The Importance of Crown Cover on the Sustainability of Cork Oak Stands: A Simulation Approach

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Abstract

The cork oak (*Quercus suber* L.) production system in Portugal, referred to as *montado*, occupies 713,000 ha representing 22% of Portugal's forest area. In the last 5 decades several changes occurred in the forest management of cork oak stands, mainly due to the reduction of hand labour and increasing mechanization, creating a new set of risk factors to production system sustainability. Of all risk factors, soil loss, crown cover reduction and lack of regeneration are responsible for the degradation processes in the montado system. In the present work a simulation study on the sustainability (ecological and economic) of cork oak stands at a regional level is presented. The ecological sustainability is classified by a soil erosion index based on the Universal Soil Loss Equation, and the economical one is evaluated by a cork production index based on cork quantity and quality. The simulations are performed using a tool named "CORKFITS 2.1" which is a single-tree spatial growth simulator decision support system (DSS), integrated with GIS geoprocessing and spatial analysis tools in order to produce maps at a regional level.

The results indicate that crown cover controls the erosion risk index, especially in areas where the slope exceeds 15%. The sustainability depends on the maintenance of crown cover, which can be achieved by a low intensity regeneration process every 20 years.

Keywords: Cork oak, growth simulator, soil erosion index, cork production index, GIS, spatial analysis

Introduction

The Portugese cork oak (*Quercus suber* L.) production system, montado, occupies 22% (713,000 ha) of Portugal's forest area, which is situated mainly in the southern part of the country. Portugal harvests about 175,000 ton a^{-1} of cork,

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representing 52% of world cork production. Portuguese industry exports 80% of the world products. Cork represents 60% of the total national forest product exports. The value of bottle stopper exportation, the main cork product, is close to pulp and superior to Port wine values.

The montado is a multi-use system linking cork production stock grazing and small grain farming. Management is fundamental to the system sustainability (ecological and economic), which can be jeopardised by the imbalance of under tree-cover activities, that leads to:

- lack of regeneration and consequent disappearance of the crown cover, loss of cork production and site degradation, mainly by soil loss (Macara, 1974; Cabral et al., 1993)
- abandonment leading to an invasion of shrubs and other oaks, thus increasing competition (reducing cork production) and the risk of forest fire (Pinto Correia and Mascarenhas, 1999).

The crown horizontal projection area and root system of individual trees, prevent soil erosion due to rainfall interception and distribution (Antunes and Coutinho, 1998; Coutinho and Antunes, 1999, 2000), promotes infiltration, nutrient recycling, organic matter content and reduces wind speed and evaporation (Cabral et al., 1993).

Site degradation due to erosion leads to stand decline (Macara, 1974; Cabral et al., 1993).

The present work deals with an ecological and economic sustainability simulation study of cork oak stands at a regional level. The study is achieved by implementing two different strategies: (1) no regeneration, and (2) the maintenance of the crown cover and the regeneration.

Methods

To test system sustainability different factors where analysed:

- Evolution of crown cover,
- Stand structure,
- Cork oak stand economics (profit index),
- Erosion risk index

In 100-year simulation runs using CORKFITS 2.1, which is a spatial single-tree growth model and a decision support system (DSS) tool integrated with the GIS geoprocessing and spatial analysis tools in order to produce maps at regional level (Ribeiro et al., 2001, Ribeiro et al., 2003). CORKFITS 2.1 was built based on growth models (cork, stem, tree height and crown), cork production models and mortality models (see flowchart in Fig. 1). CORKFITS 2.1 integrates a spatial structure generator STRUGEN based on a filtered Poisson process (Pretzsch 1992, 1997) which filters were parameterised for cork oak stands natural spatial structure to be used to simulate virtual stands as well as to simulate regeneration. In all the models except for potential functions, a random error component was added (Ribeiro et al., 2001).

