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An integrated decision support system for the Mediterranean forests

M.B. Costa Freitas[a],[*], A. Xavier[b], R. Fragoso[c]

[a] Sciences and Technology Faculty, Universidade do Algarve, Gambelas Campus, Edf. 8, MEDITBIO (Center for Mediterranean Bioresources and Food), 8005-139 Faro, Portugal
[b] Sciences and Technology Faculty, Universidade do Algarve, Gambelas Campus, Edf. 8, MEDITBIO (Center for Mediterranean Bioresources and Food), 8005-139 Faro, Portugal
[c] Management Department, Universidade de Évora, Largos dos Colegiais, N°2 Apt. 95, CEFAGE-UE (Center For Advanced Studies in Management and Economics), 7002-554 Évora, Portugal

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ABSTRACT

Mediterranean forests contain a relevant biological diversity and are relevant for local economy. However, they are subject to various risks, particularly the risk of forest fires. This turns the critical decisions of forest managers, affecting both the long-term future of the forest and daily activities, to be difficult. To simulate decisions, and help managers and policy makers, a decision support system, which integrates the biological, environmental and economic management perspectives of agricultural and forest areas, was developed and considers the activities existing in the territory. The decision support system considers the characteristics of the biophysical units that comprise the territorial study area, production technologies and conservation of agro-forestry goods and preferences of managers or stakeholders. The proposed approach was applied in a pilot Forest Intervention Zone (FIZ) located within the Algarve region inner land. The results show that the decision support system proposed is an important tool for managing the territory and for implementing the manager's decisions.

1. Introduction

The forest is an ecosystem that encases a high biodiversity and ensures the necessary ecological balance; this ecosystem is increasingly recognized as an area of fundamental importance for the maintenance of natural values and the improvement of people's quality of life. Besides forest biodiversity, it still has the potential to produce a wide range of goods and services, such as wood, wood pulp, recreation, although some of these outputs maybe incompatible (Campbell, 1999).

Forests also contain about 40% of the carbon stored in terrestrial ecosystems, being considered the "lungs of the world" and are also important sources of biomass production, which may have important uses for human activities. Leite (2005) states that the promotion of forest biomass is strategic, both at forestry sector level and energy sector level.

The Mediterranean forests have considerable biodiversity, representing about 20% of the world's floristic diversity. However, they are a fragile ecosystem in which the dry and hot summers contribute to the ecosystem fragility, namely by increasing fire risk, and where men's interference has been a constant (Falcão and Borges, 2005).

These forests are also the venue for different activities, in an almost perfect coexistence between forest, agriculture and wild life and are therefore considered and intervened by different stakeholders. Therefore, public decision and the different stakeholders preferences need to be accounted since there are different perspectives of what is a correct management.

The decisions that must be taken by forest managers are also diverse and can affect large geographical areas for a long time. Not only today decisions affect future decisions as decisions over a part of a forest can affect other parts of the forest. The number of factors that should be, simultaneously, taken into account is huge, which recommends the use of decision support systems (DSS).

Raunikar and Buongiorno (2007) state that the process of modelling the forestry sector has had substantial progress over the last 30 years, being the mathematical programming models used in the definition of the economy and the national forestry policy (Adams et al., 1996; Raunikar and Buongiorno, 2007). In the 60's, early works were published using linear programming in forestry management (Curtis, 1962 cited by Rodriguez and Borges, 1999; Leak,

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[*] Corresponding author. Fax: +351 289818419.
E-mail addresses: mbmartins@ualg.pt (M.B. Costa Freitas), amxav@sapo.pt (A. Xavier), rfragoso@uevora.pt (R. Fragoso).

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1964; Loucks, 1964; Nautiyal and Pearse, 1967) and since then due to the development of technological tools this field of research had a considerable growth.

In Portugal, forest management models often focus on a long-term strategic management. Borges and Falcão (1999) and Falcão and Borges, in several works (Falcão and Borges, 1999, 2001, 2002, 2005) refer the use of linear programming in forestry management. Borges et al. (2010) present a positive mathematical programming approach to evaluate the effects of various economic policy scenarios on forestry sector.

Borges et al. (2014) state the involvement of stakeholders in the process has profound influence on forest DSS development and use. Regarding participatory methods, Mendoza and Martins (2006) analyse methodologies that serve to prioritise and aggregate the preferences of various agents participating in the decision-making process, defining the particular various steps to fulfill the participative process. Diaz-Balteiro and Romero (2007, 2008) also make a review of the methodologies relating to participatory management of forest areas. Examples of those methodologies include Bantayan and Bishop (1998), Schmoldt and Peterson (2001), Pykalainen et al. (2001), Kangas and Kangas (2003), Diaz-Balteiro et al. (2009). In Portugal, Martins and Borges (2007) analyse collaborative participation management processes considering as case study the Forest Intervention Zones (FIZs) and Xavier et al. (2013) present several approaches for dealing with multiple agents and provide some guidelines to introduce these methodologies in a decision support system.

Moreover, in the last years there has been a considerable development of bio-economic models, namely those joining biophysical models and economic mathematical programming (Flichman et al., 2011; p. 3).

Borges et al. (2014) citing Burstein and Holsapple (2008) state that in this computer science context, a DSS is often defined as a model-based software system that contains four components: (i) a language system (LS) that enables users to communicate with and use the DSS (ii) a presentation system (PS) for displaying its outputs (iii) a knowledge system (KS) for storing all the input information and (iv) a problem processing system (PPS).

So, there can be little doubt that forest policy makers and managers will increasingly rely on DSS to balance the diverse and increasing demands placed on forest ecosystems (Borges et al., 2014). These authors point six main reasons for this:

1. DSS will become increasingly important as they can furnish tailored forest management solutions; Adaptive management of multi-purpose forestry not only requires sophisticated systems for large-scale analyses but also capabilities for iterative on-demand, on-site and ad hoc analyses together with stakeholders.
2. Social aspects will be more and more important, which increases the importance of multiple criteria decision analysis (MCDA), group decision-making, participation and more internet-based applications.
3. It is expected that social complexity increase, accompanying the increasing number of different players, with different views over the territory, as well as informational complexity is also expected to increase.
4. The analysis tools will likely follow the increasing recognition of multifunctional character of the forest.

