Decision Support Systems in Agriculture, Food and the Environment:

Trends, Applications and Advances

Basil Manos
Aristotle University of Thessaloniki, Greece

Konstantinos Paparrizos
University of Macedeonia, Greece

Nikolaos Matsatsinis
Technical University of Crete, Greece

Jason Papathanasiou
University of Macedeonia, Greece

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Chapter 20
Adaptive Management on Sustainability of Cork Oak Woodlands

Nuno de Almeida Ribeiro
University of Évora, Portugal

Peter Surový
University of Évora, Portugal

António Cipriano Pinheiro
University of Évora, Portugal

ABSTRACT

The cork oak woodland production systems result from the integration of conflicting activities in the same space creating the need of constant search of equilibrium between its components in order to achieve sustainability. In a climate change environment, associated with recent modifications in rural societies, adaptive management concepts are needed so as to maintain cork oak woodland systems sustainable. Nowadays/Currently cork oak woodlands are facing disturbances that are affecting the production system sustainability both by intensification of the activities undercover- that leads to a lack of regeneration and consequent disappearing of the crown cover, loss of cork production and site degradation mainly by soil loss-, or by the abandonment that conducts to an invasion of shrubs and other oaks increasing the competition (reducing cork production) and the risk of forest fire. Only adaptive management techniques associated with growth models and decision support systems, constructed in knowledge based monitoring system, are able to prevent cork wood land decline with the adoption of management practices focused in long term objectives. For the present study it was selected a set of permanent plots according with site quality and stand age and structure. Simulation studies results indicates that cork oak woodland system sustainability (both economical and ecological) is supported in regeneration events associated with the shrub control techniques without soil mobilization with strong dependency of cork prices and valuation of carbon sequestration, especially in the less productive soils. Without modification of actual funding policies and the valuation of carbon sequestration, the system faces increased risks of decline due to the maintenance of actual non sustainable management practices by the stake holders driven by their financial needs. This study is particularly relevant regarding that woodlands dominate the landscape

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of the south-western Iberian Peninsula, occupying approximately 3.1 million hectares in Spain and 1.2 million hectares in Portugal.

INTRODUCTION

Relevance of Cork Oak Woodlands

Woodlands dominate the landscape of the south-western Iberian Peninsula, occupying approximately 3.1 million hectares in Spain (Pulido *et al*., 2001) and 1.2 million hectares in Portugal (DGF-IFN, 2001). The forest system woodland is mostly dominated by Mediterranean evergreen oaks such as cork oak (*Quercus suber* L.) and holm oak (*Quercus rotundifolia*).

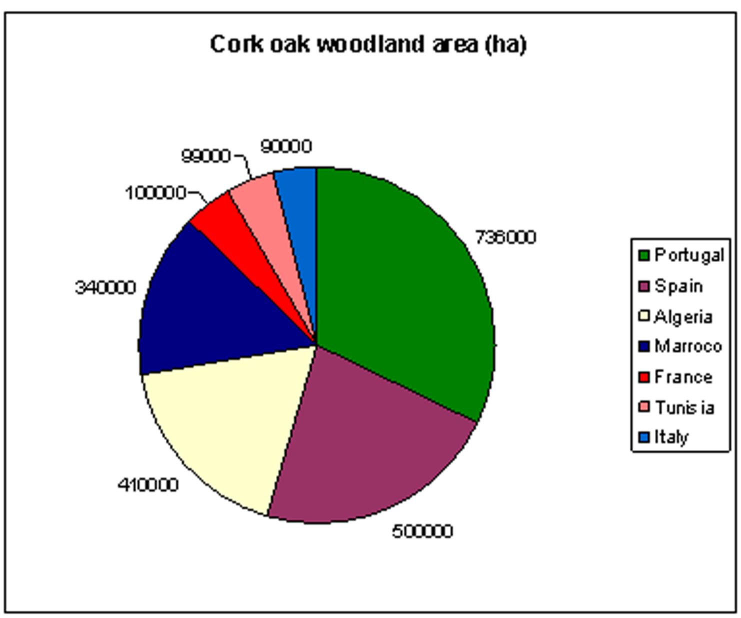
Cork oak woodlands occupy an area of 2 275 000 ha worldly and spotted as seen in Figure 1. World mean annual cork production is 340000 tons distributed according to Figure 1.