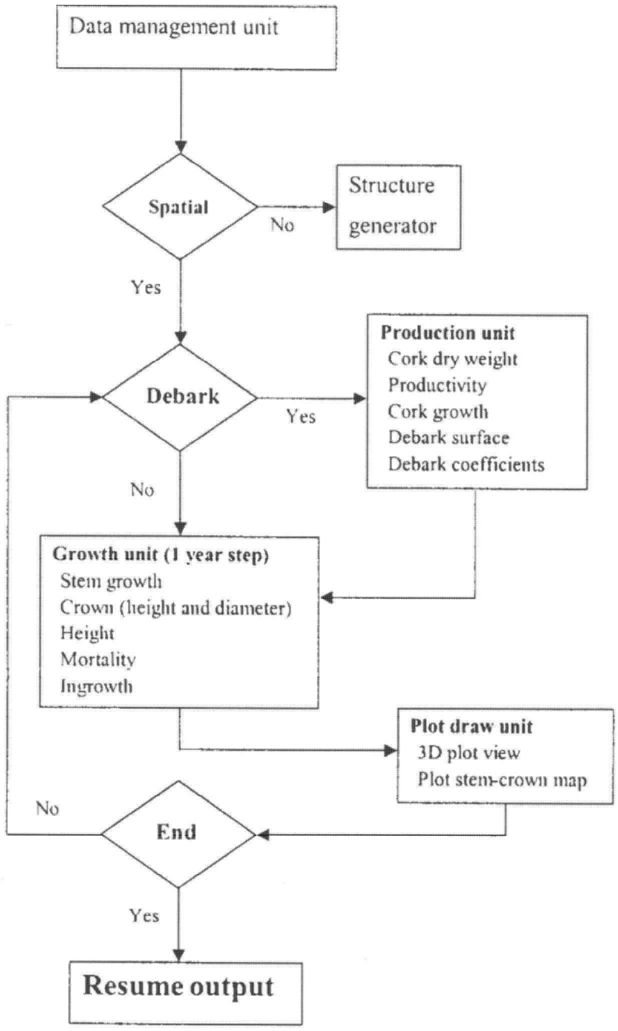

Fig. 1: CORKFITS 2.1 flowchart

The study area is part of the Sado river watershed basin (Fig. 2), and is characterised by a set of digital form data: soil, topographic and cork oak distribution maps, and cork oak forest inventory plots. The montado characteristics are presented in Table 1.

Table 1: Inventory plot stand statistics for crown cover (percentage) and tree density – number of trees per hectare

	Number of trees ha^{-1}	Crown cover (%)
n	16	16
Mean	108.1	54.3
Std. Error of Mean	17.7	5.0
5 Percentile	10.0	10.7
95 Percentile	295.0	90.5

