A FUZZY LOGIC CLASSIFICATION METHOD FOR ZONING CONSERVATION UNITS FORESTS. A CASE STUDY IN SOUTHERN BRAZIL

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This paper presents a decision support system concerning the forests classification for zoning conservation units and other areas of ecological importance in Brazil. The environmental, economic and anthropic criteria were structured in top-down decision tree operated by fuzzy logic, where the output in each node is defined by rule blocks. The primary indicators are estimated by specialists and stakeholders, according to public regulations, each one in its own fuzzy metric. A case study was applied to an ecosystem located in a coastal sandy area belonging to the State of Santa Catarina - Brazil, where a Conservation Unity is to be established. The test confirmed the identification of the “Mata do Ganso” area as a “primitive zone”. The generated model proved to be able to support decision on zoning in the remaining areas and other parks and conservations units.

Palavras-chaves: Decision Support System; Conservation Units; Ecological-Economic Zoning; Fuzzy Logic.
1. Introduction
This paper presents a decision support system concerning the classification for forest zoning in Conservation Units in Southern Brazil. The environmental, social use and economic criteria are integrated in the same analysis by a decision-tree, operated by fuzzy logic. A model was generated to verify the hypothesis that a particular forest area in Santa Catarina State – Southern Brazil (Parque do Rio Vermelho – Florianopolis, SC) could be characterized as a “primitive zone” according to the zoning definitions of the Brazilian legislation for these Conservation Units.

The method represents the main indicators in a “top-down tree” graph, and operates the integration of the indicators by membership functions and rule blocks, in the fuzzy logic format of “if, and, then” (soft decision tree).

The decision graph is designed by a committee with the support of a facilitator. Firstly, it is defined the question whose answer aims at the final decision on the acceptance of the hypothesis. The tree is developed until its indicators can be used as direct assessment tools. The direct indicators are assessed by specialists or defined according to the judgment of stakeholders.

The direct environmental indicators were defined by a resolution of Brazilian Institute for Environment – IBAMA (2002) and surveyed for field analysis. The restinga (coastal sandbank ecosystem) studied area, named Parque do Rio Vermelho, is located in the east side of Santa Catarina Island – Southern Brazil. The work hypothesis is to identify “Mata do Ganso” (Goose Woods) area as a “primitive zone” category.

Most of Brazilian Conservation Units (CUs) doesn’t dispose of regulatory and management instruments. The existing regulations and zoning definitions were conceived in the seventies, considering only the environmental criteria, unaware of the economic sustainability planning, or the social use of the ecosystem.

2. Method
2.1 The Method for Category Identification
The current multicriteria methods to support decision in forest classification are not devoid of logical and operational problems, such as: the use of data bases with different assessing systems; the strong dependency among variables, and the use of crisp data instead of fuzzy field information. The best results are obtained from stochastic programming, like the “chance constrained programming” and “goal programming” type, even though this type of modeling presents the formulation of problems with incomplete information.

Some of the methods currently used to support decision are based on combinations of two-by-two variables, ordering the best results according to the criteria defined by the stakeholders. The most used methods are the “analytical hierarchy process” family, such as “AHP” and “Expert Choice”, as Silveira et al (2008) used. The hierarchical results represent a synthesis of stakeholders’ priorities according to the criteria they have defined and are restricted to conditions of independency of the variables. The “PROMETHEE” and “ELECTRE” families also present the same problems.
There is a large use of fuzzy logic in environmental area is to classify satellite sensor imagery, that obtain better and more accurate results then hard classification, as Berberoğlu (2008) points out. Monteiro et al (2007) used the fuzzy logic with success to remote detect the selective logging in the Brazilian Amazon.

The use of fuzzy logic for decision support in forest classifications is also a growing approach. Anderle et al (1994) al developed a fuzzy multiple objective programming techniques in modeling forest planning, pointing that instead of exact coefficients we have to deal with their approximations (fuzzy numbers) in the modeling phase. They demonstrate the applicability of fuzzy multiple objective programming techniques for resource allocation problems in forest planning. Reynolds (2001) designed a knowledge base of criteria and indicators for evaluating forest ecosystem sustainability with fuzzy membership functions. Nadeau et al (2002) presented a computerized plant community classification with an application of fuzzy logic, using fuzzyTech® software to classify a forest portion, incorporating expert’s knowledge of ecosystem.