As it can be seen in Figure 1, Portugal cork oak woodland area represents about 33% of world area and 54% of mean annual world cork production. According to the United Nations Statistic Division, Portugal leads world cork exports (mainly manufactured cork products) with around 60% of the 1399075090 € generated by the exports in 2005.

Cork Oak Woodland Production System and its Multifunctionality

Cork oak woodlands are complex systems with the conjunction of production activities that share the same growing space in a landscape characterized by its site variability, especially at the soil/climate/topography levels. The trees are the base of these woodland production systems and are responsible for the ecological characteristics that are fundamental to the sustainability of all activities occurring at stand level. The ecological role of the trees by: (1) radiation and water vapor intersection are responsible for the specific microclimatic conditions found in this low density stands (Montero, *et al*., 1998); (2) savanna like

Figure 1. Cork oak area distribution (left). Mean annual production (right) (Source: Portuguese National Institute of Statistics (INE))



precipitation intersection and redistribution create areas in the stand with precipitation amounts above the total rainfall that are fundamental for water storage enhancement (David, 2000; David *et al.* 2002; Montero, 1988; Montoya, 1985, 1986); (3) The spatial distribution of the trees creates a high rugosity, reducing wind speed thus reducing plant transpiration and ecosystem water consumption (David *et al.* 2002; Montero et al., 1998); (4) the large and deep root systems of cork oak trees enhance the nutrient cycle at soil surface level with minerals absorbed in deeper and levels of the soil profiles and with the incorporation of organic matter in the soil that is responsible for a higher cation exchange capacity (Montero et al., 1998). These ecological functions of the trees create the conditions for a higher productivity of the other activities occurring under tree cover (grazing, pasture, crop production, etc.).

It's required an accurate knowledge of the resilience of the forest component in the particular combination of soil/climate/topography in order to achieve a balanced set of production activities (Ribeiro, Oliveira and Surový, 2006).

The woodland production system management aims the maintenance of a balanced sustainable land use to cope with the Mediterranean climate variability. Woodland stands (montado/dehesa) are managed in agro-silvo-pasture systems whose sustainability depends on balanced relations between their components (Pinheiro et al., 2008).

Both in forest and agriculture, the concept of multifunctionality is a key issue for the recognition of the merits of these production sectors not only for its achievement in food and raw materials production, but also for its environmental services supply and its social functions in rural areas. Inside this concept it is implicit that forest activity would produce certain goods and services exchangeable in the markets (*private services and goods*) and other goods and services, most of those of environmental and social character that would have features of *public goods or quasi-public goods*. Besides fruits, barks and fibers, forest rends to society other benefits such as: protects the environment, preserves rural landscape, provides recreation and education sites, prevents global warming, sequesters carbon, preserves the land, fosters water resources, protects wildlife, increases biodiversity, and, creates employment (Pinheiro et al., 2008).

From the economic point of view, forest functions different from fruit, bark and fibers production, provide goods and services that can be included inside the concept of "*externality*", since they generate effects that affect the utility (or the production) functions of other agents (in this case the rest of the society) without any compensation exchangeable through the markets.

The amount and the quality of goods and services provided for one forest can differ significantly, depending on the stands and the type of management.

The importance of the referred approach in building the ecological decision support system, relies in the possibility to anticipate a set of scenarios by simulation of management options that become available to help in the decision making process with all the economic benefits of a good forest planning program.

In this work we included a case study to compare two cork oak stands located at the same ecological region, with the same topography but with different site quality based on soil. It is shown that, to meet sustainability (both ecological and economical) in both stands, the management alternatives and their time scales are clearly diverse indicating the importance of the use of adaptive management tools.

METHODS

Assessing Sustainability of Woodlands Ecosystems

In general, forest investment last for a very long period, so the impact of any decision must be weighed to make sure that the ecosystem will be sustainable.

