Floresta e Ambiente 2019; 26(2): e20170702
https://doi.org/10.1590/2179-8087.070217
ISSN 2179-8087 (online)

Original Article

Forest Management

Mapping Forest Landscape Multifunctionality Using Multicriteria Spatial Analysis

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ABSTRACT

This paper presents a GIS methodological approach for mapping forest landscape multifunctionality. The aims of the present study were: (1) to integrate and prioritize production and protection functions by multicriteria spatial analysis using the Analytic Hierarchy Process (AHP); and (2) to produce a multifunctionality map (e.g., production, protection, conservation and recreation) for a forest management unit. For this, a study area in inner Portugal occupied by forest and with an important protection area was selected. Based on maps for functions identified in the study area, it was possible to improve the scenic value and the biodiversity of the landscape to mitigate fire hazard and to diversify goods and services. The developed methodology is a key tool for producing maps for decision making support in integrated landscape planning and forest management.

Keywords: species suitability maps, Analytical Hierarchy Process (AHP), Geographic Information Systems (GIS).

1. INTRODUCTION

The term "landscape" defines a spatially heterogeneous geographical area, characterized by diverse interactions among ecosystems, from aquatic and terrestrial natural and semi-natural systems to anthropic environments (Wu, 2008). Forest ecosystems provide numerous goods and services to society (e.g., wood and non-wood products, recreation, biodiversity conservation and carbon sequestration). The concept of "functions of forest ecosystems" has been widely used in this sense for decades in forest management (Blattert et al., 2017; Brun 2002; Calama et al., 2010; Kindler 2016).

Although forest landscapes can be considered multifunctional, the degree of their multifunctionality can differ because not all their spatial units have the same capacity to assure all the desired functions (e.g., production, protection and conservation, among others). The search for forest landscape multifunctionality allows assessing functions other than production that can assume the most relevant economic, social, cultural and/or environmental values (Brun 2002; Miura et al. 2015; Pinto-Correia & Vos, 2004; Távora & Turetta 2016).

From the spatial point of view, it is possible to define three types of multifunctionality (Blust & van Olmen, 2002; Brandt & Vejre, 2004): i) multifunctionality as a combination of separate spatial units with different single functions; ii) multifunctionality as the presence of different functions in the same space unit but separated in time; and iii) multifunctionality as the integration of different functionalities in the same space unit and time. Currently, the use of multi-criteria methodologies in GIS (Geographic Information Systems) provides information on the potentiality of a territory and allows evaluating the use of multifunctional strategies to compartmentalize the landscape according to its suitability and dominant land use (Joerin et al., 2001).

Multi-criteria analysis is a mathematical tool for the evaluation of alternatives that allows the comparison of different criteria-based scenarios to support decision makers in achieving judicious choices (Dodgson et al., 2009; Roy, 1996). Over time, approaches to multi-criteria spatial analysis incorporated in GIS, such as Weighted Linear Combination and its variants, Ideal Point Method, Concordance Analysis and Hierarchical Analytical Method, have increased (e.g., Hill et al., 2005; Huang et al., 2011; Jozi et al., 2010; Malczewski, 2006; Parimala & Lopez, 2012; Valente & Vettorazzi, 2005; Vizzari, 2011).

Analytic Hierarchy Process (AHP), proposed in the 1970s by Thomas L. Saaty, is one of the most widely used multi-criteria spatial analysis methods (e.g., Ananda & Herath, 2009; Steiguer et al., 2003). The AHP method decomposes a problem, question or decision into its variables, in a criteria and sub-criteria scheme and makes pairwise comparisons among them (Dodgson et al., 2009; Saaty, 2008). Comparisons between criteria are made on a scale from one to nine, where one is equally preferred and nine is extremely preferred. The AHP method converts these comparisons into numeric values that can be processed and compared across the full extent of the problem. The weight of each of variables allows evaluating each of them within the defined hierarchy. This ability to convert empirical data into mathematical models distinguishes the AHP method from other decision-making techniques (e.g., Ananda &Herath, 2009; Saaty, 2008; Valente &Vettorazzi, 2005).

