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PRESENT AND FUTURE AGROFORESTRY LAND SUITABILITY ANALYSIS IN CENTRAL PORTUGAL USING MULTICRITERIA DECISION ANALYSIS

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ABSTRACT

The expansion of monoculture tree plantations typically made up of pine or eucalyptus trees, is a main problem in Portugal. In recent years, monoculture plantations have spread across the country, driven by the pulp and paper industry. These are generally more susceptible to the spread of fire than mixed forests or agroforestry systems, which among other advantages, hold more water and reduces soil erosion. A diverse landscape with a mosaic of different uses and vegetation cover types provides a greater bulwark or natural barrier against large-scale and uncontrollable forest fires. The objective of this study is to determine the suitability for species cultivated in an agroforestry mode in the *Pinhal Interior Sul* region, as an alternative agricultural system, based on the analysis of the soil and climate limiting factors. For this purpose, the biophysical criteria determining the cultivation of common oak (*Quercus robur* L.), cork oak (*Quercus suber* L.), strawberry tree (*Arbutus unedo* L.), and sweet chestnut (*Castanea sativa* Mill.) were processed using a Geographic Information System for the present time and in the face of two future emission scenarios. The analysis was performed by the Analytical Hierarchy Process (AHP). After dividing the problem into hierarchical levels of decision-making, a pairwise comparison of criteria was performed to evaluate the weights of these criteria. The process was completed by validating the consistency of these operations. The AHP was adequate in the evaluation of the tree species' suitability allowing the integration of different criteria. It is therefore essential to be aware of the suitability and resilience of agroforestry systems to meet the need to adapt to climate change.

Keywords: *Agroforestry, Land suitability, Analytic Hierarchy Process, GIS.*

INTRODUCTION

Large-scale rural fires are a worldwide problem that has been studied in the most fire-prone regions of the world (Tedim, Leone & McGee, 2019; Vigna et al., 2021). Portugal is the most affected country by rural fires in Europe in the period between 2011 and 2020, with an average of 17,712 rural fires per year, corresponding to 131,118 thousand hectares of burned area per year, with 63,828 hectares (49%) of forest stands and 58,343 hectares (44%) of bush and natural pastures, and still affecting 8,947 hectares (7%) of agricultural area (APA, 2022). The increased presence of rural fires can be attributed to the transformation of the Portuguese landscape in the last decades, with the forest cover progressively changing to extensive monoculture landscapes of even-aged stands of fast-growing species, dominated by *Pinus pinaster* Aiton. and *Eucalyptus globulus* Labill. (DGT, 2020). Socioecological causes also act together to create the conditions for a greater incidence of burnt areas in certain regions of Portugal, resulting from the demographic changes (the population exodus from rural areas, and the aging population) that led to the expansion of unmanaged or abandoned land. These events eventually prompted the beginning of large fires in Portugal, particularly since the 80s of the XX century (Nunes, Lourenço & Meira, 2016).

In this context, a rural fire prevention strategy through an integrated and ecologically based planning approach needs to be addressed. This approach should include the implementation of sustainable land uses and well-defined management measures to achieve a fire-resilient and sustainable landscape. Those fire-resistant and resilient land uses include agroforestry systems and woodlands mainly composed of native oak species and other native broadleaved species (Magalhães et al., 2021).

Facing the trends of climate change is urgent to address land-use adaptation more coherently and promote the suitability of plant, weather, and soil conditions. Hence, that investigation identifies the suitable areas for agroforestry using a model based on multicriteria spatial analysis AHP. The suitable areas are determined by an evaluation of the climate, soil, and topographical factors and the understanding of local biophysical restraints. In this kind of situation, many variables are involved and each one should be weighted according to their relative importance in the optimal growth conditions for agroforestry systems through multicriteria evaluation and Geographic Information Systems.

Multicriteria decision analysis (MCDA) has been widely applied in various studies in different fields, many of which are published and have been cited by many authors as processes of relevant decision-making. Various techniques of MCDA have been used extensively in rural land-use suitability analysis (Alkimim, Sparovek & Clarke, 2015; Dedeoğlu & Dengiz, 2019; Mighty, 2015; Wotlolan et al., 2021; Zhang et al., 2015, Quinta-Nova & Ferreira, 2020).