Stoms et al (2002) used the fuzzy assessment to verify land suitability for scientific research reserves, characterizing imprecise suitability criteria and for combining criteria into an overall suitability rating. It was used the Ecosystem Management Decision Support (EMDS) software combined a fuzzy logic knowledge base to represent the assessment problem with a GIS database providing site-specific data for the assessment. Franklin et al (2003) refers to problems in forests classification and definition procedure to map forest attributes, noting that a challenge remains to develop methods for using fuzzy information in forest resource management and landscape planning.

This present method is an alternative way of dealing with the strong dependency among variables and the incomplete information of environments. The nodes in the decision graph integrate variables by fuzzy logic system. The decision tree is deployed top-down, as presented by Ming and Kothari (2001) and Olaru and Wehenkel (2003), defining the membership functions for the indicators in terms of linguistic variables. The rules that define the relative influence of the indicators are established according to fuzzy logic, as suggested by Prabhu and Mendoza (2004). Each thematic indicator in the graph node (the first node is always a systemic indicator) is obtained from the logical operation of their component variables. The main question to be answered by the systemic indicator is deployed until it is possible to assess direct indicators for the environment. Each variable is an indicator that represents a condition of its aspect in its own metric scale. The membership functions and the relative influence among indicators are established by specialists and stakeholders.

The decision graph. The main question in this case is the possibility to identify the ecosystem as a “primitive” category. Definition of direct and thematic indicators and the systemic indicator. The assessment of direct indicators is estimated in a fuzzy format, giving flexibility to the specialists’ team and stakeholders to express their opinion and technical evaluations as a composition of results, where discreet data are not usually the best representation of reality, and the work with insufficient information. The data input is carried out by spreadsheet as it is shown in Figure 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Input term value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water.Bad</td>
<td>0.0000</td>
</tr>
</tbody>
</table>
Figure 1. Partial example of a spreadsheet for the assessment of direct indicators

The outputs of thematic and systemic indicators are represented by crisp defuzified data for partial analysis, and fuzzy results that are the input for rule blocks. The defuzification method adopted is the “center of maximum”. This choice facilitates stakeholders’ interpretations and analyses. Figure 2 displays an example of a graph showing membership functions and defuzification of a thematic indicator.

Figure 2. Membership functions (MBFs) and results of the “Biotic Fragility” defuzification

The defuzifications carried out by the “center of maximum” method use symmetric Z membership functions with scales varying from 0.125 to 0.875.

2.2 The Rule Blocks for Thematic and Systemic Indicator

A rule block is a set of all possible rules combining input variables (if) to generate outputs (then), as shown in Figure 3.

Figure 3. Example of the influence of an input variable on an output variable
The rule blocks are of “if and then” type, expressing only the minimum condition of the “and” restriction for input integrations. This condition defines intersection between sets. The influence of each input variable on the output variable is initially established by the facilitator and re-assessed by the stakeholders. Figure 4 shows a partial example of a rule block for the ‘Balance Block’.

<table>
<thead>
<tr>
<th>IF</th>
<th>THEN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
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</tbody>
</table>

Each primary indicator is graded by possible state or condition (e.g. bad, average, and good). The state assessment of each input variable was ordered on a zero to one scale.

2.3 The case study: Identification test of the area as “primitive zone” category.
The Brazilian Institute for Environment - IBAMA has a Planning Method Guideline for Conservation Units (IBAMA, 2002) which lists criteria and indicators for environmental zoning. The guideline, however, does not indicate how to combine environmental criteria or how to integrate these criteria with the pressure that human society makes on these resources, not even how to define the level of influence that each element has on the others. This guideline, based on Decree no. 84.017/79 of September 21, 1979, article 7, defines a Primitive Zone as follows:

“II – Primitive Zone. It is that area where a small or minimum human intervention has occurred, containing species of the flora and fauna or natural phenomena of great scientific value. It must have transitional characteristics between the Intangible Zone and the Extensive Use Zone. The general handling objective is the preservation of the natural environment and, at the same time, it aims to facilitate scientific research activities and environmental education. On account of “education for preservation”, primitive forms of recreation can be allowed.”

In order to test the proposed method, a model was devised to verify the hypothesis that the ecosystem in question fits into this category.

3. Materials. The Rio Vermelho Park
Despite the great number of Conservation Units that Brazil currently has, most of them have deficiencies in terms of their regulatory instruments, domain of the areas, and even in relation to the territory boundary. These deficiencies must be seriously taken into consideration since they are essential for a good management of natural resources and its surrounding environment and for planning the use of these areas by the population.
Nowadays, there is a proposal to transform the “Parque do Rio Vermelho” into a conservation unit. This coastal sandbank area has tourist potential and it is used for leisure activities. Moreover, it has environmental importance for the region because of its location, size, dune ecosystems, sandbanks, lagoon, and ombrofila forest. Despite its great significance and total area of 1,465 hectares, this ecosystem does not have specific instruments for environmental planning and management.