Multi-criteria spatial analysis in a GIS environment has proven to be very useful in the decision-making process for forest planning and management and conservation actions of forest resources (e.g., Ananda & Herath, 2009; Balana et al., 2010; Ezzati et al. 2016; Fontana et al., 2013; van der Horst & Gimona, 2005; Kangas et al., 2000; Oliveira et al., 2014; Sacchelli et al. 2013; Saito et al. 2016; Valente &Vettorazzi, 2005; Vizzari, 2011).

In Portugal, as part of its forestry policy, the Plans of Regional Forest Planning (PRFP) are legal instruments that propose broad guidelines for land cover/use and forest management to promote and guarantee the production of goods and services and the sustainable development of forest landscapes in a multifunctional approach (Portugal, 2006). Although PRFP identifies functions to be privileged (e.g., production, protection, habitat conservation, fauna and flora species and geo-monuments, agroforestry, hunting and fishing in inland waters, recreation and landscape aesthetics) in each of the 21 regions of the country and their homogeneous sub-regions, it is only at the level of the elaboration of Forest Management Plans (FMP) that a functional zoning map for the forest landscape of the management unit is required (AFN, 2009). However, a methodology to judiciously perform this zoning is not provided and thus usually results from the application of legal constraints/restrictions to the existing land cover only.

Therefore, the hypothesis developed in this study is that the application of the AHP method in a GIS environment will allow hierarchizing the functions identified in the forest landscape of a management unit to support its multifunctionality mapping (suitability/constraints). Thus, the aims of the study were: (1) to integrate and hierarchize production and protection functions by multi-criteria spatial analysis using the Analytic Hierarchy Process (AHP); and (2) to map the multifunctionality of a management unit by the integration of identified functions (e.g., production, protection, conservation and recreation). For this purpose, a study area in inner Portugal that was dominated by forest and had an important protection area was selected for the development of this methodological approach.

2. MATERIAL AND METHODS

2.1. Study area

The study area (Figure 1) covers 3,100 ha and is located in inner Portugal (parish of Sarnadas de S. Simão, municipality of Oleiros). It is mainly occupied by forest stands (80%) almost exclusively