The last two reasons are linked with the system architecture that would advisably be modular, capable of running either separately or interactively, and raising future requirements of knowledge management within forestry DSS to a new, “intercontextual” and “intersystemic” level and, despite the increasing complexity of the systems, must be adapted to the needs and competences of their target users and be transparent. Hence, adaptive design cycles, in which systems are used, tested and adjusted in successive iterations (Rauscher et al., 2005), may be valuable.

Previous studies carried out by the authors developed integrated models and offer a line of work to be developed. Martins et al. (2014) presented an integrated agricultural and forest management model, which used compromise programming for simulating the farmers and managers’ decision. Xavier et al. (2015) presented a compromise programming approach in which a consensus model using extended goal programming (EGP) was used in order to define the consensus among stakeholders and managers and the weights in the compromise programming (CP) model for dealing with different criteria in a risky situation, considering the climatic variability for defining the different states of nature of fire risk and potential damage.

These studies focused in a multi-criteria analysis, group decision and general management of an area but did not analyse the potential of transferring the results to a geographical information system neither was established a guideline for a combined use of the models or it was developed a further model that would allow allocation at plot level for several of the variables calculated. Therefore, no complete decision support system considering both the preferences of managers/stakeholders, the different activities existing in the territory and the better allocation at plot’s level simulation (therefore considering all the main decisions the field manager may take) was proposed.

Taking into account all these aspects, the objective of this paper is to propose a decision support system that integrates all these aspects both the preferences of managers/stakeholders, the different activities in the territory and the better allocation at plot’s level simulation. This decision support system will combine all the approaches presented before in a strutted way, connecting these results to a geographical information system (GIS) and analysing important operational information for management.

The remainder of this paper is presented as follows: Section 2 presents the methodology; in Section 3 the empirical and technical implementation is presented; in Section 4 the results are presented and the discussion is made; finally Section 5 presents the main conclusions of this work.

2. Methodology

2.1. The study area

The areas situated within Mediterranean forests have a great deal of complexity and a considerable vegetal and biological diversity (Scarascia-Mugnozza et al., 2000; Palahi et al., 2008; Boydak et al., 1997), with an extraordinary genetic diversity among the biological populations (Médail and Myers, 2015, cited by Palahi et al., 2008; Fady-Welterlen, 2005). Therefore, a careful screening of a representative area has to be made, so that the main difficulties of analysing these areas are overcome by the decision support system proposed.

A forest intervention zone (FIZ) was considered suitable for the purpose, since these areas have a common management and, usually, a great diversity among the forest and agriculture. The FIZ selected was the FIZ Arade -Alte/S. B. Messines that represents a typical situation of forest management in the Algarve region (south of Portugal), in which occur different management problems associated with the integration of agricultural, forestry and livestock-rearing activities, the influence of multiple stakeholders in the decision-making process and the occurrence of significant losses due to forest fires (Xavier and Martins, 2010; Martins et al., 2014; Xavier et al., 2015). The FIZ has a total of 1783 ha and is located in the Algarve region’s inland (Fig. 1).

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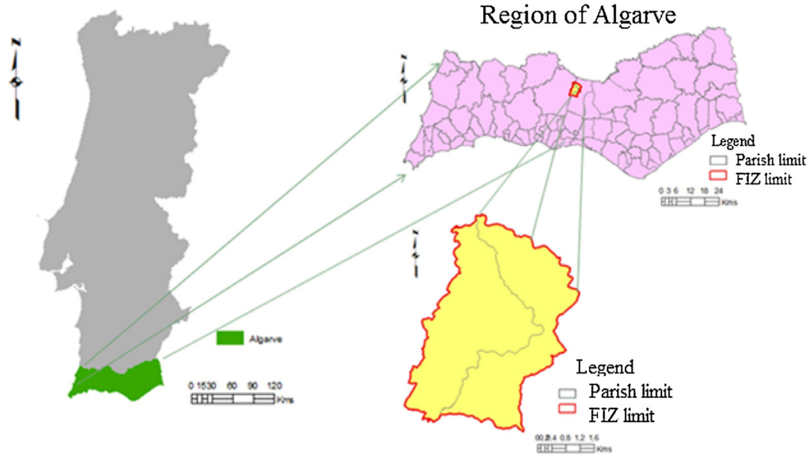

Fig. 1. The location of the selected FIZ.

The forest and shrubs occupy about 1516 hectares of the area. It is possible to identify the following forest species: *Quercus suber*, *Arbutus unedo*, *Eucalyptus globulus*, *Pinus pinea*, *Pinus pinaster*. The cork trees correspond to 80% of forest stands and its operation is intended mainly for cork, and in very specific cases valuing acorn for livestock. *Arbutus unedo* also occupies a relevant area.

The agricultural activities present residual values existing only ca. 100 hectares including the non-used agricultural lands. The temporary crops are mostly forage crops and cereals, with residual areas of horticultural crops for own consumption. The permanent crops occupy also a very residual area and include olive trees, fig trees, carob trees, citrus and vineyards.

2.2. Architecture requirements for the decision support system

The decision support system proposed continues the work carried out by previous studies focused in multi-criteria analysis, general management and group decision instead in operational results, and integrates them in an integrated framework. Xavier et al. (2013) provided a model for preferences of group analysis. Martins et al. (2014) developed an integrated agricultural and forest management model, considering all the activities in the territory, but with a simplistic aggregation of management preferences. Xavier et al. (2015) presented a compromise programming approach in which a consensus model using Extended Goal Programming (EGP) was used in order to define the consensus among stakeholders and managers and the consequent weights in the Compromise Programming model. The use of compromise programming was justified in all these works as a way to simulate decision regarding different criteria.

The combination of results and the use of them in a Geographical Information System may help to establish guidelines for managers and provides an integrated empirical and practical approach. Several questions are answered: How to combine previous developed approaches? How to provide and analyse detailed results? And, as a corollary, how to better distribute the results in space?

Database integration and analysis, linkage to growth and production models, interactive forestry modelling, integration of a GIS system for spatial analysis and linkage to different models are key aspects of a decision support system's architecture (Falcão and Borges, 2005). For the problem handled in this paper also the capability of simulating consensus and simulating different aspects of management must be considered. With all these in mind, the problem was defined according to end users objectives, mainly forestry management entities.