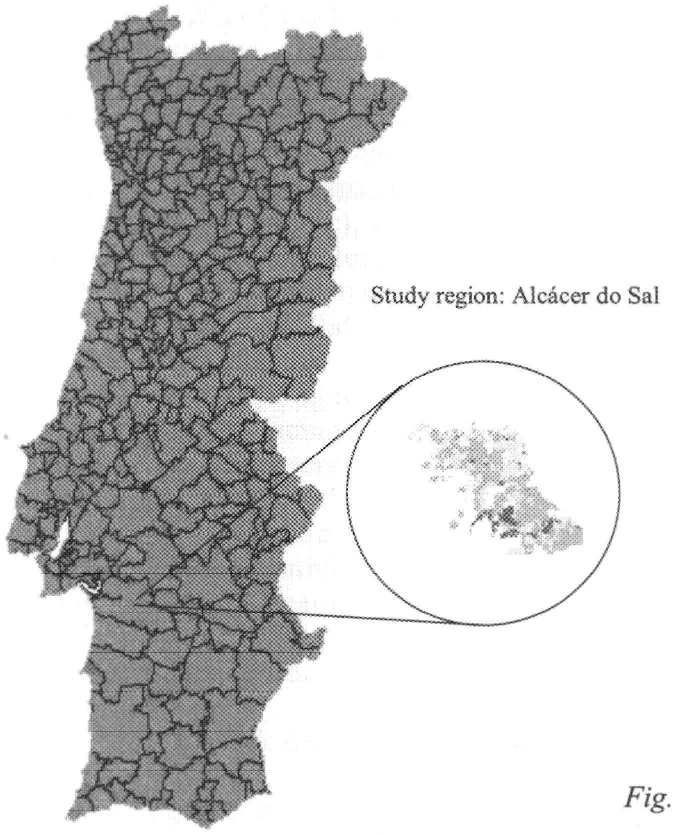

Fig. 2: Location of the study region

The ecological sustainability was assessed using a soil erosion index based on the Universal Soil Loss Equation. The economic sustainability is evaluated by a cork production index based on cork yield and quality.

The soil Erosion Index (EI) captures the effect of stand management on the soil sustainability potential. The index is based on the Universal Soil Loss Equation (USLE) (Wishmeier and Smith, 1965) factors:

Soil erodibility (K) – measures the soil resilience to detachment and transportation by raindrop impact and surface runoff.

Slope factor (S) – accounts for the effects of slope angle on soil erosion rate.

Slope length factor (L) – accounts for the effects of slope length on soil erosion rate.

Cover (C) – accounts for the influence of soil and cover management on soil erosion rate.

The USLE takes into account a reference plot, 9% slope, 22.1 m length, under continuous fallow tilled in the direction up down slope.

K-factor

An evaluation table was created over the attributes of the digital soil map according to Silva (1999), and converted to raster form in order to create an erodibility map.

LS-factor

The factors L and S are combined into the LS-factor that was generated from the Digital Elevation Model (DEM) according to the following equation and parameters:

$$LS = \left(\frac{\text{flowaccGrid}}{22.13}\right)^{0.4} * 1.4 * \left(\frac{\text{slopeGrid.sin}}{0.0896}\right)^{1.3}$$

C-factor

An evaluation table was created over the attributes of the forest inventory cork oak plots (Table 1). The resulting C-factor for each plot was extrapolated for its area of influence using Thiessen polygons.

The geographical modelling method to calculate the soil erosion index was based on map algebra (Tomlin, 1990), through the following equation EI = K×LS×C.

The simulation treatments were selected by the following criteria:

- No regeneration (r_0), to simulate imbalanced undercover management, where regeneration is not occurring (Fig. 3 and 4).
- Crown cover maintenance with regeneration (r_1), to select the regeneration opportunity in order to maintain a constant crown cover (Figs. 3 and 4).

The analysis of erosion risk index (Fig. 5) was performed by classifying the slope into 3 classes:

(1) [0%, 15%]; (2) [15%, 35%] and (3) [>35%]

The erosion risk index was classified into 4 classes:

(1) very low, (2) low, (3) high and (4) very high

The inventory plots were the initial simulation conditions and were run for five periods of 20 years each. The crown cover initial condition and the erosion risk index maps were updated using GIS geo-processing and spatial analysis tools (in ArcView 3.1).

Results

The results show that the maintenance of crown cover (Fig. 4) can be achieved within two regeneration opportunities during a 100 year simulation.

The net profit, taking into account the plantation costs and cattle removal for 5 years, shows clear advantages of treatment r_1 in comparison with r_0 (Table 2).