To know if a forest system is sustainable, or not, the following aspects must be analyzed:

- **Productivity**: the quantity and quality of goods and services produced in the unity of area;
- **Stability**: the regularity inter-years or inter-seasons of the production;
- **Lasting period**: capability of maintain a given level of production in the long run;
- **Equity**: fair distribution (equitable) of final income among the owners of production factors of ecosystem;
- **Autonomy**: capacity of auto-sustain and the degree of independence in relation to rest of the economy and society;
- **Sufficiency**: capacity to fulfill the necessities of those who live and work in the forest ecosystem.

If a forest system does not generate employment and enough income to fulfill the necessities of those who live and work in it, sooner or later it will be abandoned. As it was referred before, some forest systems (in general the pure stands of high rates of growth) produce more goods that have market prices and, therefore, while society do not put a value in the externalities, these forests tend to be more profitable and, for this reason, more attractive for private investment. So, it is important to put values on all positive externalities and taxes on the negative externalities to make different stands comparable.

In the work of Pinheiro et al. (2008) it was identified the set of externalities (positive and negative) resultant from the impact of the techniques of shrub control (with and without soil mobilization) and it was shown that adequate management techniques were only economically viable if the carbon sequestration was taken into account as a good with market.

Being the woodland system based on trees, its sustainability (continuous crown cover) is strongly associated with regeneration (natural or artificial). In fact, the system resilience is based on specific stand structures and densities that are supplied with new trees to compensate the natural rates of mortality permitting the maintenance of a stable crown cover (Ribeiro et al., 2003 and Ribeiro, Oliveira and Surový, 2006). The crown cover between 30% to 70% (slope dependent) fundamental to the specific ecological conditions created in the woodland ecosystems that enhance the efficient multifuncionality of the system and have a protective effect on soil preventing the erosion risk and improve the water and nutrient cycles (Ribeiro et al., 2004).

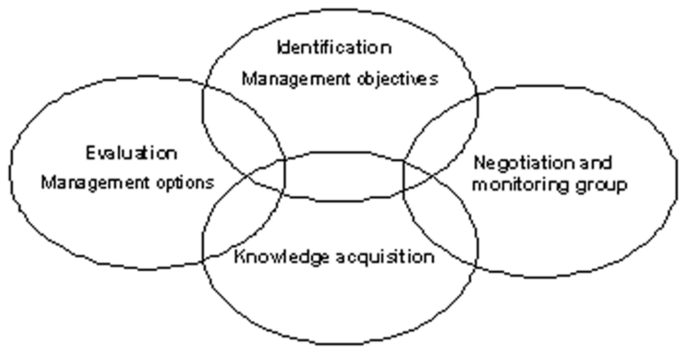
Ecological-Based Decision Support System (EBDSS)

The cork oak woodland production system presents some particularities that acts as management constrains: (1) The trees are fully protected by law and legal authorization is needed to cut, thin, prune, debark, etc., (2) The undercover is used to grow crops and/or animal production; (3) The main product is bark (cork) that is extracted every nine years (the minimum period permitted by law). Therefore the woodland cork oak system is a very complex one to manage.

Recent modification in demography and agrarian policies led to profound modifications in the management of cork oak woodlands. This affected the sustainability, both by intensification of the activities undercover, that leads to a lack of regeneration and consequent disappearing of the crown cover, loss of cork production and site degradation mainly by soil loss, and by the abandonment that conducts to an invasion of shrubs and other oaks increasing the competition (reducing cork production) and the risk of forest fire (Ribeiro *et al*., 2004).

In this work it is used an ecological based decision support system (ECCORK) based on

Figure 2. Ecological decision support system diagram



a spatial explicit tree growth simulator (CORK-FITS) following the adaptive management concept developed specifically for cork oak woodlands, as shown in Figure 2 (Ribeiro, Oliveira and Surový, 2006, Ribeiro *et al*., 2007).