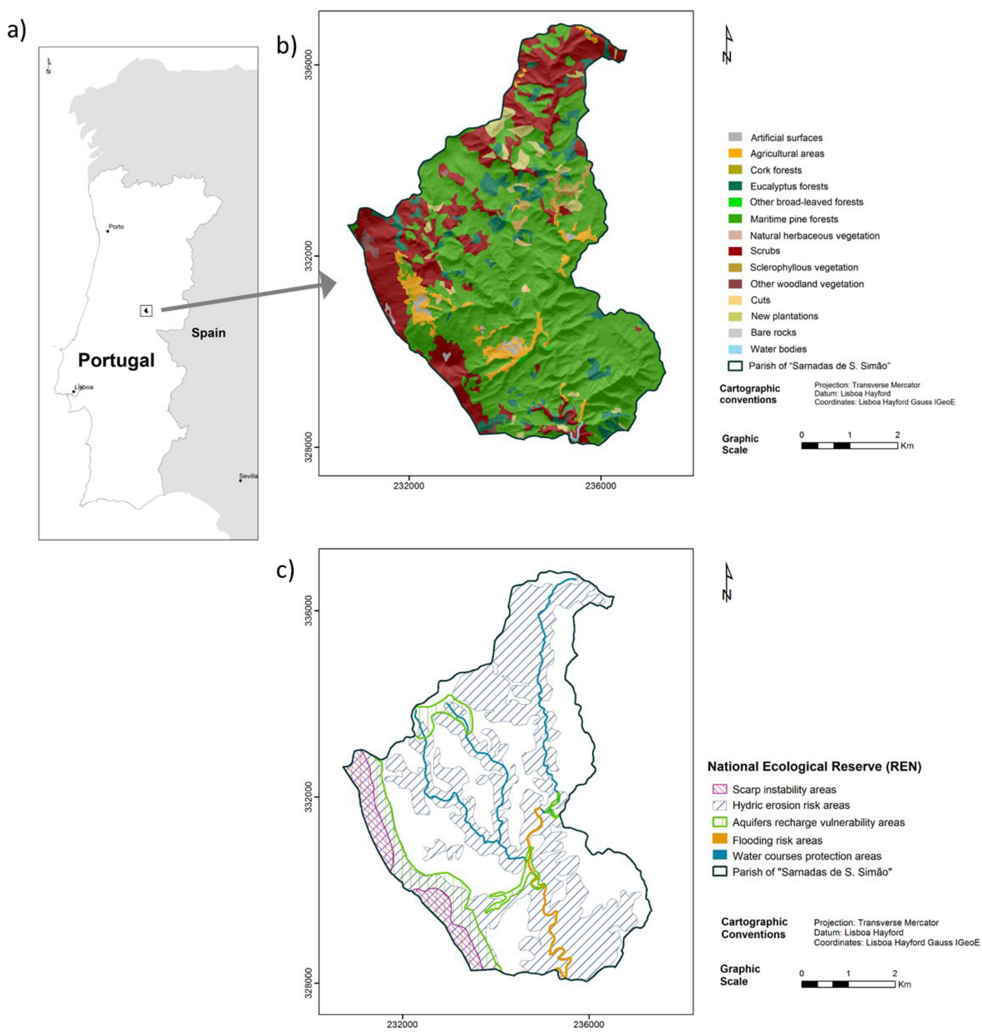

Figure 1. Study area: (a) geographical location of the study area (Sarnadas de S. Simão, municipality of Oleiros); (b) land cover map; and (c) National Ecological Reserve (REN).

composed of Maritime pine (*Pinus pinaster* Aiton, 68%) and Eucalyptus (*Eucalyptus globules* Labill., 12%) (Figure 1b). It also has an extensive protected area classified as a National Ecological Reserve (REN) (Figure 1c). The "Serra do Muradal" mountain is located in the western portion of the study area, which is an area (rocky outcrops consisting of quartzite ridges that form an Appalachian-type relief) of the "Naturtejo da Meseta Meridional" geopark that belongs to UNESCO's global network of geoparks.

The area under study is covered by PRFP of the "Pinhal Interior Sul" region (PRFP PIS), the homogeneous sub-region of "Pampilhosa and Alvéolos" (Portugal, 2006), and the Municipality Plan of its municipality (Oleiros, 2015).

2.2. Methodology

For the development of the GIS model (Figure 2), the five functions foreseen in PRFPPIS were considered to organize the multifunctionality of the area landscape under study: 1) production, 2) protection, 3) conservation 4) agroforestry and 5) recreation.

The maps of forest species suitability for the study area produced by Navalho et al. (2017) were used for the definition of production function spaces (Figure 2). These maps had in their genesis the methodology of Ferreira et al. (2008) and Dias et al. (2008), which was based on the soil, climate and ecological-cultural characteristics of each species (Figure 3).

In the present study, only the six most important species found in the study area, according to PRFP PIS guidelines, were considered: Pyrenean oak (*Quercus pyrenaica* Willd.), Cork oak (*Quercus suber* L.), Holm oak (*Quercus rotundifolia* Lam.), Strawberry tree (*Arbutus unedo* L.), Maritime pine and Eucalyptus (Portugal, 2006).

The agroforestry function, which considers both characteristics of the study area and species recommended for afforestation / conversion, was integrated into the production function.