These sandbanks are the habitat for a highly diversified flora and fauna, and some of these species are rare and endemic. Tourism is the main current activity in the park, with low quality alternatives for leisure, recreation, camping and other activities that allow direct contact with nature.

The forest area of the study is located within the limits of Parque do Rio Vermelho, between the coordinates S 27° 32’52.0” and W 48° 26’11.0”. This region is known as Mata do Ganso [Goose Woods]. This name is due to the fact that the region is used by various migrating and resident species of birds as a place for resting, shelter, feeding, and nestling. The area consists of a sandbank region in a good state of conservation, presenting exuberant vegetation with a great diversity of trees, shrubs and herbaceous species, and a relative amount of epiphytes and lianas. The interior of the woods has a well-defined structure with an always-present shrub-herbaceous stratum, including young tree species that are between two and three meters tall.

3.1 The top-down decision tree

The presented top-down decision tree was produced in a strategic planning workshop, that counted with administrators and employees of the park, researchers from the local university and representatives from the regional community. The aim of the workshop was to generate an orientation plan to be submitted to the province govern. The used method was the SWOT analyses (Strengths, Weaknesses, Opportunities and Threats). The definitions of witch variables would compose the tree and with witch weigh, was a matter of agreements. The main idea that oriented the workgroup was that the tree graph must devise fidelity representation and robustness. The robustness refers to the possibility of widening the scope of the model use to studies with other zone identification categories, different ecosystems and conservation units.

The decision tree is displayed in Figure 5.
3.2 The membership functions and rule blocks
The membership functions (MBFs) of the fuzzy variables were all defined as triangular and symmetric and with three terms. These definitions allow non-specialists in fuzzy logic to understand and operate the system to assess values and weights, as shown in Figure 6.

Figure 6. Membership functions example ob biotic fragility

The primary indicators were surveyed by the authors.
3.3 Systemic indicator and thematic indicators used in this study

The systemic indicator is the main answer of the model. The thematic indicators were deployed from the systemic indicator, until the indicator becomes a matter of direct survey. The selected thematic indicators are, in level of importance: anthropization balance, environmental cultural relevance, support capacity, environmental potentiality, physical relevance, ecological relevance, environmental fragility, environmental singularity, physical fragility and biotic fragility.

Anthropization balance is the combination between social and economic pressures on the ecosystem and its existing potentials.

Environmental cultural relevance refers to the relevance of environment aspects such as: rare species or the ones threatened with extinction; endemic species; natural well preserved areas; reproduction areas; historical and cultural patrimony; archaeological and architectural aspects. Thus, the deployed indicators show cultural, physical significance and ecological relevance.

Supporting capacity means the capacity shown by the ecosystem to support a level of activities with the minimum of negative effects on the environmental resources, promoting the maximum of satisfaction for the users (visitors, researchers and staff members). The ecosystem can be classified according to its big, medium or small supporting capacity, taking into account the state of fragility, risks and vulnerability, potentialities and environmental management.

Environmental potentiality means any services or resources of the ecosystem that can directly benefit the human population. Among these services we can mention: the waste reception; carbon dioxide capture; biological, geological and chemical cycles; recreation and leisure.

Examples of potential environmental resources are: lumber; pharmaceutical products; resins and raw material from other restinga specialized plants.

Physical relevance refers to the geomorphology, geology and the physical functionality of the ecosystem. Aspects such as: landscape; soil; aquifer recharge; rivers and ponds; sandbanks; cuestas or any other natural elements which make a certain area become a unique landscape.

Ecological relevance can be measured through the successional state and the environmental singularity, and can be classified as: prominent and non-prominent.

Environmental fragility assesses the sensitivity of the ecosystem to adverse environmental impacts. It’s also concerned to its resilience. The criteria for environmental fragility evaluation are: biotic fragility, regarding the state of the flora and of the fauna; and physical fragility, regarding the subterranean water, superficial water and soil.

Environmental singularity refers to the ecosystem prominent characteristic that makes it extraordinary, unique. The indicative characteristics of singular environments are: high biological diversity indices; species threatened with extinction, rare or endemic areas and important areas for reproduction, feeding and nestling.

Physical fragility refers to the sensitivity of the soil and water resources both subterranean and superficial.

Biotic fragility refers to the sensitivity of the organic elements to natural or human threat. It can be assessed by the loss of the local flora and fauna diversity and by the imbalance in the ecological system.