In general, the theoretical concepts of adaptive management are based on an integration of knowledge acquisition (based on growth monitoring) that can permit to modify management options according to the objectives in a changing environment (climatic, socio-economic, demographic, etc.) based on a panel of negotiation (mainly constituted by entrepreneurs) and evaluation of past management results (Walter and Holling, 1990Rauscher, 1999). Falcão et al. 2006, refers that the combination of decision support tools with recent computer visualization techniques represents a good solution to deal with the complexity of forest ecosystem management and its spatial interactions with the landscape. These visualization techniques are especially useful at the level decision of the panel of negotiation, as referred above.

The construction of the ECCORK decision models is based on repeated measured data obtained in a set of 87 permanent plots (67 installed in 1995, 5 installed in 2000, and 15 installed in 2003) and in the knowledge acquisition site level (soil, management, climate, vegetation, bird population, etc.) and at tree level (growth, cork production, intensity of debark, crown pruning, etc.) (Ribeiro *et al*., 2003a). The decision making models include ecological indices (vegetation and animal biodiversity), management risk indices (soil erosion and fire hazard) and economical indices (cork production, cattle production, carbon sequestration, etc.) (Ribeiro *et al*., 2007, Surový et al., 2004).

Data

For the present study it was selected a set of permanent plots with dendrometrical characteristics described on Table 1.

For the present study it was selected a set of permanent plots according with: (1) site quality, based in the minimum principle, applied to the presence of at least one growth limitation factor in the soil (depth, rooting depth, external and internal drainage, etc.) to classify it as soil 1 and 0 otherwise (Ribeiro, et al., 2006); and stand age and structure with the selection of one young even aged stand and one mature uneven aged stand.

The stand 1 it is an even aged stand seeded in 1968. From this stand, two plots were selected: (1) plot 221 is located in soil site 0 (without growth limitations); (2) and plot 225 is located in soil site 1 (with growth limitations). The stand 2 is

Table 1. Descriptive statistics of permanent plots

Plot number /amount of trees		cbh	th	cw	e
	Mean	95.64	8.69	9.26	2.97
	Standard error of the mean	4.49	0.19	1.44	0.09
221 (n=26)	**Standard deviation**	22.91	0.97	7.33	0.50
	Minimum	67.0	6.90	3.36	1.43
	Maximum	179.5	9.90	40.69	3.58
	Mean	103.28	8.09	14.26	3.57
	Standard error of the mean	4.57	0.23	2.39	0.16
225 (n=20)	**Standard deviation**	20.42	1.26	10.68	0.71
	Minimum	76.5	5.8	5.09	2.71
	Maximum	146.5	10.5	47.18	5.89
	Mean	119.30	8.25	22.54	2.35
	Standard error of the mean	8.49	0.33	3.65	0.12
321 (n=22)	**Standard deviation**	39.86	1.56	1709	0.59
	Minimum	59.0	5.60	4.69	1.11
	Maximum	193.0	12.80	64.98	3.34
	Mean	101.44	8.99	17.17	2.56
	Standard error of the mean	5.70	0.23	2.42	0.07
322 (n=33)	**Standard deviation**	32.72	1.36	1.39	0.38
	Minimum	51.0	5.90	4.42	1.91
	Maximum	195.5	12.80	73.71	3.58

n = number of trees; cbhb = perimeter at breast height before debark (cm); th = tree height (m); e = caliper (cm); cw = cork dry weight

an uneven aged stand approximately 90 years old and it was regenerated on former agricultural crop fields (usually on exhausted soils). In this stand it was also selected two plots: (1) Plot 322 is located in soil site 0 (without growth limitations); (2) and plot 321 is located in soil site 1 (with growth limitations).

In Portugal the location of the set of plots used in the present study can be seen in Figure 3.

The 2000 m^2 plot statistics are presented in Table 1.