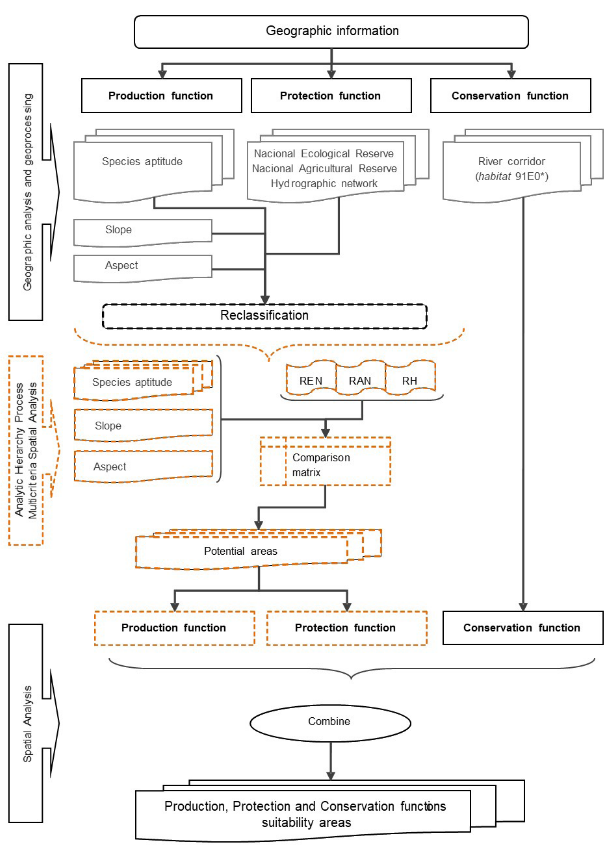

Figure 2. GIS methodological approach for mapping forest landscape multifunctionality.

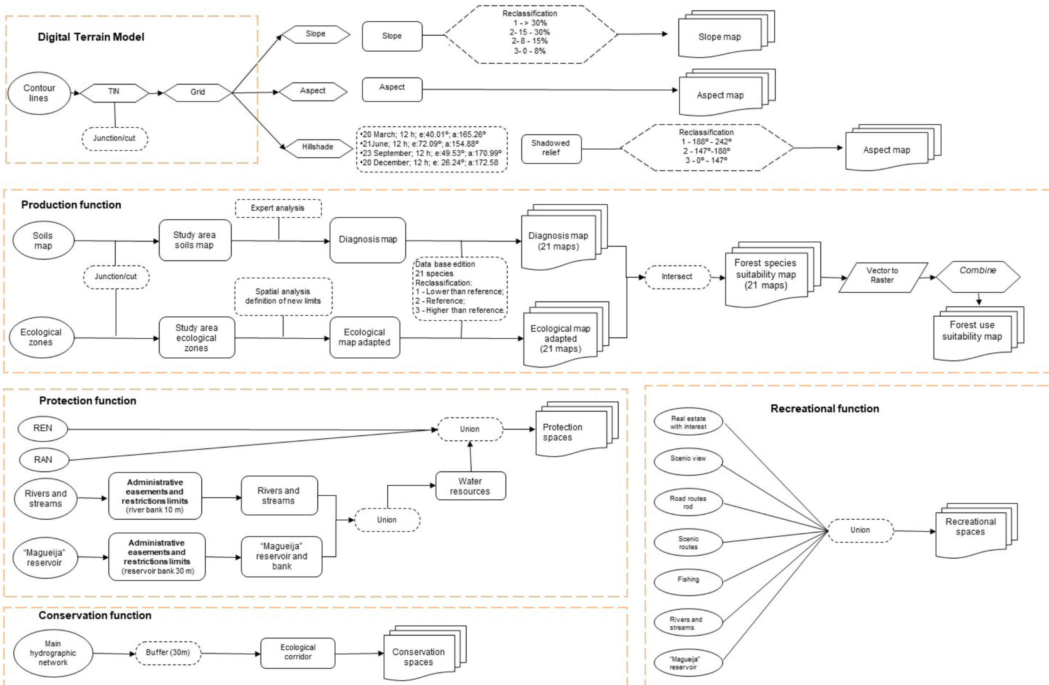

Figure 3. GIS model for geographic information production.

To define protection function spaces (Figures 2 and 3), administrative easements and restrictions of public utilities included in the Municipality Master Plan in which the study area belongs were considered (e.g., sensitive areas from the point of view of soil and water resources protection): National Ecological Reserve (REN), National Agricultural Reserve (RAN) and Hydrographic Network (RH) (Oleiros, 2015).