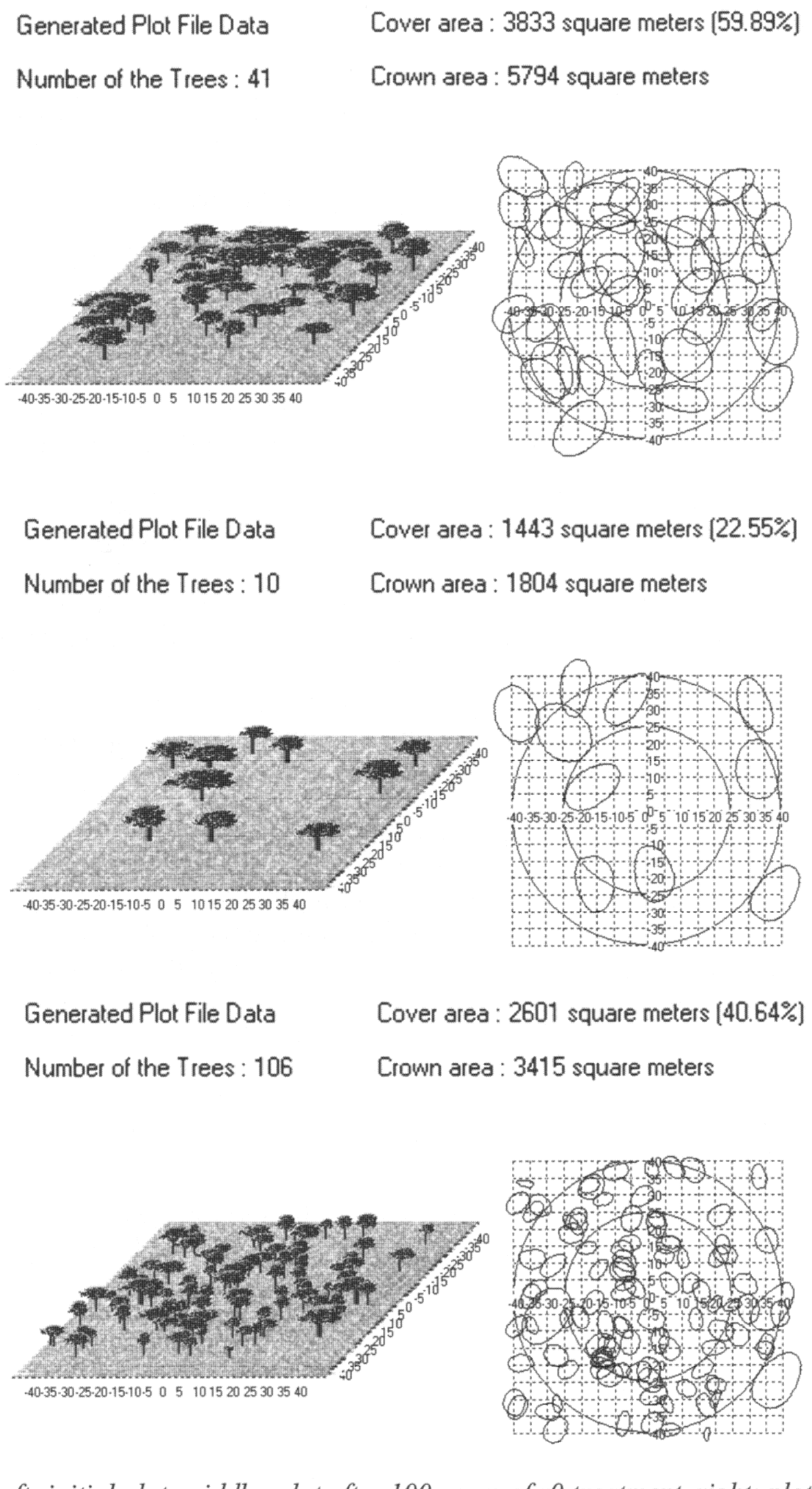

Fig. 3: Left: initial plot, middle: plot after 100 years of r0 treatment. right: plot after 100 years of r1 treatment