Model Structures

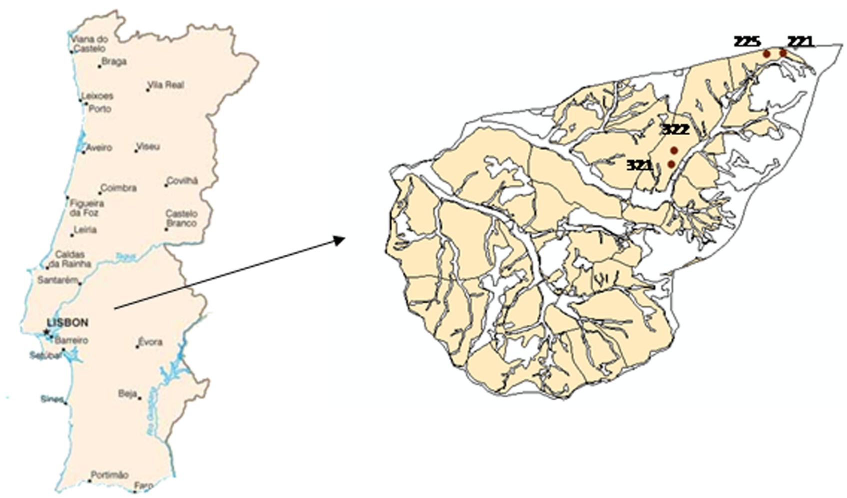
A cork oak single tree spatial growth simulator, CORKFITS, was constructed with data generated by the monitoring system (Ribeiro *et al*., 2003). The simulator was built assuming the potential increment modifier principle (Pretzsch, 1997, Ribeiro *et al*., 2006):

$$z = zpot * modifier + \varepsilon$$

where zpot is the potential growth as function of site; modifier is the reduction factor as function of spatial competition index and the intensity of debark; ε is a random error.

CORKFITS growth model is composed by sub growth models (cork, stem, tree height and crown), cork production models and mortality models (Ribeiro *et al*., 2006). A structure generator STRUGEN, based on a filtered Poisson process (Pretzsch, 1992, 1997), whose filters, were parameterized for cork oak stands natural spatial structure

Figure 3. Location in Portugal of the plots 221, 225, 321 and 322 used in the present study



(Ribeiro *et al.*, 2003b). This structure generator simulates virtual stands as well as regeneration (Ribeiro *et al.*, 2004, Ribeiro et al. 2006).

CORKFITS 2.1 flowchart can be seen in Figure 4.

ECCORK is a computer application which uses CORKFITS to simulate stand growth with spatial resolution at tree level and calculates, at stand level the indices for: (1) vegetation and animal biodiversity, (2) management risks (soil erosion and fire hazard); (3) and economical indices (cork production, cattle production, carbon sequestration, etc.). Then, the values are used to select the best solution according with an additive utility function (Ribeiro et al., 2007).

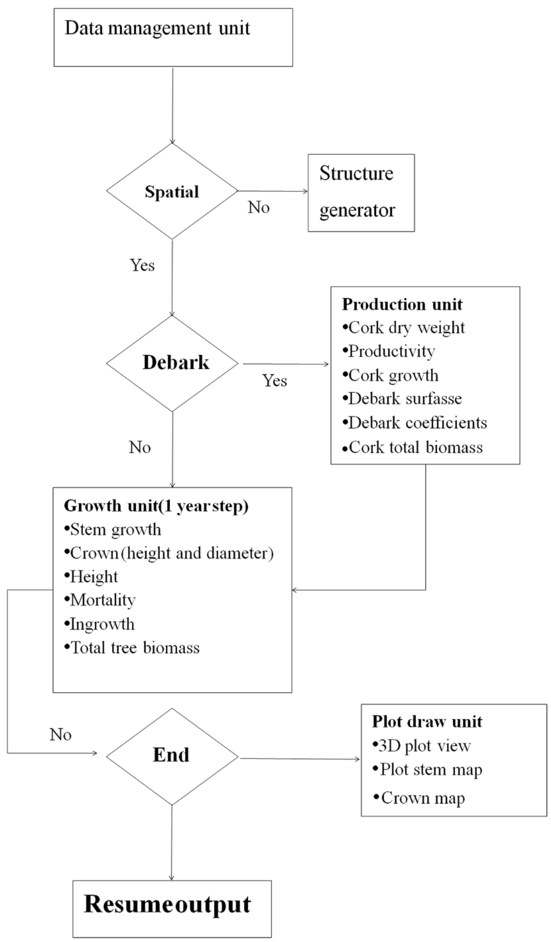
Simulation Runs

In the present study, it is important to analyze the importance of the valuation of carbon sequestration in the decision of shrub control management technique. Therefore, for the simulation runs, each plot was simulated according with the site quality with the following assumptions:

