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Research article

Fuzzy logic applied to prospecting for areas for installation of wood panel industries

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ABSTRACT

Prospecting for suitable areas for forestry operations, where the objective is a reduction in production and transportation costs, as well as the maximization of profits and available resources, constitutes an optimization problem. However, fuzzy logic is an alternative method for solving this problem. In the context of prospecting for suitable areas for the installation of wood panel industries, we propose applying fuzzy logic analysis for simulating the planting of different species and eucalyptus hybrids in Espírito Santo State, Brazil. The necessary methodological steps for this study are as follows: a) agricli-matological zoning of different species and eucalyptus hybrids; b) the selection of the vector variables; c) the application of the Euclidean distance to the vector variables; d) the application of fuzzy logic to matrix variables of the Euclidean distance; and e) the application of overlap fuzzy logic to locate areas for installation of wood panel industries. Among all the species and hybrids, *Corymbia citriodora* showed the highest percentage values for the combined very good and good classes, with 8.60%, followed by *Eucalyptus grandis* with 8.52%, *Eucalyptus urophylla* with 8.35% and Urograndis with 8.34%. The fuzzy logic analysis afforded flexibility in prospecting for suitable areas for the installation of wood panel industries in the Espírito Santo State can bring great economic and social benefits to the local population with the generation of jobs, income, tax revenues and GDP increase for the State and municipalities involved. The proposed methodology can be adapted to other areas and agricultural crops.

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1. Introduction

Processes involving forestry operations are relatively complex, in particular those involving environmental, economic, and social issues (Diaz-Balteiro and Romero, 2008). The installation of new forestry enterprises requires territorial planning and mapping of the region's resources. Prospecting for suitable areas for forestry operations, where the goal is to reduce production and transportation costs, as well as to maximize profits and available resources, constitutes an optimization problem (Balana et al., 2015; Galik et al., 2012; Lyle et al., 2015; Nilsson, 2009).

Geographic Information Systems (GISs), defined by Burrough and McDonnell (1998) as computational acquisition systems, involving the storage, analysis, and visualization of geographic data, have been shown to be key tools for planning and for obtaining spatial information (Carver, 1991; Eugenio et al., 2011, 2016a, 2016b; Ferrari et al., 2015; Ferrari et al., 2012; Jankowski, 1995; Lorenzon et al., 2017; Luppi et al., 2015; Moreira et al., 2015; Klippel et al., 2015; Pereira and Duckstein, 1993; Peluzio et al., 2013; Pirovani et al., 2014, 2015; Santos et al., 2016a,b,c; Silva et al., 2015). In a GIS, spatial and non-spatial data can be combined in mathematical and statistical models to simulate complex scenarios and facilitate decision making (Nisar Ahamed et al., 2000; Maracchi et al., 2000).

Traditionally, Multi-Criteria Analysis (MCA) is applied for solving spatial problems involving various criteria and local candidates for a particular use (Cortina and Boggia, 2014; Félix et al., 2012; Fisher, 2010; Jiang and Eastman, 2000; Joss et al., 2008; Lewis et al., 2015; Malczewski, 2002; Aghajani Mir et al., 2016; Oldeland et al., 2010; Phillips et al., 2011; Triepke et al., 2008; Tervonen et al., 2015). This technique is based on Boolean logic and the Weighted Linear Combination (WLC) technique (Malczewski, 2002). In Boolean logic, there are only true (1) or false (0) values. True values correspond to suitable areas and false values to unsuitable areas for the objective of the study. WLC already consists of the standardization of continuous values on a numerical scale and a combination of criteria on a weighted average, depending on the weights assigned (Jiang and Eastman, 2000; Saaty, 1980).

Being a binary model, Boolean logic rarely describes natural phenomena faithfully, a map of discrete features being the result of this technique (Jiang and Eastman, 2000). Joss et al. (2008) reported that the method fails when quantitative variables are not available or when modeling involves a large number of qualitative variables. A further problem, related to WLC, is inadequate standardization of data and the difficulty of establishing weights consistent with reality, as these must be defined by a team of specialists on the subject (Jiang and Eastman, 2000; Kangas et al., 2006; Laukkanen et al., 2002).

