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Definition of priority areas for forest conservation through the ordered weighted averaging method

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ABSTRACT

The general objective of this study was to evaluate the ordered weighted averaging (OWA) method, integrated to a geographic information systems (GIS), in the definition of priority areas for forest conservation in a Brazilian river basin, aiming at to increase the regional biodiversity. We demonstrated how one could obtain a range of alternatives by applying OWA, including the one obtained by the weighted linear combination method and, also the use of the analytic hierarchy process (AHP) to structure the decision problem and to assign the importance to each criterion. The criteria considered important to this study were: proximity to forest patches; proximity among forest patches with larger core area; proximity to surface water; distance from roads; distance from urban areas; and vulnerability to erosion. OWA requires two sets of criteria weights: the weights of relative criterion importance and the order weights. Thus, Participatory Technique was used to define the criteria set and the criterion importance (based in AHP). In order to obtain the second set of weights we considered the influence of each criterion, as well as the importance of each one, on this decision-making process. The sensitivity analysis indicated coherence among the criterion importance weights, the order weights, and the solution. According to this analysis, only the proximity to surface water criterion is not important to identify priority areas for forest conservation. Finally, we can highlight that the OWA method is flexible, easy to be implemented and, mainly, it facilitates a better understanding of the alternative land-use suitability patterns.

1. Introduction

Anthropic forest fragmentation has been one of the main causes of changes in the structure, as well as in the ecological processes, in different types of landscapes. Fragmentation can be described by some of its effects, such as the increase in the isolation of the patches, decrease in their size, and increase in their exposure to external disturbance, such as the invasion by alien species or changes in their physical conditions (Geneletti, 2004a). Those effects can potentially lead to a decline in the ecosystem biodiversity, as well as in its stability and ability to recover from disturbances (Baskent, 1999; Saunders et al., 1991).

The actions of forest conservation must go, therefore, in the opposite direction to the fragmentation (Geneletti, 2004b). Thus, the maintenance and/or the restoration of the biodiversity of affected landscapes will be guaranteed. Mcneely et al. (1990) highlighted that biodiversity involves all species of plants, animals, microorganisms, as well as the ecosystems and processes in which it takes part. An important aspect of conservation planning should be the spatialization of those actions (Phua and Minowa, 2005). In this context, the definition of priority areas represents an effective and economic method. According to Collins et al. (2001), the priority areas analysis aims at identifying the most appropriate spatial pattern for future land uses, according to specific requirements, preferences or predictor factors of some activity or objective.

Multicriteria evaluation (MCE) is one of the decision-making processes employed in the prioritization of areas, and its integration with geographic information systems (GIS) has been considered an important improvement to the conventional map overlay approaches (Malczewski, 1999; Thill, 1999; Eastman, 2001). Such integration (what and where to conserve) has facilitated, according to Kangas et al. (2000) and Vlahos and Herbst (2000), the planning, optimization, and success of forest conservation actions, driving the actions according to their degree of risk, suitability, or priority. The basis to decision making, in MCE, that can be measured and evaluated, is named criterion. It is the evidence upon which an individual can be assigned to a decision set. Criteria can be of two

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kinds: factors and constraints, and can pertain either to attributes of an individual or to an entire decision set (Eastman, 2001). A factor is a criterion that enhances or detracts from the suitability of a specific activity under consideration. The factors used in the decision-making process are those that represent the critical characteristics of a habitat (Randhir et al., 2001). It is, therefore, most commonly measured on a continuous scale, what is an advantage in relation to the representation of the landscape characteristics in specific intervals, what normally leads to the loss of information and error propagation. Constraints impose limitations on the set of decision alternatives (Malczewski, 1999). They serve to exclude areas and to determine space limits to the distribution of the choice possibilities (Eastman, 2001).

In general, decision makers rank a set of decision alternatives and choose the best according to their preferences. To be able to rank, they select the criteria that are relevant to the current problem and that are of significance in their choice (e.g. Bouyssou et al., 2001). To rank the alternatives, each one of them should be evaluated with respect to each criterion. Decision-support methods can be used to analyze the decision situation to help the decision maker to make the best, or at least a satisfactory choice (Kangas and Kangas, 2005).

Malczewski (2006) cited that there are two fundamental classes of MCE methods in GIS environment: the Boolean overlay operations (non-compensatory combination rules) and the weighted linear combination (WLC) methods (compensatory combination rules). The WLC method is more flexible in terms of evaluating management alternatives compared to Boolean operations (Malczewski, 2000). It has been the most often used approach in different applications. Lathrop Jr. and Bognar (1998), Geneletti (2004b) and Phua and Minowa (2005) employed WLC to identify forest conservation priorities. Mendoza and Prabhu (2000) and Gkaraveli et al. (2004) applied the GIS-based WLC method to the determination of priority areas for forest restoration.