The proposed system is adaptive and integrates all the activities existent within the territory (agricultural, forestry or livestock breeding activities), in an interconnected way providing operational results, presenting a specific module for the activities' plot allocation and connecting these results to a Geographical Information System (GIS).

Four different modules compose the decision support system (Fig. 2): (1) information module; (2) integrated management model; (3) decision preferences module; (4) location module.

1) Information module—This module integrates the databases needed to develop the model. Database connection and integration is made in this module, namely by the use of numeric information introduced with specific spatial references.
2) Integrated management module—This module allows optimizing the most relevant criteria considered, using a bio-economic management model, that integrates all the available information and produces results by biophysical unit and by farm type. It also produces biodiversity indicators and a structural fire damage indicator that allows the calculus of potential economic losses caused by forest fires. A multi-criteria approach using compromise programming is included in this module.
3) Decision preferences module—This module allows the definition of consensus among different stakeholders, using an extended goal programming (EGP) methodology that allows defining the majority and minority consensus among different objectives, but also intermediate solutions. This tool is particularly important in situations in which there are different stakeholders with different points of view and preferences, regarding several different criteria. The weights obtained for the criteria can be newly inserted in the MCDM approach implemented in the previous module.
4) Location module—This module complements the previous integrated management model and allows the module 2 results (by biophysical unit) to be distributed at plot level for a detailed field application.

Between all these modules, there are interfaces that correspond to linkages between two steps of implementation and may include exportation of data to other analysis systems. These interfaces are crucial for connecting the several modules.

The proposed decision support system integrates the best from an optimization program and tries to represent the results using a geographical information system (GIS). Therefore, it presents relevant information for the manager, since the resulting information can be spatially represented.

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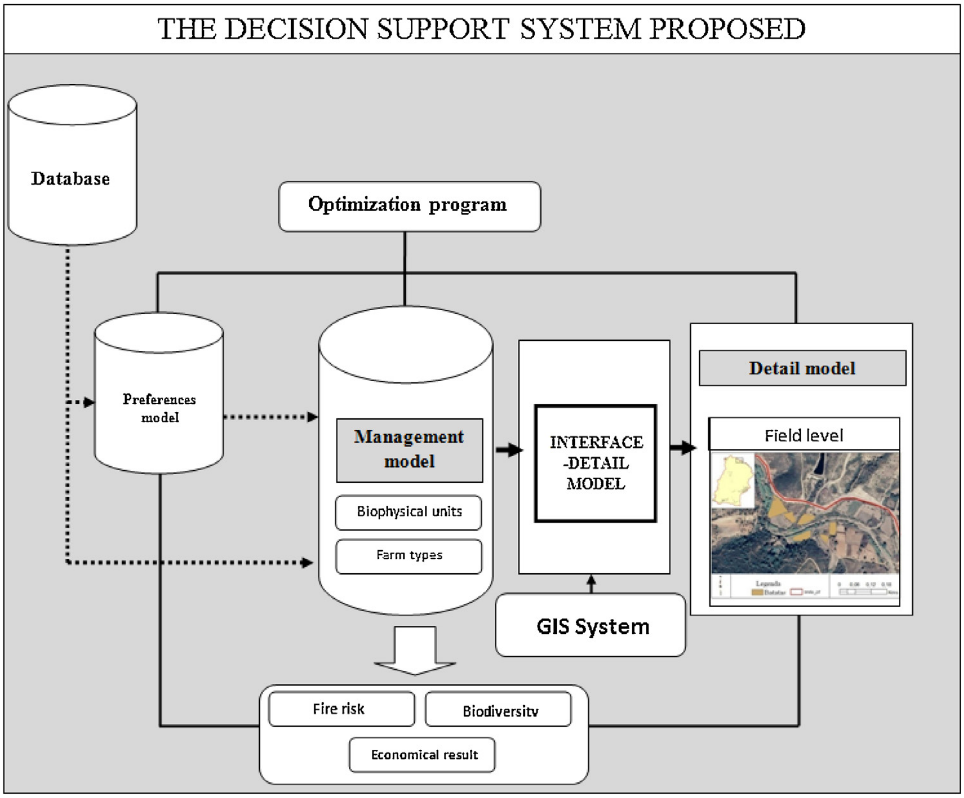

Fig. 2. The conceptual architecture of the decision support system proposed.

The management module is the central module for the decision support system and considers the possible activities in the territory. In this module the activities are considered in an interconnected way as proposed by Martins et al. (2014) and so there are some activities (secondary activities) whose inputs are produced by other activities in the model (primary ones), trade-offs being established among them. What allows the activities' classification as secondary or primary activities is not their physical dimension but if their management depend, or not, from other activities. The main primary activities include temporary crops, permanent crops, forestry, and livestock breeding activities. Secondary activities are composting and selling of biomass for energy. As the problem is developed in a FIZ, with a common management for forest, there are some resources that are considered common (the labour and the forest). At the same time, producers are the owners of different farm types, practicing different agricultural activities, which are not subject to common management. This configures a multi-agent problem since we have different agents in the territory: the farmers—with different farm types and so different objectives-, the forest producers (that are also farmers) and the FIZ managers (Xavier and Martins, 2010; Martins et al., 2014).

2.3. The mathematical definition of the decision support system

2.3.1. The management module

The management module analyses the technologies to be used by each activity and the destiny of production (Martins et al., 2014). The allocation of land to forest activities, permanent crops and temporary crops is made according to the existing forest stands. The agro-forest and livestock production can be used in farm or sold.

This model calculates the economic result for all the area and for each farm type, a biodiversity indicator and a fire damage indicator. The biodiversity index is an impact index following the formulation of Martins et al. (2014). The fire damage indicator measures the total damage, which is a function of a fire hazard indicator and potential damage. The hazard indicator is based on the combination of geographical variables (closeness to roads, forest paths' density, slopes, sun exposure of slopes and population density) with land use (forest activities, permanent crops and temporary crops) (for more details see Martins et al., 2014). The calculus of potential damage follows the approach proposed by the Portuguese National Forest Authority (AFN); it can be used to determine hazardousness and considers several components: danger/hazard and the potential damage which results from the combination of the economic value and vulnerability (DGRF, 2007). Finally, the combination of potential damage with the hazard indicator enables the calculus of total damage.