Regarding the definition of conservation function spaces (Figures 2 and 3), a river corridor along watercourses (30 m for each side of the banks) was considered as conservation habitat (e.g., habitat 91E0 * – riparian or paludal alder forests (*Alnus* sp.), willows (*Salix* sp.) or birch trees (*Betula* sp.), subtype "riparian alders forests" 91E0pt1).

Finally, recreational spaces were defined by the integration of information obtained from: i) characterization studies elaborated in the scope of the Municipality Master Plan revision in which the study area belongs; and 2) field recognition and inventory of all possible sites of interest (Figure 3).

Multi-criteria spatial analysis was performed only for the production and protection functions because the conservation function had only one criterion (Figure 2). The method of multi-criteria spatial analysis selected was the Analytic Hierarchy Process (AHP) because it was the most appropriate method for this case study (e.g., Ananda & Herath, 2009; Phua & Minowa, 2005). The definition of the criteria for each function used the Participatory Technique with the consultation of experts (e.g., Valente & Vettorazzi, 2005) in the field of rural spatial planning, forest management and nature conservation.

Regarding production function mapping by the AHP method, in addition to suitability maps of the six recommended species (Pyrenean oak, Cork oak, Holm oak, Strawberry tree, Maritime pine and Eucalyptus), two other variables that influence the species development were also included: slope and aspect (Figures 2 and 3). It is noteworthy that the study area presents slopes of more than 30% in almost half of its extension (44%), and slopes dominantly face (have aspects) N, NE, E, SE and S (approximately 66%).

The criteria for species suitability, slope and aspect were reclassified according to their importance as limiting factors (Table 1 and Figure 4a, b, c). The same procedure was applied to the protection function mapping by the AHP method, with the REN, RAN

Table 1. Criteria for production and protection functions.

Criteria		Description	Classification
Production Function	Species suitability: Pyrenean oak, Cork oak, Holm oak, Strawberry tree, Maritime pine and Eucalyptus	Higher than reference	3
		Reference	2
		Lower than reference	1
	Slope (*d*)	0 <*d*< 8%	3
		8<*d*<15%	2
		15<*d*< 30%	2
		d>30%	1
	Aspect (*e*)	0º<*e*<147º	3
		147º<*e*<188º	2
		188º<*e*<242º	1
Protection Function	National Ecological Reserve (REN)	REN	0
		Areas with no restriction	1
	National Agricultural Reserve (RAN)	RAN	0
		Areas with no restriction	1
	Hydrographic Network (RH)	Administrative easement	0
		Areas with no restriction	1

Legend: [Production Function] 1 –Low and/or null suitability, 2 – Medium suitability and 3 – High suitability; [Protection Function] 0 – Area with constraints (easements and/or restrictions) and 1 – Area with no constraints.

