2009) Cork bottle stoppers and other cork products In: Cork oak woodlands on the edge: ecology, management, and Restoration. Island, St. Louis. pp 59 – 68.

Montero G, Vallejo R (1992). Variación del calibre del corcho medido a distintas alturas. Forest Systems 1(2): 181 – 188. http://recyt.fecyt.es/index.php/IA/article/viewArticle/4696 [In Spanish].

Moreno G (2008). Response of understory forage to multiple tree effects in Iberian dehesas. Agriculture, Ecosystems and Environment 123(1–3): 239–244. http://dx.doi.org/10.1016/j.agee.2007.04.006

Natividade JV (1950). Subericultura. Direcção Geral dos Serviços Florestais e Aquicolas, Lisboa, 387 pp. [In Portuguese].

Oliveira V, Knapic S, Pereira H (2012). Natural variability of surface porosity of wine cork stoppers of different commercial classes. International journal of vine and wine sciences 46 (4): 331-340

Otieno DO, Mirzaei H, Hussain MZ, Li YL, Schmidt MWT, Wartinger M, Jung E, Ribeiro N, Pereira JS, Tenhunen J (2011). Herbaceous layer development during spring does not deplete soil nitrogen in the Portuguese *montado*. Journal of Arid Environments 75(3): 231-238 http://dx.doi.org/10.1016/j.jaridenv.2010.10.011

Palma JHN, Paulo, JA, Tomé M (2014). Carbon sequestration of modern Quercus suber L. silvoarable agroforestry systems in Portugal: a YieldSAFE-based estimation. Agroforestry Systems. 88(5): 791-801 http://dx.doi.org/10.1007/s10457-014-9725-2

Paulo JA (2011). Development of a growth and yield model for the sustainable management of cork oak stands. PhD thesis for Forestry and natural resources management. Universidade Técnica de Lisboa, Instituto Superior de Agronomia, Lisboa, Portugal, 188 pp. http://hdl.handle.net/10400.5/3850 [In Portuguese].

Paulo JA, Faias SP, Gomes AA, Palma J, Tomé J, Tomé M (2015a). Predicting site index from climate and soil variables for cork oak (Quercus suber L.) stands in Portugal. New Forests 46(2): 293-307. doi: http://dx.doi.org/10.1007/s11056-014-9462-4

Paulo JA, Faias SP, Ventura-Giroux C, Tomé M (2015b). Estimation of stand crown cover using a generalized crown diameter model: application for the analysis of Portuguese cork oak stands stocking evolution. iForest. http://www.sisef.it/iforest/contents/?id=ifor1624-008

Paulo JA, Pereira H, Tomé M (submitted). Analysis of variables influencing tree cork caliper in two consecutive cork extractions using cork growth index modelling.

Paulo JA, Tomé J, Tomé M (2011). Nonlinear fixed and random generalized height-diameter models for Portuguese cork oak stands. Annals of Forest Science 68: 295 – 309. doi: http://dx.doi.org/10.1007/s13595-011-0041-y

Pausas JG, Pereira JS, Aronson J (2009). Chapter 1. The Tree. In: Cork oak woodlands on the edge: ecology, management, and Restoration. Island, St. Louis., pp 11–23-

Pereira H (2007). Cork: biology, production and uses. Elsevier, Lisboa, 336 pp.

Pereira H, Melo B, Pinto R (1994). Yield and quality in the production of cork stoppers. Holz als Roh- und Werkstoff 52: 211-214 http://dx.doi.org/10.1007/BF02619093

Pereira H, Tomé M (2004). Non-wood products: Cork Oak. In: Burley J., Evans J. and Youngquist J.A. (Eds.), Encyclopedia of Forest Sciences. Elsevier, Oxford, pp. 613–620.