The formulation of the management model considering the states of nature is as follows:

$$E = \Sigma pr\,(pS - TC - DT) \tag{1}$$

$$\Sigma_j X^j \le q^j \tag{2}$$

$$\Sigma_j X^j Y = S + U \tag{3}$$

$$DT = FR \times DP \tag{4}$$

$$E_{sn} - E + N_{sn} \ge 0 \tag{5}$$

$$RSK = \Sigma_{sn} N_{sn} \tag{6}$$

$$BIOD = \Sigma pr\left(X^j.BD\right) \tag{7}$$

where E is the average total economical result, p are the prices of products, TC are the total costs in each state of nature; X^j is the variable that represents the activities of j agro-forest activities (forest, permanent and temporary crops and livestock) under each production technology, each farm type, each biophysical unit and each state of nature; and S and U are the selling and in farm use variables of agro-forest products; q^j is the upper bound of land allocated to each X^j agro-forest activity; and Y are the matrices of productivity

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coefficients for each agro-forestry activity, respectively (Martins et al., 2014; Xavier et al., 2015); *DT* is the total damage of forest fires in each state of nature, *FR* is the fire hazard indicator for each state of nature and *DP* is the potential damage of forest fires, in each state of nature; E_{sn} are the economical results in each state of nature *sn* and N_{sn} are endogenous variables that account for the negative deviations of economic results in each state of nature *sn* relative to the average expected value (E); *RSK* is the expected total negative economic deviation due to forest fires (Martins et al., 2014; Xavier et al., 2015); *BIOD* is the biodiversity indicator and *BD* is a matrix of the unitary biodiversity impacts of each activity X^j. Eq. (1) allows calculating the average expected economic result, considering the different states of nature. The allocation of activities according to the different biophysical and historical restrictions is made in Eq. (2). Eq. (3) represents the agro-forest and livestock production for selling or in farm use. Eq. (4) computes the total damage of fire risk and Eqs. (5) and (6) calculate for the MOTAD approach the total absolute deviation as a linear estimator of variance (Hardaker et al., 1997; Martins and Marques, 2007). Finally, Eq. (7) refers to the biodiversity indicator.

The management module uses multi-criteria decision methods (MCDM), that have been applied in solving problems of natural resources' management, including agricultural and forest resources. Its formulation allows exploring the complex links of Mediterranean ecosystems, namely the links between different criteria in a complex framework (Martins et al., 2014).

Considering the use of compromise programming proposed by Xavier et al. (2015), the metrics L1 and L∞ that will define the compromise set are calculated according to:

$$\text{Min } L1 = w_E \times I_E + w_{BIOD} \times I_{BIOD} + w_{RSK} \times I_{RSK} \ \text{s.t.} x \in F \tag{8}$$

and

$$Min\ L\infty = d \tag{9}$$

s.t.

$$w_E \times I_E \le d \tag{10}$$

$$w_{BIOD} \times I_{BIOD} + d \le 1 \tag{11}$$

$$w_{RSK} \times I_{RSK} \le d \tag{12}$$

and $x \in F$

Instead of compromise programming, goal programming (GP) may be implemented, through weighted goal programming (WGP), lexicographical goal programming (LGP), Chebyshev goal programming (CGP) or generalized goal programming (EGP) (Diaz-Balteiro and Romero, 2008; Diaz-Balteiro et al., 2013).

2.3.2. *The preferences module*

For simulating the decision and preferences of the landowners or managers, this module uses the extended goal-programming model proposed by González-Pachón and Romero (2004, 2007), applied in forestry management by Diaz-Balteiro et al. (2009), which is based in pairwise comparison matrixes. This methodology was adapted to this study by Xavier et al. (2013) who used and applied it to other different scales and Xavier et al. (2015) who implemented such model to determine group consensus.The objective function of this module (13) allows the optimal majority or minority consensus, depending on the values of a control parameter **λ** and a consensus matrix $m_{ij}^{(c)}$ (Diaz-Balteiro et al., 2009; Xavier et al., 2013).

The mathematical formulation cam be summarized as follows (for more details see also Xavier et al., 2015):

$$\text{Min}_{PR} = \left(1-\lambda\right) D + \lambda \left[\Sigma_{k=1}^{m} \Sigma_{i=1}^{n} \Sigma_{\substack{j=1 \\ j \neq i}}^{n} \left(n_{ij}^{k} + p_{ij}^{k}\right) \right] \tag{13}$$

$$m_{ij}^{(c)} - m_{ij}^{k} + n_{ij}^{k} - p_{ij}^{k} = 0 \ i,j \ \in \left\{1,\ldots n\right\} e \ k \in \left\{1,\ldots m\right\} \tag{14}$$

$$\Sigma_{i=1}^{n} \Sigma_{\substack{j=1 \\ j \neq i}}^{n} \left(n_{ij}^{k} + p_{ij}^{k} - D \le 0 \ k \ \in \left\{1,\ldots .m\right\} \tag{15}$$

$$t \le m_{ij}^{(c)} \le t\prime \ \ and \quad n \ge 0, p \ge 0 \tag{16}$$

where, n_{ij}^{k} and p_{ij}^{k} are the auxiliary variables representing the negative deviations and positive deviations that measure the underestimation or overestimation between the consensus matrix $m_{ij}^{(c)}$, which is unknown and the same ratio m_{ij}^{k} obtained exogenously for *k* stakeholders; the variable *D* is the maximum deviation; *t* and *t*' are the limits of the scale used; λ is a control parameter, between 0 and 1; and *i* and *j* are the pairwise decision criteria.

The objective function in Eq. (13) minimizes the values of the positive and negative deviations (n_{ij}^{k} and p_{ij}^{k}) and maximum disagreement *D*. In Eqs. (14) and (15) the consensus matrix is calculated and the deviations are defined, respectively. In Eq. (16) the limits for the scale used are defined. After consensus matrix is estimated, the preferred weights w_j compatible with the matrix can be derived as defined by Xavier et al. (2013) and integrated in the MCDM approach defined in the management module.