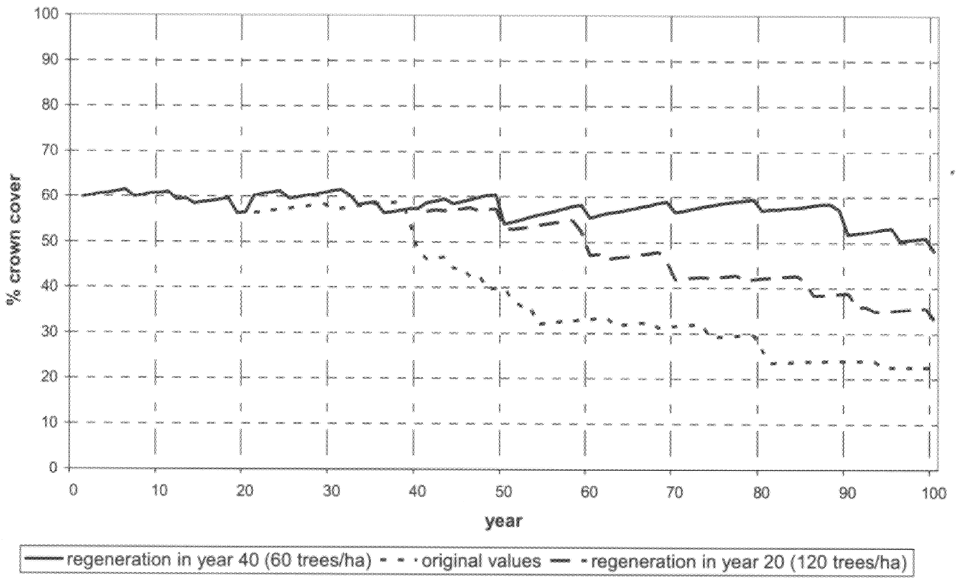

Fig. 4: Crown cover evolution in simulation blue: treatment r1 and red treatment r0

Table 2: Inventory plot cover in moment year 0, and year 100 with treatment r0 and r1, economic results in moment 0, and 100 with treatment r0 and r1, and difference at moment 100 between treatment r0 and r1.

plot	cover 0	cover 100 r_0	cover 100 r_1	profit 0	profit r_0	profit r_1	Crown cover r_1-r_0	Profit r_1-r_0
673817A3	90.5	63.8	71.8	2210.99	972.74	2565.47	8.0	1592.73
673815D1	23.0	24.5	0*	318.94	980.14	0*	0*	0*
663796B3	10.7	2.1	18.9	151.14	21.52	1123.38	16.8	1101.86
663796A1	45.2	39.3	50.1	565.35	1223.60	1267.84	10.8	44.24
663794G4	65.1	29.3	61.3	1327.23	899.78	2750.37	32.0	1850.59
653724B5	69.5	47.0	63.4	1339.37	1195.37	1532.05	16.4	336.68
653722I4	59.3	27.6	54.8	942.95	583.07	1359.70	27.2	776.63
653722H4	76.7	51.3	70.1	1453.12	1129.49	1724.52	18.8	595.03
643697I7	31.0	24.1	27.6	375.34	486.17	564.30	3.5	78.13
633627C2	51.8	36.2	48.7	701.70	747.72	1363.49	12.5	615.77
623595G5	60.6	18.8	57.5	1215.11	381.753	2419.34	38.7	2037.59
623593E1	49.0	35.4	44.8	705.21	472.44	825.58	9.4	353.14
623591G7	63.1	31.6	56.3	1335.24	606.09	1622.96	24.7	1016.87
623589H6	60.1	51.9	67.0	1049.02	1213.03	1547.25	15.1	334.22
623585B1	52.9	48.8	0*	769.48	1541.56	0*	0*	0*
613517E5	59.9	22.5	58.6	1063.42	456.75	2684.75	36.1	2228.00

* - No regeneration was needed to maintain the cover

cover t - crown cover percentage in moment t and with treatment r_0 or r_1, profit t - profit in moment t and with treatment r_0 or r_1, crown cover r_1-r_0 – difference of cover in moment 100 between treatment r_1 and r_0, profit r_1-r_0 – difference of profit in moment 100 between treatment r_1 and r_0