In this study, the Analytic Hierarchy Process (AHP) was used as an MCDA technique with a GIS to identify the areas suitable for promoting agroforestry uses in a study area located in the Center region of Portugal, by the integration of several criteria. AHP is an inductive, multicriteria method, effective in the estimation of the likelihood of unique events, and in the face of multiplicity, uncertainty, and the limitation of information. The suitability analysis was examined for the present time and in the face of two future emission scenarios (RCP 4.5 and 8.5) because it is essential to be aware of the suitability and resilience of agroforestry systems to meet the need to adapt to climate change.

MATERIAL AND METHODS

The study-case area is located in the Central Region of mainland Portugal (Figure 1). It has an area of 2079 km^2 and includes seven municipalities: Castanheira de Pêra, Pedrógão Grande, Figueiró dos Vinhos, Sertã, Pampilhosa da Serra, Oleiros and Proença-a-Nova with a very high risk of rural fire (ICNF, 2022). During the period between 2015 and 2020, the burnt area in the case-study area reached 1145 km^2, corresponding to 55% of the study-case area. This subregion is mainly occupied by forest stands of pine trees and eucalyptus (69.4%) and shrubland (15.0%), with only 11.5% corresponding to woodlands, agroforestry, and agriculture.

The Regional Forest Management Plan for the Coastal Center Region of Portugal recommended a set of wooden species suitable for the study area (ICNF, 2019). For this study, we select the following deciduous species of interest for exploration under agroforestry systems: common oak (*Quercus robur* L.), strawberry tree (*Arbutus unedo* L.), cork oak (*Quercus suber* L.), and sweet chestnut (*Castanea sativa* Mill.).

Data under representative concentration pathway (RCP) 4.5 for 2041-2060 was used for future climate analyses, which is obtained from the WorldClim database (Fick & Hijmans, 2017). In the future conditions, we have considered two representative concentration pathways (RCPs) scenarios (RCP 4.5 and RCP 8.5) fitted for 2070.

Emissions in RCP 4.5 (Intermediate scenario) peak around 2040, then declines, resulting in a global temperature rise between 1.1 to 2.6 ºC by 2081-2100 (relative to 1986-2005). In RCP 8.5 (Worst-case climate change scenario) emissions continue to rise throughout the 21st century, resulting in global temperature rise between 2.6 to 4.8 ºC by 2081-2100 (relative to 1986-2005).

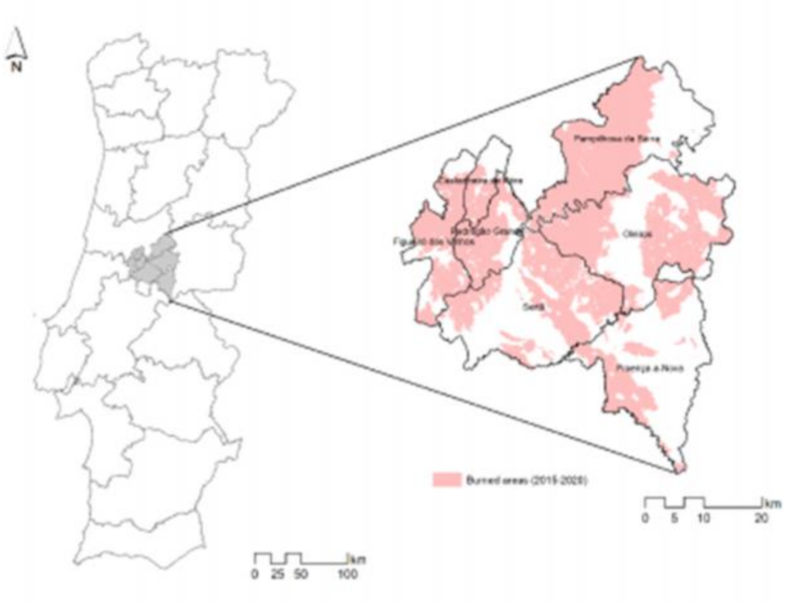


Figure 1. Study area location

The classification of the plant species' suitability resulted from the integration of a set of biophysical criteria based on ecological requirements. Geoprocessing and spatial analysis were performed to geographic data, namely climate (annual mean temperature and annual precipitation), soils (texture, depth, and pH), and altitude. Different references were consulted on the ecological requirements of the species (Ribeiro et al., 2012; Correia & Oliveira, 1999; Correia & Oliveira, 2003).

The different layers corresponding to each criteria were classified in two suitability levels: low to medium suitability (1) and high suitability (2). After creating layers resulting from the reclassification in suitability levels, the general suitability for each species was performed using a multicriteria decision analysis - the Analytic Hierarchy Process - AHP (Saaty, 1987).