Fuzzy logic or fuzzy methods constitute an alternative for resolving the problems of MCA (Baja et al., 2015; Collins et al., 2001; Jiang and Eastman, 2000; Kangas et al., 2006; Sicat et al., 2005). Zadeh (1965) developed the theory of fuzzy sets, defining it as a means of expressing subjective information that is uncertain and qualitative, such as that found in nature, in numerical language (Silvert, 2000).

In contrast to binary logic, fuzzy theory is aimed to classify criteria on a scale of 0–1, where values close to 0 represent the "falsity" and values close to 1 indicate the "veracity" of a proposal (Lewis et al., 2015). This logic allows models involving uncertainty near the limit of suitable and unsuitable areas to be more flexible (Jiang and Eastman, 2000; Kangas et al., 2006). The easing of the results can be expressed also by the compensatory effect between the "less acceptable" values of one variable and the "most acceptable" values of another (Malczewski, 2002; Silvert, 2000).

In this process, the parameterization of the criteria is achieved in a complex manner by means of sigmoidal adjustment, both linear and Gaussian, among other techniques, in order to better represent the behavior of the phenomena involved (Jiang and Eastman, 2000). Another advantage of using fuzzy logic is that the opinion of the analyst interferes less, since the weights of the variables are not defined but only their maximum and minimum values for it to be acceptable in a model (Kangas et al., 2006).

Many models based on fuzzy logic have been developed, mainly in the areas of suitability analysis of land use (Collins et al., 2001; Jiang and Eastman, 2000; Joss et al., 2008; Malczewski, 2004), agricultural suitability (Nisar Ahamed et al., 2000), climatic classification (Mcbratney and Moore, 1985), the study of ecological indexes (Silvert, 2000), the evaluation of environmental impacts (Payraudeau and van der Werf, 2005), risk mapping (Chen et al., 2001; Vadrevu et al., 2010; Wang et al., 2011), forestry planning (Boyland et al., 2006; Diaz- Balteiro and Romero, 2008), and urban planning (Chang et al., 2008; Sui, 1992), among others.

According to the Brazilian Association of Forest Plantation Producers (ABRAF, 2013), in 2012, the wood panel industries produced 7.3 million cubic meters of components for the furniture and construction industries. Among the states in Brazil, Espirito Santo State (ES) has the largest amount of planted forests, with 5.6% of the total number of eucalyptus plantations. In this context, for prospecting for areas suitable for the installation of wood panel industries, this study proposes the application of fuzzy logic for simulating the planting of different species and eucalyptus hybrids.

2. Materials and methods

2.1. Physical aspects of the study area

The study area, Espírito Santo State, Southeastern Brazil, has a land area of 46,052.64 km^2 and is located between 17°53′29″ and 21°18′03″ S latitude and 39°41′18″ and 41°52′45″ W longitude. It borders the Atlantic Ocean to the east, Bahia State to the north, Minas Gerais State to the west, and Rio de Janeiro State to the south (Fig. 1). The state has four climate types according to the Köppen classification: Cwb, a subtropical highland climate with dry winters and mild summers found in the state's mountainous region, Cwa, a subtropical climate with dry winters and hot summers found in the state's southwestern region, Am, a humid or sub-humid tropical climate found in the state's northeastern region, and Aw, a tropical climate with dry winters found in the state's western region.

2.2. Methodological steps

The following methodological steps were needed to apply fuzzy logic to simulate the planting of different species and eucalyptus hybrids in Espírito Santo State, Brazil, for the prospecting for suitable areas for installing wood panel industries.

1 Agriclimatological zoning of different species and eucalyptus hybrids.
2 Selection of the vector variables.
3 Application of the Euclidean distance to vector variables.
4 Application of fuzzy logic to matrix variables of Euclidean distance.
5 Overlap fuzzy for prospecting areas for the installation of wood panel industries.