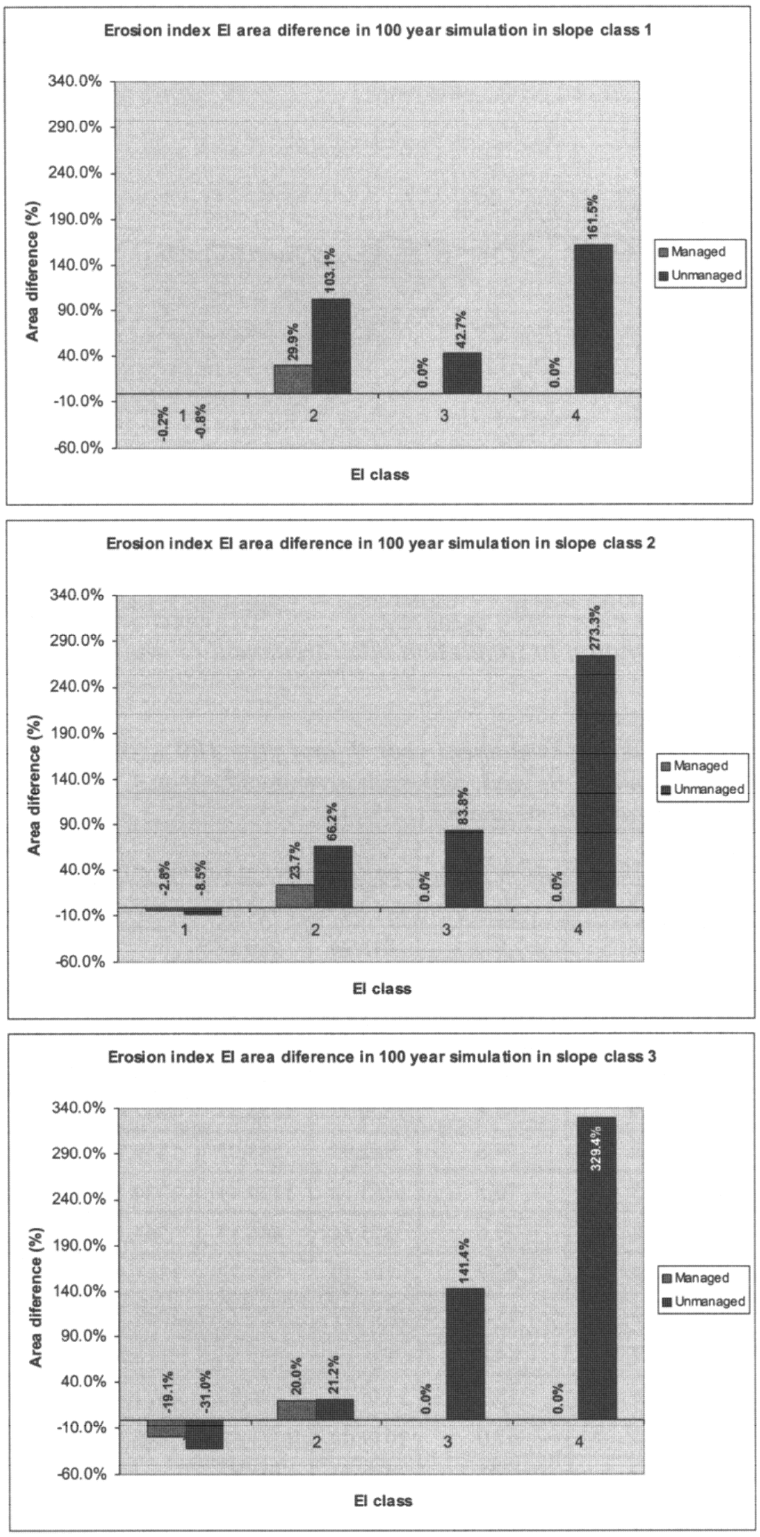

Fig. 5: Difference in percentage of the erosion risk index areas in 100 year simulations for slope classes 1 to 3 for the treatment r0 (unmanaged) and r1 (managed)