The AHP consists of four essential phases: criteria generating and spatial analysis, standardization, and suitability assessment. First, a spatial database was created to include all vector and raster layers and data models. All spatial layers were prepared, and the consistency of coordinates was maintained in ArcGIS 10.8 software. All criteria included in the analysis had to be standardized. Standardization makes all spatial layers constant and in the same measurement units' format (Saaty, 1987). Hence, all vector layers were converted into raster format and the reclassify tool in ArcGIS was used to standardize and assign values for each criterion.

The AHP decomposes a problem, question, or decision, in all the variables that constitute it, in a scheme of criteria and sub-criteria and then makes pairwise comparisons between them (Saaty, 1987).
The pairwise comparison matrix was created using a scale of 1-9 in order to determine the relative importance of each criteria. The matrix format in pairwise comparisons defines A = $[c_{ij}]_{nxn}$ as follows:

$$\begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ c_{1n} & c_{2n} & \cdots & c_{nn} \end{bmatrix}$$

After generating all pairwise comparison matrices, the vector of weights, w $\{w_1, w_2, ..., w_n\}$ is calculated according to Saaty's eigenvector method. This is followed by two steps to calculate weights: First, normalizing the pairwise comparison matrix A = $[c_{ij}]_{nxn}$ based on the following equation:

$$c_{ij} = \frac{c_{ij}}{\sum_{j=1}^{n} c_{ij}}$$

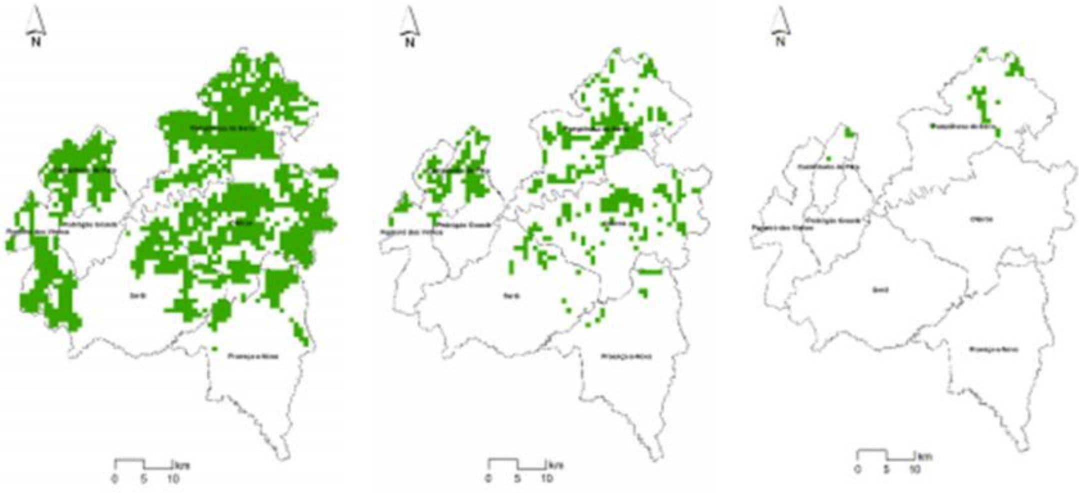
In the pairwise comparison matrix, n refers to the number of elements (Mikhailov, 2003). One of the strengths of the AHP method is measuring the inconsistencies by calculating Consistency Relationship (CR) which is a comparison between the consistency index (CI) and the random consistency (RI) index as follows:

$$CR = \frac{CI}{RI}$$

CR specifies the degree of consistency or inconsistency (Scholl, Manthey, Helm & Steiner, 2005). It denotes the probability that the matrix judgments were made randomly (Saaty, 1987). If the CR value is less than 0.10, the pairwise consistency is fairly acceptable. On the contrary, if the value is higher than 0.10, this indicates inconsistencies in the evaluation and hence the original weights should be recalculated.
In the suitability assessment stage, the weighting linear combination approach is used to produce a composite suitability map. All spatial layers were converted into raster models and the reclassify tool was employed to classify all layers to a standardized measurement suitability scale between 1 and 3, where 1 indicates the least suitable while 3 denotes the most suitable. The weighted overlay technique was performed to combine all weighted spatial layers and produce a suitability map, using the GIS-based AHP extension developed by Marinoni (2004).