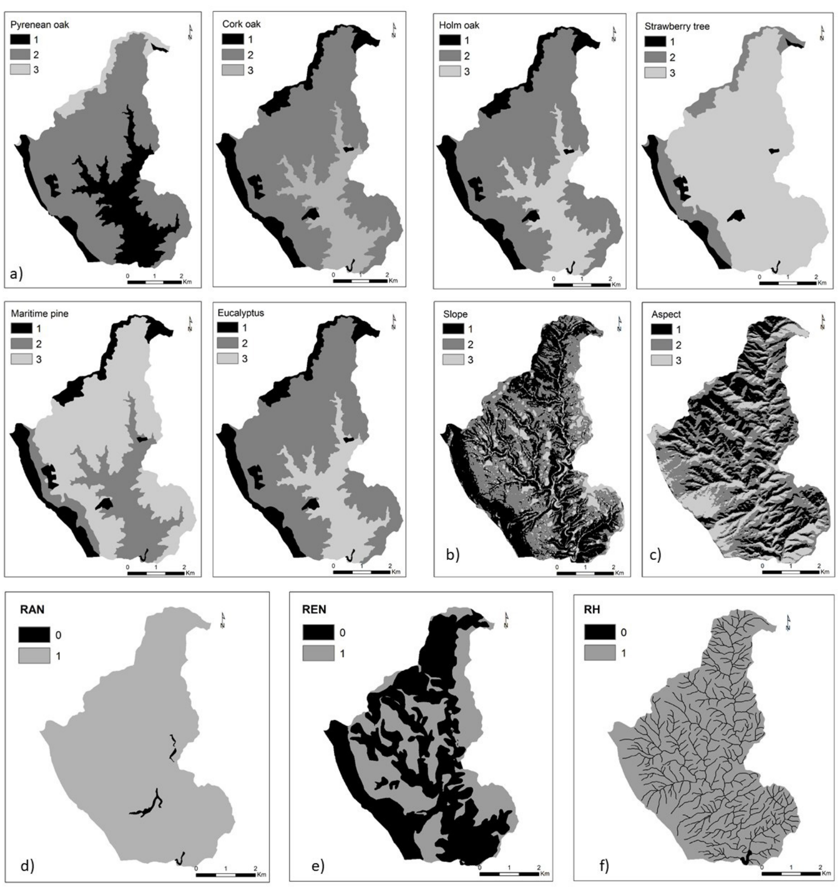

Figure 4. Input maps in the AHP method for production and protection functions: (a) species suitability maps (i.e., Pyrenean oak, Cork oak, Holm oak, Strawberry tree, Maritime pine and Eucalyptus); (b) slope map; (c) aspect map; (d) REN map; (e) RAN map; and (f) RH map. Legend: [(a), (b) and (c)] 1 – Low and/or null suitability, 2 – Medium suitability and 3 – High suitability; [(d), (e) and (f)] 0 – Area with constraints (easements and/or restrictions) and 1 – Area with no constraints.

and RH criteria reclassified by the Boolean method (0 - with restriction, 1 - without restriction) (Table 1 and Figure 4d, e, f).

After problem hierarchization, the decision-making criteria for each of the functions under analysis were pairwise compared in a square decision matrix (Table 2) according to a scale of importance of nine numerical values.

The AHP method was completed by determining the relative importance of each criterion/sub-criterion and validating the consistency of these operations. If the consistency ratio (CR) obtained values less than 10% (RC <0.1), it was considered that there was coherence in the pairwise comparison of the matrix (Saaty, 2008). In the present study, weights were calculated using the AHP tool, developed by Marinoni (2017), available in the ArcGIS software (ESRI, 2010).

Maps were obtained for the production function (e.g., recommended species: Pyrenean oak, Cork oak, Holm oak, Strawberry tree, Maritime pine and Eucalyptus) and for the protection function (e.g., REN, RAN and RH restrictions) from the application of the AHP method (Figure 2). Subsequently, the suitability of the study area for the production, protection and conservation functions (river corridor with the riparian priority habitat 91E0pt1) was assessed using the *Combine* tool of the ArcGIS *Spatial Analyst* extension (ESRI, 2010) to generate combinations associated with above-mentioned layers (Figure 2). Thus, the recreation function map (points of interest) was overlaid.

3. RESULTS

The application of the AHP method allowed the categorization of the study area based on its suitability for production and protection functions (Figure 5).

The integration of species suitability, slope and aspect criteria in production function mapping for the six forest species under study (Pyrenean oak, Cork oak, Holm oak, Strawberry tree, Maritime pine and Eucalyptus) by the AHP method (Figure 5a) resulted in a more detailed categorization of local potential growth conditions for the species (e.g., higher suitability corresponds to higher classification values). Production function maps (Figure 5a) indicate areas of high suitability for Pyrenean oak in the northwestern zone, for Cork oak, Holm oak and Eucalyptus in the central zone, for Maritime pine around this central zone and for the Strawberry tree on south-facing slopes practically over the entire study area.