Pereira JS, Mateus JA, Aires, LM, Pita G, Pio C, David JS, Andrade V, Banza J, David TS, Paço TA, Rodrigues A (2007). Net ecosystem carbon exchange in three contrasting Mediterranean ecosystems – the effect of drought. Biogeosciences 4: 791–802. http://doi.org/10.5194/bg-4-791-2007

Pinto CA, Nadezhdina N, David JS, Kurz-Besson C, Caldeira MC, Henriques MO, Monteiro FG, Pereira JS, David TS (2014). Transpiration in Quercus suber trees under shallow water table conditions: the role of soil and groundwater. Hydrological Processes 28 (25): 1099-1085 http://dx.doi.org/10.1002/hyp.10097

Pinto-Correia T, Barroso F, Surová D, Menezes H (2011a). The fuzziness of *Montado* landscapes: Progress in assessing user preferences through photo-based surveys. Agrofor Syst 82:209–224. http://dx.doi.org/10.1007/s10457-010-9347-2

Pinto-Correia T, Ribeiro N, Sá-Sousa P (2011b). Introducing the *montado*, the cork and holm oak agroforestry system of Southern Portugal. Agroforest Systems 82: 99–104. http://dx.doi.org/10.1007/s10457-011-9388-1

Pinto-Correia T, Vos W (2004). Multifunctionality in Mediterranean landscapes - past and future. In: Jongman R (ed). The new dimension of the European landscapes. Wageningen FRONTIS Series. Springer, Dordrecht, pp 135–164

Pizzurro GM, Maetzke F, Veca DSLM (2010). Differences of raw quality cork in productive cork oak woods in Sicily in relation to stand density. Forest Ecology and Management 260: 923 – 929 http://dx.doi.org/10.1016/j.foreco.2010.06.013

Ramachandran Nair PK, Nair VD, Mohan Kumar B, Showalter JM (2010). Chapter Five – Carbon Sequestration in Agroforestry Systems. Adv. Agron. pp 237–307.

Ribeiro F, Tomé M, (2002). Cork weight prediction at tree level. Forest Ecology and Management 171(3): 231-241. http://dx.doi.org/10.1016/S0378-1127(01)00780-0

Sánchez-González M, Calama R, Cañellas I, Montero G (2007). Variables influencing cork thickness in Spanish cork oak forests: A modeling approach. Annals of Forest Science 64(3): 301-312. http://dx.doi.org/10.1051/forest:2007007

Santos-Silva C, Gonçalves A, Louro R (2011). Canopy cover influence on macrofungal richness and sporocarp production in *Montado* ecosystems. Agroforest Systems http://dx.doi.org/10.1007/s10457-011-9374-7

Serrada R, Montero G (2008). Compendio de la selvicultura aplicada en España. INIA, Madrid [In Spanish].

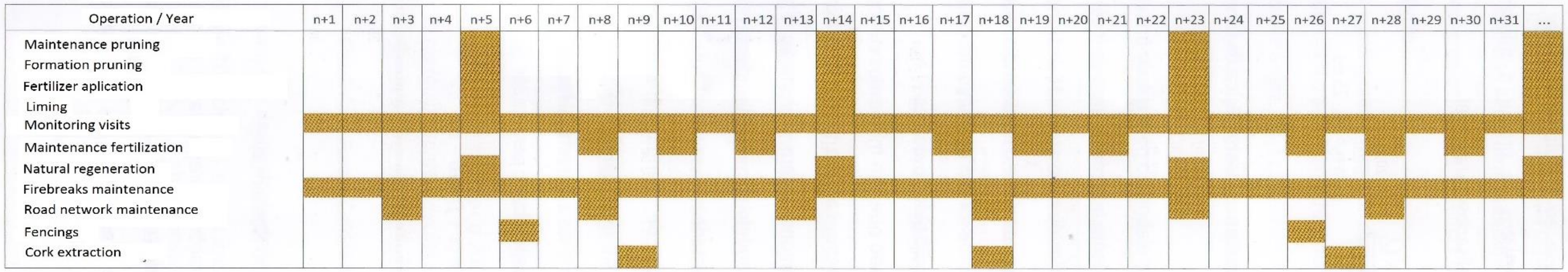
Tsonkova P, Quinkenstein A, Böhm C, et al (2014). Ecosystem services assessment tool for agroforestry (ESAT-A): An approach to assess selected ecosystem services provided by alley cropping systems. Ecol Indic 45:285–299. http://dx.doi.org/10.1016/j.ecolind.2014.04.024

UNAC (2013). Estudo de determinação dos pontos de valor acrescentado da fileira da cortiça. União da Floresta Mediterrânica. 59 pp. Lisboa, Portugal. http://www.unac.pt/images/ficheiros/Livro_AgroGes_VF_site2.pdf [In Portuguese].