2.3.3. *The location module*

The location module consists of a linear optimisation problem that locates the more profitable agro forestry activities in the areas that present more advantages. It works with the results of the management model (module 2) redistributing them by biophysical unit in each plot. Thus, this mathematical programming model can be written as follows:

$$\text{Max}_{\text{loc}} = \Sigma_{\text{x}=1}^{\text{X}} \Sigma_{\text{p}=1}^{\text{P}} \left(\text{PL}_{\text{p}}^{\text{j}} \times \text{pot}^{\text{j}}\right) \times \text{re}_{\text{p}}^{\text{j}} \tag{17}$$

$$\Sigma_{\text{p}}^{\text{P}} \text{PL}_{\text{p}}^{\text{j}} = \text{X}^{\text{j}} \tag{18}$$

$$\text{min} \le \text{PL}_{\text{p}}^{\text{j}} \le \text{max} \tag{19}$$

$$\text{PL}_{\text{p}}^{\text{j}} \le \text{sol}_{\text{p}}^{\text{j}} \tag{20}$$

where $\text{PL}_{\text{p}}^{\text{j}}$ is the area of activity *j* on plot *p*; $\text{re}_{\text{p}}^{\text{j}}$ is the economic result of activity *j* on plot *p*, pot^j refers to the biophysical potential of each plot for each activity *j*; *max* and *min* are the maximum and minimum historical limits for allocation of an activity *j* in plot *p*; $\text{sol}_{\text{p}}^{\text{j}}$ corresponds to the restrictions on plot *p* for activity *j* - productivity conditions and slopes that allow developing the crops.

In detail, Eq. (17) is the objective function, which aims to maximize the benefits of temporary crops allocation in the plots with more suitable biophysical conditions. Given this formulation, the model chooses the plots with greater potential to maximize crop yield, considering the most profitable crops. Eq. (18) determines consistence among the activity *j* and the results of this variable allocation in each plot $\text{PL}_{\text{p}}^{\text{j}}$. Eq. (19) limits each activity in a certain plot to its historical minimum and maximum limits and Eq. (20) determines that the area of each activity *j* in plot *p* is developed in the appropriate biophysical conditions of soils and slopes $\left(\text{sol}_{\text{p}}^{\text{j}}\right)$.

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Table 1
Biodiversity scale of impacts.

Very high	Matrix of impacts		
	Effect on biodiversity	Degree of biodiversity present in the landscape	Description
	1	Very high	The activities don't affect the current degree of biodiversity and positively influence this degree. The number and types of plants and animals are favoured by these activities
↓	2	High	The activities don't affect the current degree of biodiversity
	3	Medium	The activities lead to a small decline of the biodiversity. The impact is visible but is not significant
	4	Medium low	The activities lead to a decline of biodiversity to almost half.
	5	Low	There is a significant decrease of biodiversity. The decline is considerable and many species disappear.
Very low	6	Very low	The activities lead to a disappearing of almost all types of plants and natural animals. There is a total decline on the level of biodiversity. There is a complete decline in all species.

Source: Xavier et al. (2015) and Martins et al. (2014).

Table 2
The construction of the fire hazard indicator.

Indicator		Different contributions of each element	Contribution for the potential fire risk—maximum value of the criteria
Land uses		Different contributions of each land use (according to a defined risk level 1–7)	590
Aspect		Different contributions according to the orientation (to south maximum values)	60
Slope		The higher the slope the higher the contribution	210
Roads	Proximity to the roads network	Defined according to the proximity	90
	Density of agricultural and forestry pathways	Defined according to the density	
Demographic density		Value of the indicator	50

(Source: CRIF; Martins et al., 2014).

3. Empirical implementation

To define landowners' preferences and collect farm data, a survey was developed and applied to a sample of 60 cases, following a random sampling process. The rate of answers was 89% meaning that only six landowners have not answered to the survey, because they refused or it was impossible to interview. Thus, the 54 landowners inquired represent about 50% of the main land area.

The implementation of the survey followed several steps and had as background the survey developed by Xavier and Martins (2010) in the framework of the PROTECT project (An Integrated European Model to Protect MEDiterranean Forests from Fire).

In a first step an analysis of the available information was made, namely the National Agricultural Census and other statistical sources and forest projects. In a second phase the results and insufficiencies of a pilot survey developed in the framework PROTECT project were analysed. In a third phase, the final version of the survey was created and in a fourth phase the survey was implemented and evaluated through several sources of data.

The survey comprises a set of direct and short questions and was conducted individually in the landowners' residence. Its results were complemented with other data sources (aerial photography, forest prevention plans, and others) to fill the missing information.

The main topics, considered in the survey included the following: 1—Location of the farm/land; 2—Identification; 3—Activities developed in farm/land; 4—General land use; 5—Gross margins; 6—Forest area characteristics; 7—Forest fires; 8—Type of producer; 9—Labour force and cooperation; 10—Preferences (likert scale or pairwise comparisons) (Annex 1).

In what concerns environmental indicators, the FIZ area was divided in biophysical units according to the slope and the soil type. The main FIZ soil types were considered and 6 slope classes. These combinations led to 22 biophysical units that were aggregated into 6 because some had not a physical dimension to justify their inclusion (Xavier et al., 2015).

Another crucial aspect considered was the construction of the biodiversity indicator. For this approach, we followed Martins et al. (2014) using an impact indicator composed using partial biodiversity indicators, referring to each production activity generic impact on biodiversity. The scale of impacts ranks from 1 (there is an increase in biodiversity) to 6 (there are high losses in biodiversity) (Table 1).

Regarding the hazard indicator, its methodology follows the IGEO (2008) and the CRIF (Forest Fire Risk Cartography) methodology (for more details see, for instance, Martins et al., 2014. Table 2 represents the weighting of the several parameters that compose the fire hazard indicator. The fire hazard is classified as follows (considering the updated version of the institute responsible for the creation of this indicator): class I—Low (1–103); class II—Moderate-Low (103–01); class III—Moderate (301–538); class IV—High (538–702); class V—Very high (702–1000).