The protection function map produced by the AHP method (Figure 5b) resulted in a categorization of areas with constraints due to REN, RAN and RH (e.g., soil and water resources protection areas correspond to low classification values).

In the production function (Table 3), the highest weights correspond to the criterion of species suitability (more than half of the sum of weights) compared with slope and aspect criteria. This reveals that ecological, soil and climate conditions are crucial in species distribution. It was found that there was good consistency in the pairwise matrix comparison (RC = 0.063 <0.1). In the protection function (Table 3), the most important constraint on assessing protection areas was REN, because REN is a biophysical structure that integrates a set of areas under special protection and because it covers most of the study area (Figure 1). Once again, there was consistency in the comparison of the matrix (RC = 0.037 <0.1).

The multifunctionality suitability map (Figure 6) of the study area, which resulted from the combination of production, protection and conservation functions and the overlapping of the recreational function, shows the coexistence of several functions in some areas.

Table 2. Comparison matrix for production and protection functions.

Criteria		Species suitability	Slope	Shadows
Production Function	Species suitability	1	5	7
	Slope	0.2	1	3
	Aspect	0.143	0.333	1
Protection Function	REN	1	3	5
	RAN	0.333	1	3
	RH	0.2	0.333	1

Table 3. Weight criteria for production and protection functions.

Criteria		Eigenvector	Higher eigenvector	Weight
Production Function	Species suitability	3.065	0.963	0.731
	Slope	-0.033	0.248	0.188
	Aspect	-0.033	0.107	0.081
Consistency ratio – RC=0.063 <0.1				
Protection Function	REN	3.039	0.916	0.637
	RAN	-0.019	0.372	0.258
	RH	-0.019	0.151	0.105
Consistency ratio – RC=0.037 <0.1				

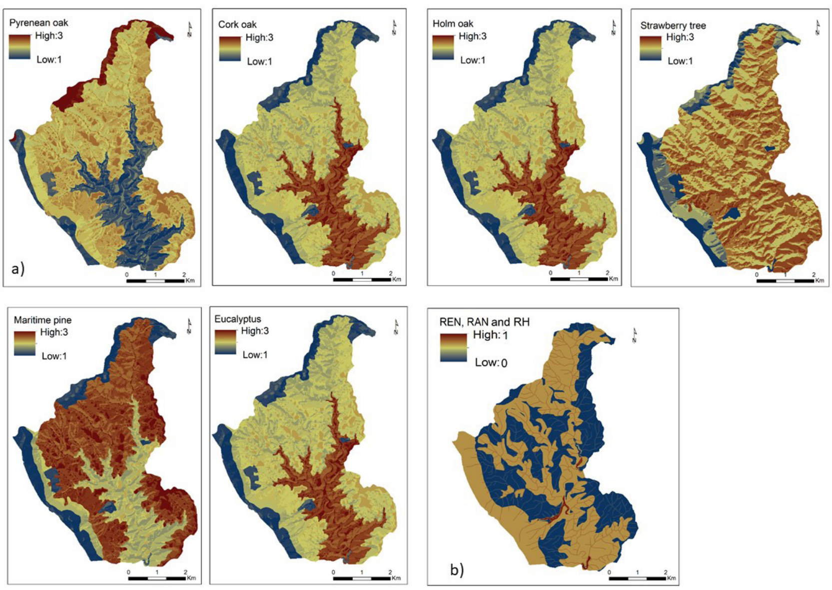

Figure 5. Maps of the production and protection obtained by AHP: (a) production function (Pyrenean oak, Cork oak, Holm oak, Strawberry tree, Maritime pine and Eucalyptus); (b) protection function (REN, RAN and RH). [(a)] 1 to 3 – Low and/or null suitability to high suitability; [(b)] 0 to 1 – Area with constraints (easements and/or restrictions) to no constraints.