- The first debark will occur when the tree reaches 70 cm of cbh (perimeter at 1.3m), this value is defined by law, and occurs when the tree is 15-25 years old (dependent on site and individual competition status).
- The debark period is 10 years.
- The continuous crown cover objective is the maintenance of the plot initial occupation.
- It is assumed that, on average, an adult cow need 10 ha of undercover natural pasture.
- Two shrub control systems are tested: (1) Treatment A by mechanical shrub cutting; (2) and Treatment B by soil disking.
- Carbon sequestration represents the sum of the sinks (trees plus soil): (1) Tree- estimated at individual level; (2) Soil- estimated according with the shrub control system (with and without soil mobilization) and the time span under the referred systems.

The list of conflicting interests to be tested are: (1) Cork production maximization (quantity and quality); (2) Maintenance of a constant crown cover; (3) Implementing sustainable stand struc-

Figure 4. CORKFITS flow chart



ture (uneven) with regeneration management; (4) and Soil erosion minimization with the use of shrub control system (with and without soil mobilization).

In the present study, the method used to analyze the forest investment profitability is the Net Present Value, NPV, because it seems to be the best economic/financial indicator to estimate the value of forest investment (Brunson, 1993, Hepburn and Koundouri, 2007).

The NPV of any investment can be estimated by

$$NPV = \sum_{i=0}^{i=T} \frac{R_i - C_i}{\left(1+r\right)^i}$$

where, R_i and C_i are, respectively, the revenue and the expense occurred in year i, r is the annual rate of discount and T stands for the life of the investment.

Table 2 summarizes the assumptions used in this study.

In Figure 5 it can be seen some details of the outputs generated by ECCORK that were used in the calculations of NPV. Observing Figure 5 it can be seen (bottom right chrt) that the continuous crown cover was obtained with two regeneration moments, one at the year 20 with the intensity of 50 tree ha^{-1} and another at the year 50 with the intensity of 40 tree ha^{-1}.

RESULTS AND DISCUSSION

In Table 3 it is presented the Net Present Value (NPV) for all combinations of cork and carbon

Table 2. Assumptions for cork oak investment

Year(s)	Activity	cost/benefit (€ ha^{-1})
5-100 (every fifth year)	Infesting control by soil disking (Treatment A)	-60
3-100 (every third year)	Infesting control by shrub cutting (Treatment B)	-90
1-100	Annual revenue from cattle	15.9
0- 100 (every tentn year)	Cork production, approximately 1900 kg	3800.00 to 7600.00 a)
0- 100 (every tentn year)	Stripping off cost (0.23 €/kg)	-437

a) The revenue from cork selling depends on its quality. It is assumed that the price ranges from 1.33 € per kilogram to 4.00 € per kilogram prices. NPV is an indicator very sensible to the discount rate used. So, considering the present economic situation in addition to forestry as a long run investment, 3% seems the adequate rate of interest to calculate the NPV in this situation.

Observing Table 3 one can conclude that in all plots, Treatment A is only better than Treatment B if carbon is not valuated (carbon price equal to zero), justifying why actually the largest percentage of cork oak area shrub control management is done by soil disking (that involves soil mobilization). It is important to remember that soil mobilization has a large impact: (1) Soil organic matter content losses and consequent loss of soil structure; (2) on fine roots of cork oak trees; (3) on erosion risks; (4) and in the success of natural regeneration.

Observing young stand plot results (221 and 225), one can detect that the site quality is not a limiting factor if regeneration is succeeded and the shorter life span of the trees in site quality 1 can be overcome by the intensity and period of regeneration. Nevertheless, the NPV is always lower in site quality 1 areas and this fact increases the difficulties in the adoption of Treatment A that is especially important to the sustainability of these sensible soil/tree systems.