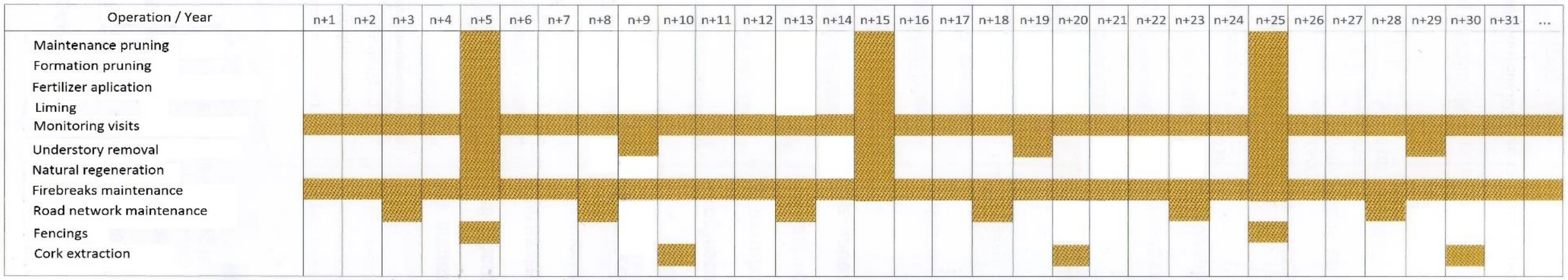
van der Werf D, Keesman K, Burgess P, Graves A, Pilbeam D, Incoll LD, Metselaar K, Mayus M, Stappers R, Keulen H, Palma J, Dupraz C (2007). Yield-SAFE: A parameter-sparse, process-based dynamic model for predicting resource capture, growth, and production in agroforestry systems. Ecological Engineering 29: 419–433. http://dx.doi.org/10.1016/j.ecoleng.2006.09.017

Annex A. Proposed chronograms for *montado* management operations, according to a sustainable management model. A - *montado* from the Tejo and Sado rivers basins; B - *montado* of the Alentejo region and C - *montado* in mountain regions. Source: UNAC (2013)

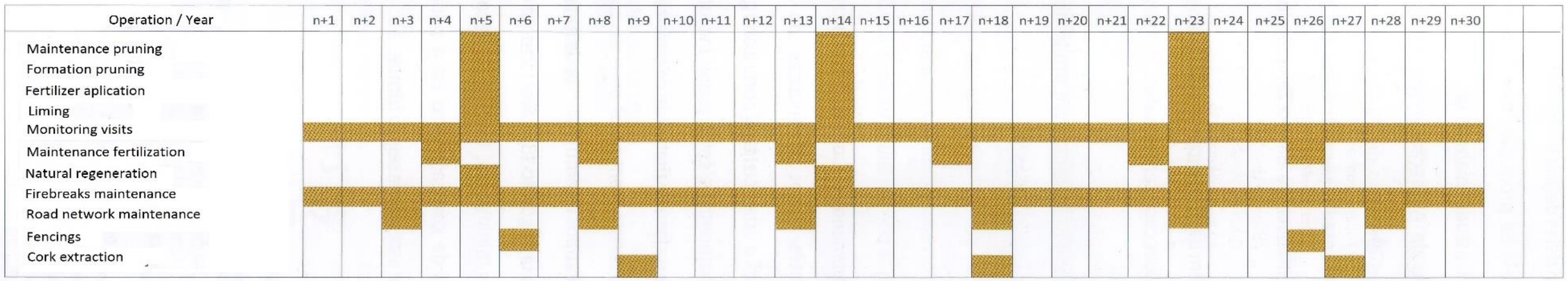
A



B



C



Annex B. Proposed chronograms for *montado* management operations, according to a minimal management model. A - *montado* from the Tejo and Sado rivers basins; B - *montado* of the Alentejo region and C - *montado* in mountain regions. Source: UNAC (2013)