RESULTS AND DISCUSSION

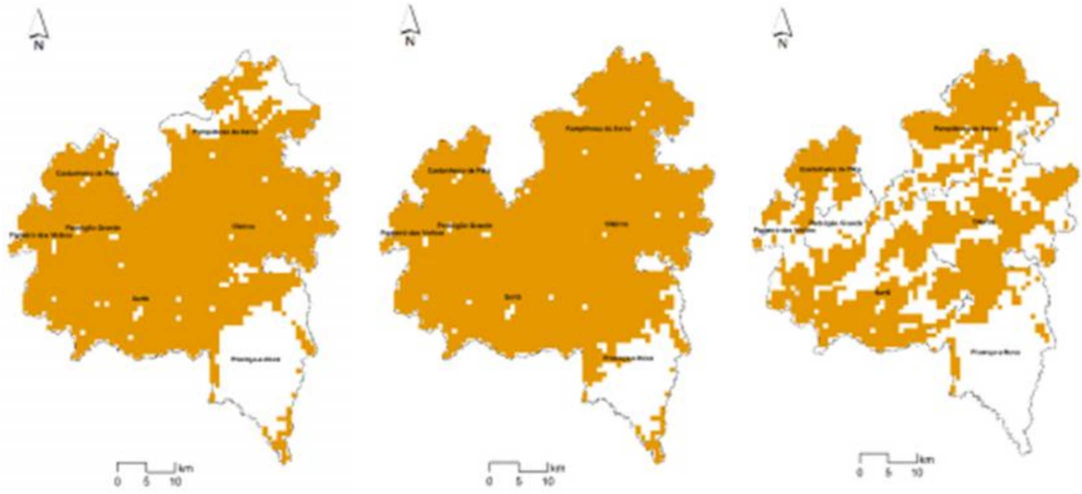
Based on the map analysis (Figure 2), about 861,8 km^2, corresponding to 42.1% of the total area, are classified as highly suitable for common oak in the present situation. For the Intermediate future scenario output (RCP 4.5 - 2070), the total area with high suitability for the common oak decreases to 272.8 km^2 (13.3%) and reduces even more worst-case climate change scenario (RCP 8.5 - 2070) with 24.1 km^2, corresponding to only 1.2% of the total area.



a) b) c)

Figure 2. Common oak highest suitability maps: a) Present; b) RCP 4.5 - 2070; c) RCP 8.5 - 2070.

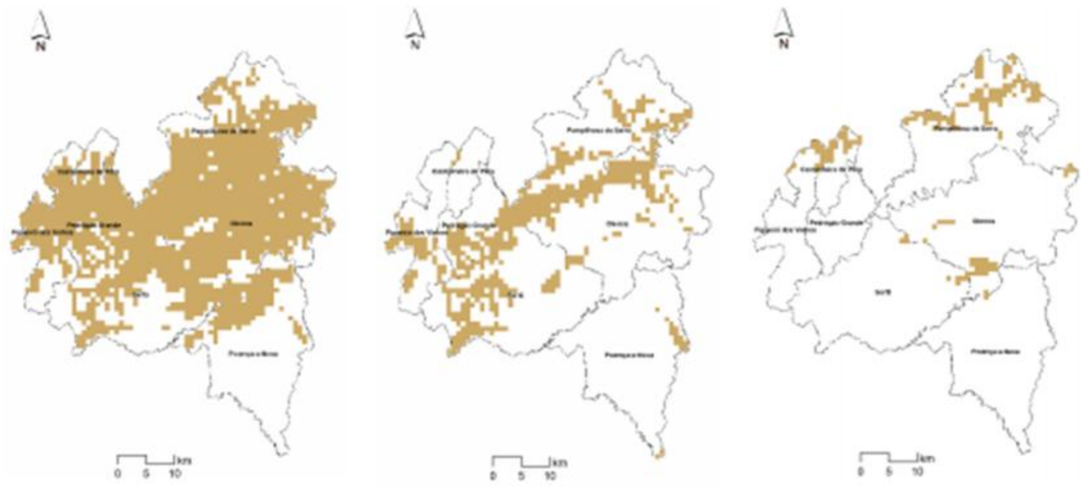
For the cork oak (Figure 3) in the present the study area presents high suitability in 80.1% of the territory (1639.6 km^2). However, for future scenarios there are notable differences, with an increase of highly suitable area for the intermediate scenario (4.5 - 2070), with a total area of 1812.5 km^2 (88.6%), while for the worst-case scenario the potential distribution of the species drops to 1128.4 km^2 (55.2%) and becomes more fragmented.



a) b) c)

Figure 3. Cork oak highest suitability maps: a) Present; b) RCP 4.5 - 2070; c) RCP 8.5 - 2070.