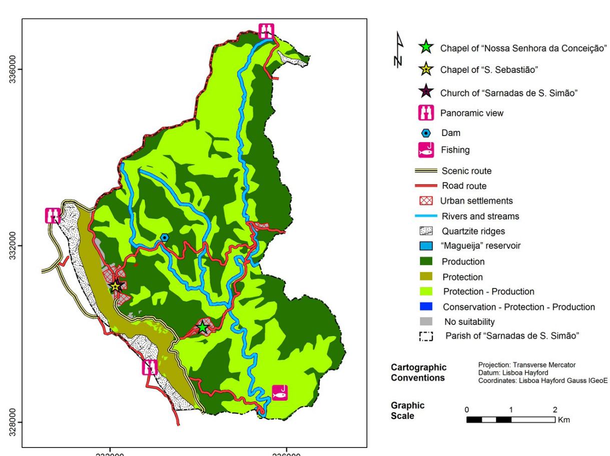

Figure 6. Multifunctionality suitability map for the study area – production function, protection function, conservation function and recreational function.

4. DISCUSSION

It is observed in protection function maps that areas with constraints (Figure 5b) match areas of high suitability for Cork oak and Holm oak (native species) (Figure 5a). Therefore, due to the current land cover in the study area, in which Maritime pine and Eucalyptus are the dominant species (Figure 1b), the possibility of converting some of the existing stands to mixed Maritime pine and Cork oakor Holm oak stands, or to pure or mixed of Cork oak or Holm oak stands will allow the diversification of this forest landscape and the production of other goods (non-wood products) and services (landscape biodiversity and aesthetics). In fact, the integration of the agroforestry function can be obtained by promoting agroforestry systems of Cork oak and/or Holm oak. Pyrenean oak can also be used, although preferably in high-suitability area (Figure 5a). As a result, these maps provide crucial information to support planning for the introduction of native oaks into the study area as recommended in RFPP PIS.

Based on the results obtained, it is understood that considering the categorization of functions, priority for the protection function should be given (Figure 5b) because it occupies an area greater than 60%, as proposed by Ferreira et al. (2008). The next priority should be given to the production function (Figure 5a, including the agroforestry function), then, the conservation function and, finally, the recreation function. Additionally, the analysis of the multifunctionality suitability map (Figure 6) shows the coexistence of several functions, which indicates its complementary feature (Blust & van Olmen, 2002; Brandt & Vejre, 2004). Therefore, even though legal constraints do not prevent the use of protection areas for forestry and agricultural purposes, it is necessary to adopt adequate management practices to promote the conservation of soil and water resources.

Finally, it is argued that the maps produced (Figures 5 and 6) provide support for integrated landscape planning with a view to improving the scenic value and biodiversity of the landscape and at the same time reducing fire risk and diversifying the supply of goods and services. This purpose can be achieved by the introduction of native oaks in their best suitability areas (e.g.,Pyrenean oak, Cork oak and Holm oak). In fact, these species have lower combustibility and flammability compared to species currently existing in the study area (e.g., Maritime pine and Eucalyptus) (Navalho et al., 2017).

5. CONCLUSIONS

The application of multi-criteria spatial analysis using the AHP method proved to be effective, even though not many criteria were used. This method allowed evaluating the degree of importance of each of the criteria considered and the hierarchization of forest landscapes for production and protection functions. In addition, it is important to emphasize that the weight criteria obtained by the Participatory Technique depend on the experience of experts.

The multifunctionality suitability map of forest landscape integrated the functions identified in the study area and is key for the determination of species silvicultural prescription to be promoted in each spatial unit regarding their dominant suitability (e.g., production, protection, conservation and/or recreational).

The developed methodology allowed the production of support maps for decision making in integrated landscape planning and forest management, both in the scope of the Regional Forest Planning and at the scale of Forest Management Plans.

SUBMISSION STATUS

Received: 14 june, 2017
Accepted: 15 jan., 2018

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FINANCIAL SUPPORT

Cristina Alegria (Grant/Award Number: 'CERNAS-IPCB [UID/AMB/00681/2013 by FCT – Foundation for Science and Technology FCT]'). Luís Quinta-Nova (Grant/Award Number: 'UID/GEO/04035/2013 by FCT – Foundation for Science and Technology').

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