Through the observation of the mature stand plot results (321 and 322) it can be seen that site quality 0 plot 322, shows better results of NPV than site quality 1, plot 321 indicating that the reduced live span has larger effects in structures with older trees. Here, the adoption of Treatment A is even more essential to increase the soil properties that, in combination with the non root disturbance, can increase the tree vigour and con-

Figure 5. Details of the outputs for the simulation of plot 321. In the top left and right figures it can be seen the stand crown map and profile in the year 0 and 100 of the simulation. In the down left chart it can be seen the cork production with (blue) and without (red and orange) regeneration. In the bottom right chart it can be seen the crown cover percentage with (blue) and without (red and orange) regeneration.

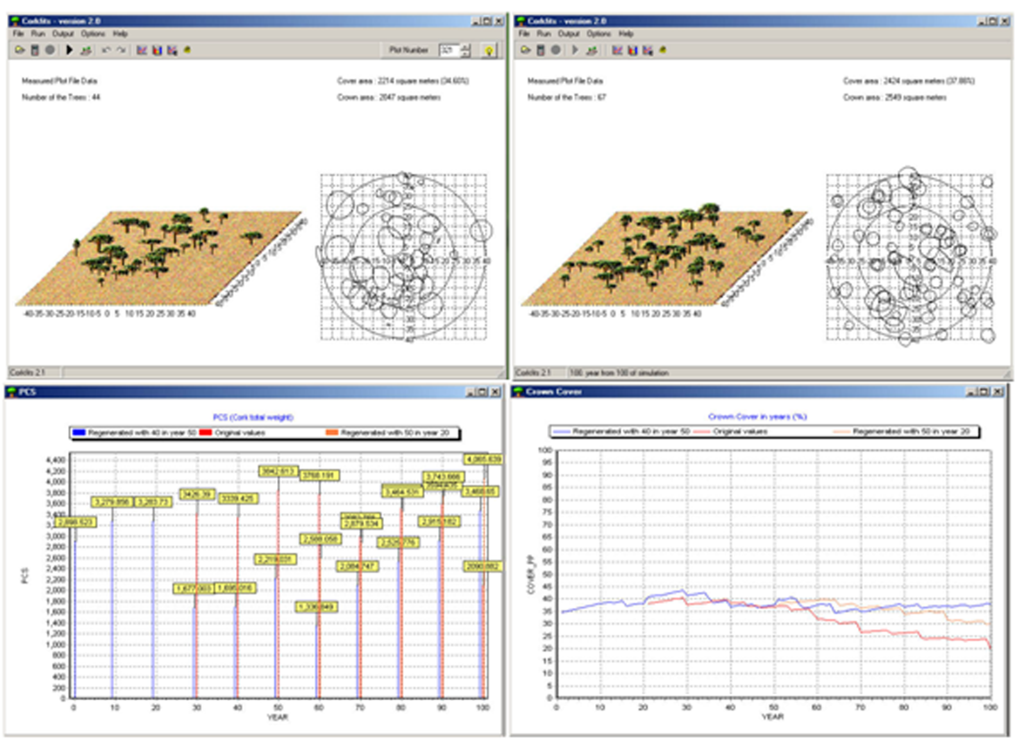


Table 3. Plots Net Present Value (NPT), per hectare, of cork oak forest, estimated at 3% interest rate for all site quality and vegetation

Plot	Soil site quality	Carbon price (€ ton^{-1})	Cork Price (€ per 15 Kg)					
			20		40		60	
			A	B	A	B	A	B
221	0	0	5592	5956	11759	12163	17926	18330
		10	6080	6009	12247	12177	18434	18343
		20	6568	6029	12735	12196	18902	18363
		30	7056	6055	13224	12222	19391	18390
225	1	0	5136	5540	10961	11366	16787	17191
		10	5591	5553	11417	11379	17242	17204
		20	6047	5572	11872	11398	17697	17223
		30	6502	5598	12327	11423	18152	17248
321	1	0	6381	6785	13628	14032	20875	21280
		10	6908	6800	14155	14047	21403	21294
		20	7435	6820	14683	14067	21930	21315
		30	7962	6847	15210	14094	22457	21341
322	0	0	7036	7440	15047	15451	23058	23462
		10	7556	7455	15566	15465	23577	23476
		20	8075	7475	16086	15486	24097	23496
		30	8595	7502	16606	15513	24616	23523

Treatment A: mechanical shrub cutting and Treatment B: soil disking; Soil site quality 0: Soils without growth limitations for cork oak and Soil site quality 1: Soils with growth limitations for cork oak

sequent productivity and life span, thus reducing the effect of site quality.