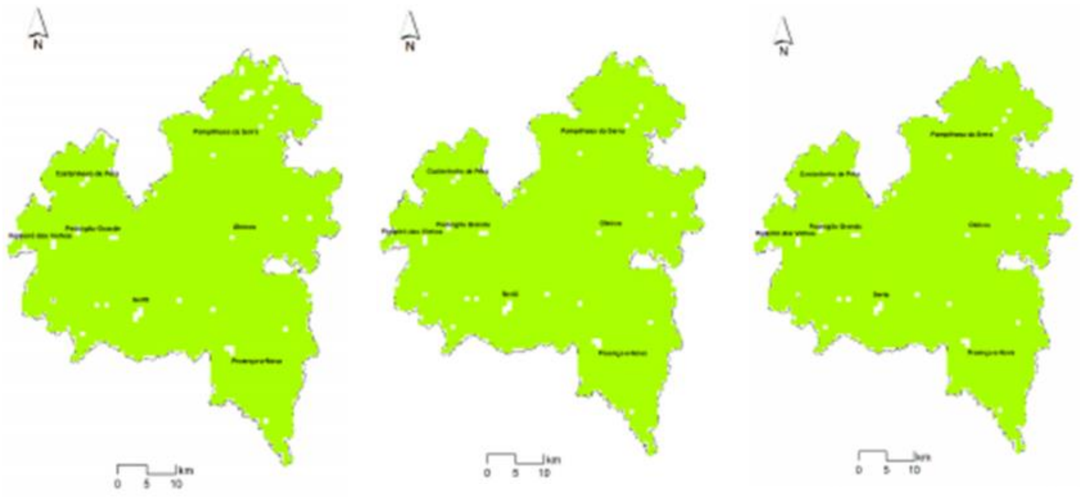
The high suitability area for the sweet chestnut (Figure 4) in the present corresponds to 1235.2 km^2 (60.4%). For both future climate scenarios the potential high suitability area decreases, with 413.3 km^2 (20.2%) for the intermediate scenario, and 124.0 km^2 (6.0%) for the worst-case scenario.



a) b) c)

Figure 4. Sweet chestnut suitability maps: a) Present; b) RCP 4.5 - 2070; c) RCP 8.5 - 2070.

The high suitability distribution for strawberry tree (Figure 5) occupies practically all the available arable land in the study area (2004 km^2; 97.9%), and will practically not change over time, although there will be a slight increase in both future scenarios, with 2018.5 km^2 (98.7%) for the intermediate scenario, and 2021.9 km^2 (98.8%) for the worst-case scenario



a) b) c)

Figure 5. Strawberry tree suitability maps: a) Present; b) RCP 4.5 - 2070; c) RCP 8.5 - 2070.

CONCLUSIONS

The carrying out of the study on suitable forest wooden species which can be exploited within agroforestry systems in a fire-prone region of Portugal as a way to prevent large-scale rural fires and promote a sustainable land use, using GIS and an MCDA technique, allows the following conclusions to be drawn:

- This methodological approach allowed us to assess the suitability of four forest species in a Central region of Portugal. The AHP was based on a set of criteria contributing to a reflection on the adequacy of those species for the climatic, topographic and soil characteristics of the region.
- The main results obtained indicate that the methodology used could provide a guide map for decision makers to achieve a more sustainable use of the territory facing their ecological limitations and considering future climate scenarios.

- It’s important the local authorities that support the farmers create tools to raise awareness and guide them about the global climatic changes and their implications.
- According to the results obtained, that revels that species more adapted to Atlantic conditions like common oak and sweet chestnut will decrease, so it’s urgent to promote species more adapted to future climate conditions. On the other hand, the strawberry tree has high suitability in almost all regions in the present and future scenarios.
- For further study is recommend selecting other native species (e.g., holm oak) more adapted to Mediterranean conditions in order to adapt to the bioclimatic shifts towards higher latitudes and/or altitudes.
- It’s important to privilege diverse landscapes in the studied region characterized by the mosaic of agrosilvopastoral systems serving as an alternative to the current extensive monoculture landscapes of even-aged stands of fast-growing species.

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