The Boolean and WLC approaches can be generalized within the framework of the ordered weighted averaging (OWA) (Malczewski, 1999; Jiang and Eastman, 2000; Malczewski et al., 2003; Malczewski and Rinner, 2005). The OWA is a family of multicriteria aggregation operations (or multicriteria decision rules) and its concept has been developed in the context of fuzzy set theory (Yager, 1988). However, the use of these operations is not limited to fuzzy sets (Malczewski et al., 2003). They involve two sets of weights: the weights of relative criterion importance and the order weights. By specifying an appropriate set of order weights one can generate a wide range of outcome maps (decision strategy) (Malczewski, 2006). Although OWA is a relatively new concept, there have been several applications of this approach in the GIS environment. Malczewski (1999) used the OWA for analyzing land suitable for a housing project in Mexico. Jiang and Eastman (2000) demonstrated the utility of the OWA for land-use suitability problems in Africa. Calijuri et al. (2000) used it in the identification of areas suitable for landfills, in Brazil. Malczewski et al. (2003) successfully tested the OWA concept and implementation as a core of a multicriteria evaluation spatial decision support system to evaluate areas in a Canadian watershed for rehabilitation and enhancement projects. Makropoulos and Butler (2006) suggested that OWA could be useful as a decision-making tool for urban water management in London. Boroushaki and Malczewski (2008) illustrated the application of GIS-based OWA in the identification of the most suitable lands for housing development in a Canadian Province.

According to Eastman and Jiang (1996), the OWA offers a complete spectrum of decision strategies along the primary dimensions of the tradeoff degrees (among criteria) and risk in the decision-making process. Malczewski (2004) mentioned that the method is considered flexible due to its ability in assuming a variety of solutions, ranging from risk-aversion (a location must meet every criterion for being included in the decision set) to risk-taking (a location will be included in the decision set even if only a single criterion passes the test).

In this context, the general objective of this study was to evaluate the ordered weighted averaging (OWA) method, integrated to a GIS, in the definition of priority areas for forest conservation in a Brazilian river basin, aiming at to increase the regional biodiversity. The specific objective was to evaluate the importance and influence of the selected factors on the decision-support process, through a sensitivity analysis.

2. Methodology

2.1. Study area

Corumbataí river basin is located in the Central-Eastern region of the State of São Paulo, Brazil, between the latitudes 22°04′46″ S and 22°41′28″S, and the longitudes 47°26′23″W and 47°56′15″W, with approximately 170,000 ha. Its original forest cover is highly fragmented, due to an unplanned process of land-use and occupation. This basin's landscape represents well the situation of a large portion of the Brazilian territory originally covered by the Atlantic Rainforest (considered one of the world's hotspots), where the natural resources and, consequently, the biodiversity, are seriously affected by anthropic action. This river basin (Fig. 1) is covered by only 11% of native forest (Semideciduous Seasonal Forest) and 1% of Savanna. Pastures and crops are the predominant land-use, with the first covering 44% of the basin and sugarcane covering around 26%.

The forest remnants play a relevant role in nature conservation, considering that conservation actions, at the landscape level, have to guarantee the processes and structure integrity of the anthropic landscapes. Due to the inherent importance of Corumbataí river basin as a representative of the Atlantic Rainforest landscape and the Corumbataí river as an strategic source of fresh water for a large region, there is a concentrated effort from local, state and national government agencies, experts related to universities and research institutes, and NGOs to study the components (e.g. flora and fauna) and processes (e.g. forest connectivity) of that basin and to define actions for its restoration. From 1999 through 2001, a Director Plan for the basin was developed, focusing on the relation between forest cover and water resources. The plan was funded by the Water Department of the Municipality of Piracicaba, the largest city in the Corumbatai River Basin. This study is an evolution of the Director Plan, and can help decision makers (specially government agencies) in the forest restoration of the river basin, including the protection and, overall, the sustainability of quality and quantity of its components and processes.

2.2. Ordered weighted averaging

The ordered weighted averaging (OWA), in a GIS environment (IDRISI Kilimanjaro), was employed in the definition of priority areas for forest conservation. The steps, from the definition of the criteria set important to decision-making process through the criteria aggregation, using GIS-based OWA, will be described in the following items.

2.2.1. Criteria

In the definition of criteria (factors and constraints) and of the criterion importance weights, the Participatory Technique was used, which involved opinions of a group of experts in the various