In all plots, it seems that a value for carbon between 20 and 30 € ton^{-1} is optimal to the adoption of Treatment A. If it is considered the impact of Treatment A and B systems on the production of other goods and services produced by cork oak woodlands (see Table 4), it is easy to foresee the direction of the funding forest politics needed to invert the direction of the decline observed in some woodland areas. The valuation of: (1) biodiversity, by certification of forest area management and products, (2) of water infiltration through discounts on water prices; (3) of soil conservation by the amount of spared soil, summed with the carbon value, could create the environmental economic market that would lead the woodland cork oak systems to sustainability.

FINAL REMARKS

The simulation results on the set of plots used in the present study suggests that, for cork oak wood land sustainability, it is important to change the shrub control management to mechanic systems without involving soil mobilization. These shrub cutting systems are important to avoid soil mobilization impact on: (1) Soil organic matter content losses and consequent loss of soil structure; (2) on fine roots of cork oak trees; (3) on erosion risks; (4) and in the success of natural regeneration. The ecological gains (see Table 10) are important

Table 4. Effects of two different shrub control methods on the quantity of goods and services provided by cork oak forest.

Goods and services produced by cork oak forest	Shrub cutting (Treatment A)	Soil disking (Treatment B)
	Increase (+) Decrease (-)	***Increase (+) Decrease (-)***
Goods and services with market		
• Cork	+	-
• Acorn	+	-
• Animals (cows, sheep, pigs)	-	+
• Mushrooms	+	---
• Number of regenerating plants	+	-
• Carbon sequestration	++	--
Biodiversity		
• Animal biodiversity index	+	-
• Vegetation biodiversity index	++	+
• Ecossystem quality	+++	--
Site resources preservation		
• Erosion risk index	---	+++
• Water retention	++	--
• Soil organic matter content	+++	---
• Fire risk index	++	--

Notes: The number of signs + or - shows the magnitude of expected effect. The sign +- means neutral effect

to increase system sustainability by reinforcing the resilience that, as it was referred, is largely related with soil stability and with the intensity of regeneration (natural or artificial).

Simulation results also showed that without the valuation of the carbon sequestration, the best woodland management practices (Treatment A) are less interesting than the actual ones (Treatment B) considering the NPV (Tables 6 to 9). This fact is driving the stakeholders to follow non sustainable management practices, creating the need to change the forest public policies in order to evaluate the production of *public goods or quasi-public goods* of environmental and social character, promoting good management practices. The simulation study results suggest a value for carbon between 20 and 30 € ton^{-1} to make Treatment A system attractive to stakeholders.

The amount and stability of cork production, as well as the lasting period of production depend crucially on the management system followed. The economic sustainability depends mainly of the cork price. As it can be seen from tables 6 to 9, NPV varies mainly with cork price. In table 6, for instance, when the price of cork is 20 and carbon is not valuated, NPV is equal to 5592 (equivalent to an annual constant income of 177 €), but if the price of cork is 60, NPV will be 17926 (equivalent to an annual constant income of 567 €). Presently, cork is suffering several threats because of its substitutes. Cork prices have been declining since 2003 which is making investments unprofitability. If cork oak woodlands become unprofitable, stakeholders will cease the use of sustainable management techniques. This would lead to stands invasion by shrubs and other oaks, increasing competition and the risk of forest fire and the consequent disappearance of this type of forest.

In conclusion, cork oak system only can be economically and environmentally sustainable if society valuates carbon and other goods and services generated by this production system and government has suitable credit policies for this long-run maturity investment.

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