To implement the proposed decision support system some technical procedures have to be considered, encompassing three major steps: (1) Inserting the information in a GAMS (General Algebraic Modelling System) code for the second and the third module; (2) Exportation of the data to a GIS system or database system (Microsoft Excel may be an option). The system's architecture allows for easy linkage to GIS interfaces thus facilitating information interpretation by the end users; (3) Further insertion of the results in GAMS for the last module and connection with a GIS interface.

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Table 3
The *pay-off* matrix.

Criteria	Economic result	Risk	Biodiversity
Economic Result	469379	399678	460214
Risk	82445	0	114461
Biodiversity	1.679	2.494	1.316

(source: model results).

4. Results

The management module runs a model that creates a complete management plan with detailed information of inputs and outputs, economic indicators and technologies' distribution by biophysical unit.

As the model is multiobjective and bio-economic, the management plan depends on the optimal compromise between the economic result maximization, biodiversity maximization and fire risk minimization (see the pay-off matrix in Table 3).

The diagonal of the matrix give us the ideal points of the criteria, the other cells representing the value of the remaining criteria. In this case, the ideal points are 469379 € for the economic result, zero for fire risk and 1.316 for biodiversity.

Maximizing the economic result leads to a fire risk of 82445 € and a general biodiversity indicator of 1.679, meaning the plan maintains the area biodiversity. In risk minimization, it is obtained a risk of 0 and an economic result of 399678 €, meaning that the economic result decreases 15%, which is less than its variability when the economic result is optimized. In this situation the biodiversity indicator is 2.494, this is, decreases almost 90% compared with its ideal point. The optimisation of the biodiversity index leads to an economic result of 460214 € and a fire risk of 114461 €. Thus, a reduction of 2% on the former results in a greater increase on the later (27%).

The following table (Table 4) presents economic indicators and also the value of production and the operational costs, which give us the relation with the other sectors of economy.

The results are also allocated by biophysical unit and farm type. The following table (Table 5) shows an example of technologies' selection by farm type, according the above ground cover.

As presented earlier it is possible to export the management model results to a GIS system, which enables a spatial representation of the results (see Fig. 3).

In detail, regarding the hazard indicator (Fig. 3a) we can see that the areas with a satisfactory value for this indicator (lower than 301 i.e. lower-moderate) are those with agricultural land uses; on the other hand, the areas with higher slopes and forest uses have the higher values of the hazard indicator. The biodiversity indicator (Fig. 3b) reveals an opposite distribution. Fig. 3c) represents the economic losses caused by forest fires, showing that urban areas, as expected, reveal higher values for this indicator. Finally, Fig. 3d) represents technologies relating to the debarking activity, which include only different types of traction or hiring the service (e.g. TA2—use of a tractor, TA3—use of a caterpillar tractor, TA4—hired service).

Table 4
FIZ: economic indicators, value of production and operational costs.

Economic result	Total	469379.0
	per ha	263.1
	per farm	3502.8
Value of production	Temporary crops	257550.9
	Permanent crops	20119.4
	Livestock breeding	58906.3
	Forest activities	228216.5
	Biomass valorisation	1035.8
Subsidies		57541.7
Operational Costs	Seeds	8249.9
	Fertilizers	14153.5
	Machinery	68128.8
	Labour	11871.0
	Livestock feeding	3300.9
	Hired services	406.2
	Others	32538.9
	Total	138649.2
Damages of forest fires		18560.8

(source: model results).

4.1. The preferences module

The preferences module allows designing the consensus of the majority and of minority as follows (Fig. 4), but also intermediate solutions (Xavier et al., 2013). The results of this module indicate that in both the majority and minority consensus the most valued criteria is fire risk. However, there is an important difference between the various solutions as in the minority consensus economic result looses its importance for the biodiversity criteria.

Results obtained from the preferences module can be inserted as preference weights in the previous multi-criteria decision making problem.

Table 5
Example of technologies' selection for biophysical unit b5 by farm type: Farm type 1 (FT1); Farm type 2 (FT2); Farm Type 3 (FT3); Farm type 4 (FT4); Other Farm Types (OFT) (ha).

Type of above ground biomass	Farm type	SOB1	SOB7	SOB8	MED6	MED7	EUC7	PB7	PMS7	SOBA7	SOBA8	SOBA14	MEDA1
T1	FT1	0.000	58.865	0.000	0.000	4.193	0.000	0.083	0.025	27.832	0.000	0.000	0.000
T1	FT2	0.000	18.542	0.000	0.000	0.718	0.000	0.000	0.000	2.245	0.000	0.000	0.000
T1	FT3	8.452	0.000	0.000	0.587	0.000	0.000	0.000	0.000	0.000	0.000	1.060	0.000
T1	FT4	23.281	0.000	0.000	1.782	0.000	0.000	0.000	0.000	0.000	0.000	0.954	0.000
T1	OFT	0.000	2.811	0.000	0.000	0.211	0.000	0.000	0.000	0.000	0.000	0.000	0.000
T2	FT1	0.000	8.235	0.000	3.464	0.000	0.274	0.000	0.001	14.426	0.000	0.000	0.000
T2	FT2	0.000	2.656	0.000	0.750	0.000	0.088	0.000	0.000	1.262	0.000	0.000	0.000
T2	FT3	0.000	0.000	1.180	0.479	0.000	0.000	0.000	0.000	0.000	0.548	0.000	0.334
T2	FT4	0.000	0.000	3.251	1.455	0.000	0.000	0.000	0.000	0.000	0.494	0.000	0.300
T2	OFT	0.000	0.393	0.000	0.174	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
T3	FT1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.046	0.000
T4	FT2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.194	0.000
T1	FT3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
T2	FT4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.242	0.000
T3	OFT	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Species: SOB: *Quercus suber*; PMS: *Pinus pinea*; MED: *Arbutus unedo*; PB: *Pinus pinaster*; SOBA: Burnt *Quecus suber*; MEDA: Burnt *Arbutus unedo*; Above ground biomass use: T1: *Cistus landanifer* shrubs; T2: Other shrubs; T3: Pastures; Technologies: 1: caterpillar tractor and a brush shredder; 6: manual mechanical cleaning; 7: manual cleaning; 14: cleaning of the area by animals.