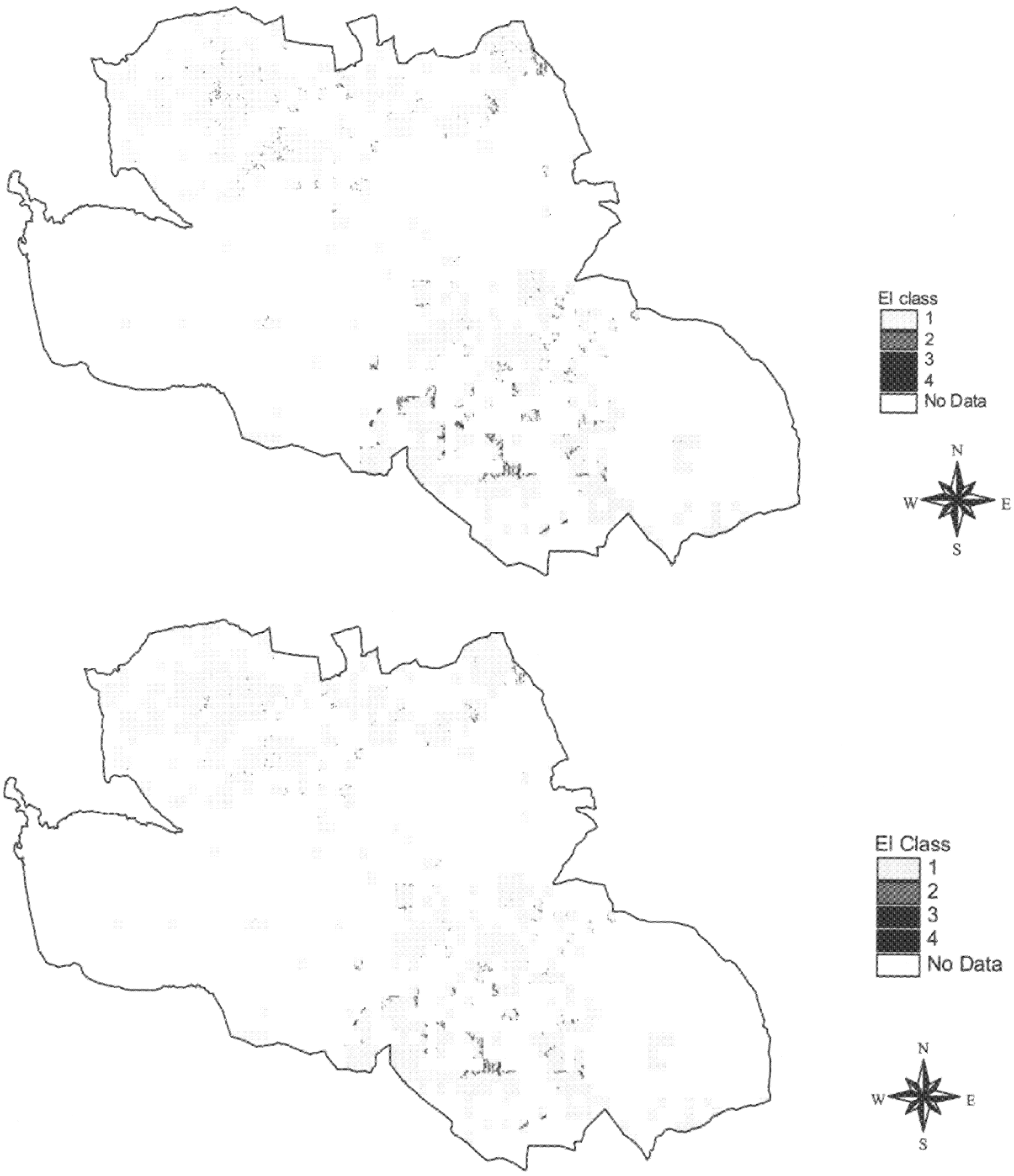

Fig. 6: Maps of erosion risk classes (EI classes) in simulation years 0 (top) and 100 (bottom)