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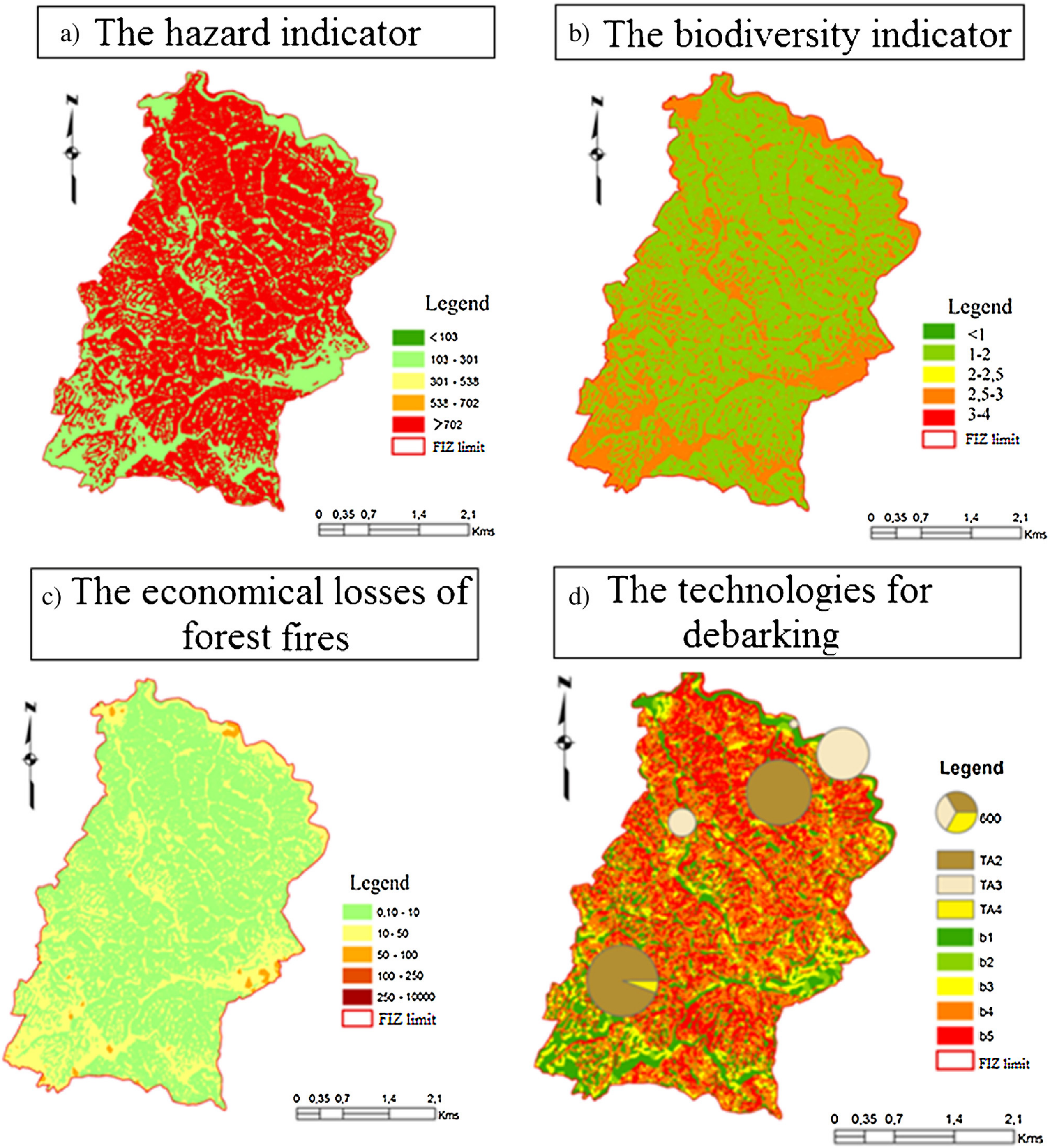

Fig. 3. Examples of the GIS results by biophysical unit.

4.2. *The location module*

With the location module it is possible to obtain detailed cartographical information at plot level giving precious information on the general distribution of agroforestry activities or to detail the accurate distribution of the land uses inside each plot, using the data provided by the management module. It is a useful planning tool, especially considering that the farmers can be different from landowners, and there is an entity (the FIZ manager) that is responsible for the best allocation of any given production project. Figs. 5 and 6 represent such results for the temporary crops. Fig. 5 depicts the general distribution of potato in the several plots while Fig. 6 represents a detailed distribution of each temporary crop inside a plot suitable for their development.

5. Discussion

Results show that the DSS proposed can deal with some current problems of forest management stated by Borges et al. (2014), namely, a regional scale, more than one decision maker, multiple objectives from different stakeholders and a supply of several products behind wood, being some of them non tradable products. This

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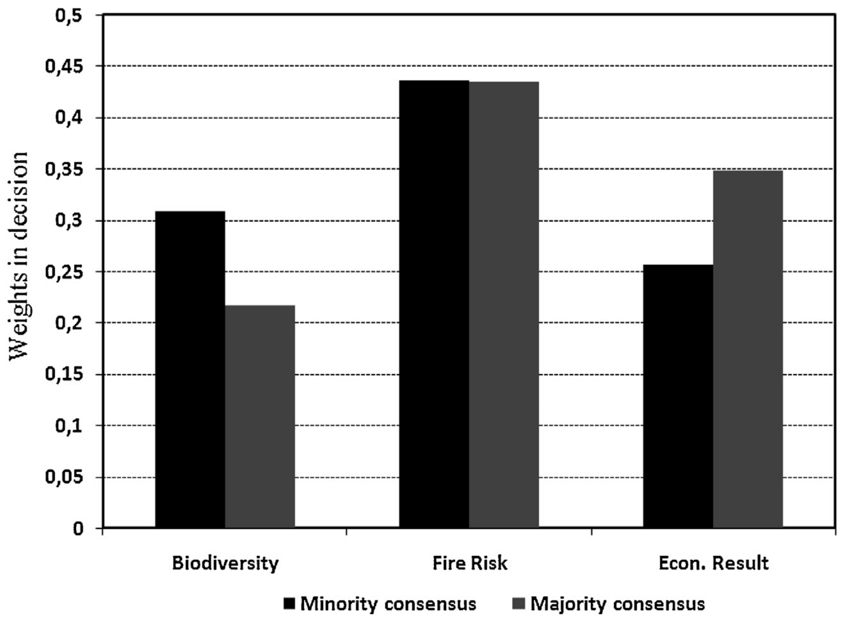

Fig. 4. The majority and minority consensus.

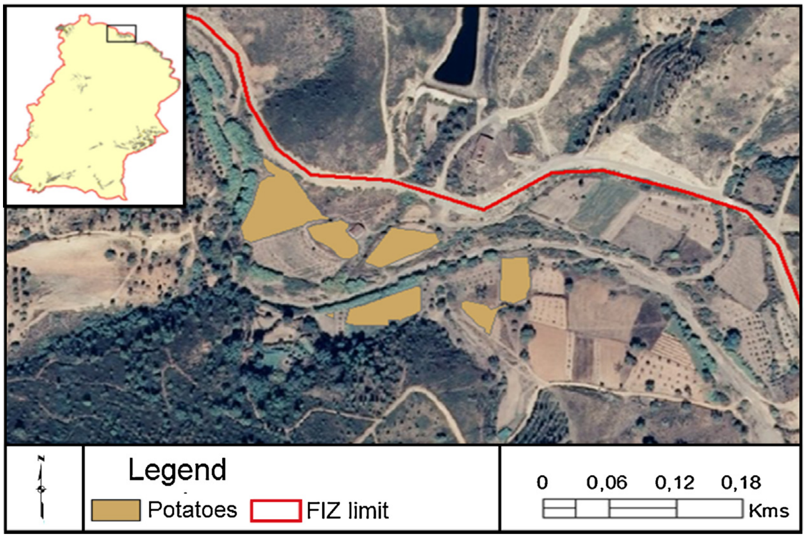

Fig. 5. Potato distribution in several plots.

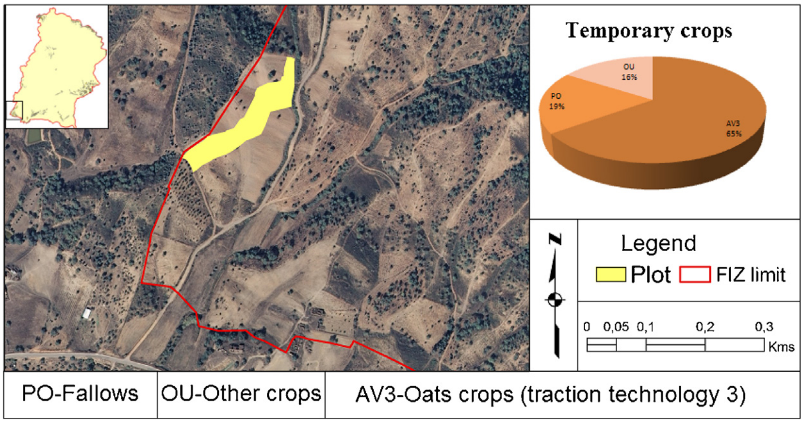

Fig. 6. Example of the results inside each plot.

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context, which is difficult, has become even more complex due the increasing awareness for sustainability (Hahn and Knoke, 2010).

The DSS proposed considers these issues in the specific regional context of the Mediterranean forest of southern Portugal. Data used in the management module tailor the economic, social, technological and environmental characteristics of the study area. In this DSS, regional forest level is of primary interest, but a more detailed level is also considered, first at farm and biophysical unit levels and then through the location module, which makes it possible to achieve an efficient allocation of agro-forest areas to a plot level according to the specific features of biophysical units within farm types.

Standardised forests reduce biodiversity and cannot be adapted to fit new policy challenges (Gadow et al., 2008). The DSS developed allows an integrated view of the forest and provides guidelines for forest management based on efficient and non-dominate solutions, which can promote diversity and a flexible allocation of resources.

Adaptive management also requires interactive systems able to provide analysis with stakeholders, since social issues are increasing in importance (Johnson et al., 2007; Reynolds et al., 2008). As it was stated before the DSS developed integrates a multi-criteria optimization structure based on a compromised programing model, which allows introducing the existing trade-off between conflicting objectives in decision making process. However, behind including multiple objectives, the DSS considers different stakeholders in the decision process. In the preferences module weights for the different criteria considered can be derived, taking into account the level of consensus among several stakeholders involved.

A wide range of DSS has been developed to address the main problems of forest management (Borges et al., 2008). Many of them can combine their results on geographic information systems, are based on quantitative support and provide automated solutions (Borges et al., 2014). But the DSS proposed is able to promote efficient and participative forest management solutions that can be addressed to a specific location at plot level, according to the attribute level of decision criteria (for instead economic results) and biophysical conditions, such as slope.

6. Conclusion

This paper proposes a decision support system that may help in the sustainable and efficient management of agro-forestry areas with multiple agents, stakeholders and different criteria. The decision support system proposed integrates three main modules, which comprise a management module, a preferences module and a location module that locates the activities in precise plots.

The location module represents an effective way for allocating areas of agro-forest activities in precise plots considering the possibility of making efficient decisions concerning the maximisation of economic results and environmental aspects related to biodiversity and minimisation of fire risk; social aspects are also considered in this framework, since the preferences of different stakeholders are introduced in the decision making process.

Results depend on the decision support system context of application. Thus, specific socio-economic and biophysical conditions, such as land use, slope, proximity to roads' network, density of agricultural and forestry pathways and demographic density surely influence both forest fire and economic losses (also in urban areas). The application of the decision support system to the Algarve inland region, in southern Portugal, showed that economic result and risk have a greater trade-off than economic result and biodiversity. In this context, it is also important to underline that the forestry activity, in a depressed area such as the Algarve inland, with severe depopulation and aging problems, is still an economic activity with an interesting relation with the other sectors of economy.

The decision support system proposed in this paper is able to deal efficiently with the main problems of forest management, such as a regional scale, multiple objectives, different stakeholders and supply of other products than wood. In addition to the flexible and integrated form as the decision support systems deals with forest management problems, the location module is an original contribution, which is not current in other previous decision support systems.

Further research and developments should be focused on increasing the participation of multiple stakeholders in the decision process. In order to achieve that, other alternative techniques of multi-criteria decision-making and a user-friendly interface should be studied.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landusepol.2015.12.015.

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