The sustainability of original plot crown cover prevents an increase of the erosion risk index mainly in areas with slope classes 2 and 3. Figures 6 and 7 show an increase of the erosion risk index (classes 3 and 4) on slope classes 2 and 3. Erosion risk control can be achieved by a management adapted to this slope classes of the area (Fig. 7).

Regarding the results of simulation run, crown cover is an essential factor to avoid erosion risk.

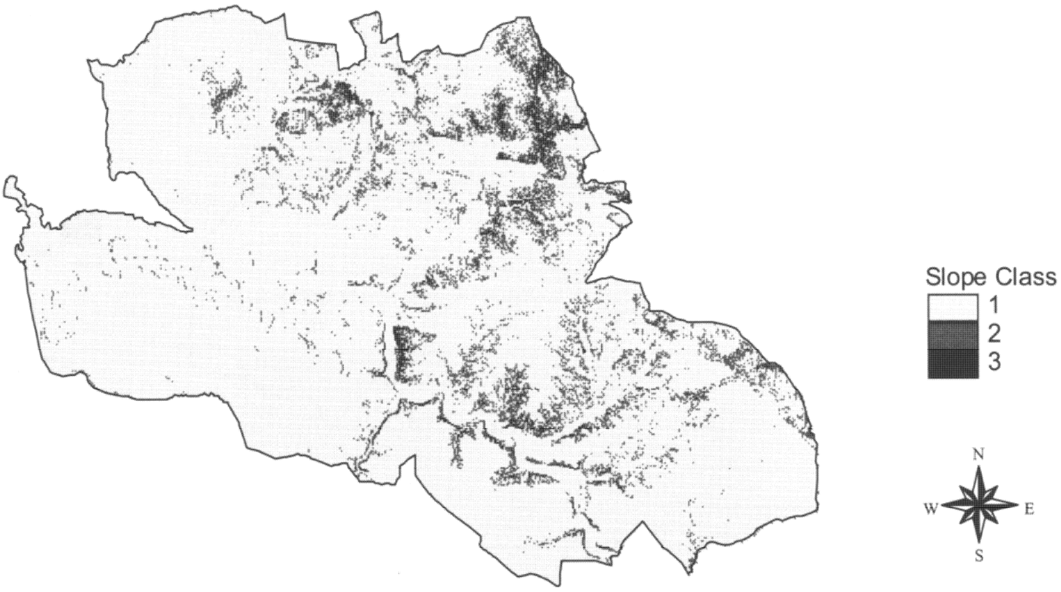

Fig. 7: Map of slope classes

One issue is the definition of the crown cover level limit that keeps sustainability, which can be handled through differential management according to the area slope classes.

Another issue is the stand structure:

- High crown cover of large trees (mature trees) can involve over time a lack of cover due to natural mortality in a lack of regeneration scenario.
- High crown cover of small trees (young trees) can fulfil successfully the crown cover sustainable development, in time, but not the economical one due to the competition effects on cork quality.

These opposing conditions can be handled with the introduction of erosion risk in the decision support system of the CORKFITS model.

Conclusions

The introduction of the Erosion Risk Index into the CORKFITS 2.1 software environment proved beneficial to an ecological sustainability analysis. By managing for continuous crown cover and promoting periodic regeneration, the other objectives could be considered as fulfilled. Once management objectives are defined and ranked, CORKFITS can provide a set of variables and options to achieve the desired objectives. In addition, management objectives can be tested and evaluated under different scenarios. According to the Erosion Risk Index definition, the crown cover is fundamental in controlling it, especially in areas with slopes exceeding 15%.

Acknowledgements

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