3.4 Primary direct indicators
The direct indicators are: environmental resources; environmental services; socio-economic pressure; cultural relevance; geomorphology and landscape; physical functionality; biological diversity; ecological significance; sucessional state; environmental vulnerability; soil vulnerability; water vulnerability; environmental handling; fauna and flora. They can be described as follows:

Environmental resources refer to the materials that can be directly consumed by man or used as a productive system.

Environmental services are the ecosystem functions that indirectly help to keep human life stable and healthy, such as carbon capture and storage, control of water pollution and recreation.

Socio-economic pressure refers to the human demand for environment services and resources. Cultural relevance refers to the existence of archaeological sites, historical architecture and the local culture that passes on how to use the flora and fauna as the basic resources for popular remedies, food and religion.

Geomorphology and landscape can be assessed by analyzing these aspects: ancient landscape and its natural processes; the origin, nature and structure of the rocks; the climate; other forcing functions as the salt marshes.

Physical functionality refers to functions like underground water recharge, natural processes of ponds, rivers, natural barriers to wind and to the sea, thermal regulations and landscape conformations.

Biological diversity, fauna and flora can be evaluated by statistical indices of diversity, considering not only the taxonomic categories but also the species with relative importance to a particular ecosystem.

Ecological significance refers to the existence of endangered, rare, endemic species, sites for reproduction or any other significant characteristics of the ecosystem.

Succession state can be surveyed by analyzing the species, individual measurement and other indicators.

Environmental handling refers to the human activities which have been developed to protect the conservation areas.

Soil vulnerability is the relation between the threat and the possible damage to the soil.

Water vulnerability is the relation between the threat and the possible damage to the water resources.

Environmental vulnerability is the relation between the threat and the possible damage to life in the ecosystem.

4. Results

4.1 Results obtained from the systemic indicator and the thematic indicators

The following table indicates the criteria used in this study, the composition of each indicator and the results obtained in the Mata do Ganso study. All the variables were defuzzified by the “Center of Maximum” method.

<table>
<thead>
<tr>
<th>Thematic indicators</th>
<th>Direct indicators</th>
<th>Values</th>
<th>Results</th>
</tr>
</thead>
</table>
### Values

L= low; M= medium; H= high

### 4.2 Systemic indicator to classify the area as belonging to a Primitive zone

The final result of the analysis of this ecosystem indicates that it can be considered as an area belonging to a primitive zone. It was obtained by the integration of informations found in indicators of supporting capacity, anthropic balance, and environmental/cultural relevance. The percentage result obtained from the defuzzified analysis is 64.28%. This means that the area investigated can be classified as a primitive zone according to the characteristics determined by Brazilian National System of Nature Conservation Units – SNUC (2000), but there is little possibility to have any other identities.

### 5. DISCUSSION

Decisions about the identification of ecosystems, and their classification according to the laws, have serious implications on restrictions and licensing of uses of the environment. This work was originally developed for the generation of a decision support method to the Brazilian National Council on the Environment – CONAMA, which establishes standards, criteria and standards for the control and maintenance of quality of the environment in Brazil. The rules, however, do not bring clear definitions on what criteria must be met, to what degree and how should be the aggregation of indicators.

The academic studies on the aggregation of indicators for identification of ecosystems have a history of use of multicriteria methods with difficult understanding by stakeholders and methodological limitations, as pointed out earlier in this paper.

The environmental licensing in Brazil is carried out by unconnected and encyclopedic projects, with detailed particular studies and without integrating conclusions (Boclin, 2006).

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Description</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Defuzzified Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotic fragility</td>
<td>Fauna state</td>
<td>L=0,1; M=0,3; H=0,7</td>
<td>68.29%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flora state</td>
<td>L=0,2; M=0,4; H=0,6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical fragility</td>
<td>Water</td>
<td>L=0,0; M=0,1; H=0,9</td>
<td>95.45%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil</td>
<td>L=0,0; M=0,1; H=1,0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Singularity</td>
<td>Diversity</td>
<td>L=0,3; M=0,5; H=0,8</td>
<td>86.36%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Significance</td>
<td>L=0,0; M=0,0; H=1,0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potentiality</td>
<td>Resources</td>
<td>L=0,9; M=0,2; H=0,0</td>
<td>26.92%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Services</td>
<td>L=0,3; M=0,8; H=0,3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical relevance</td>
<td>Physical functionality</td>
<td>L=0,0; M=0,4; H=1,0</td>
<td>91.67%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Geomorphologic conditions</td>
<td>L=0,0; M=0,2; H=1,0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental fragility</td>
<td>Biotic fragility</td>
<td>Thematic indicator</td>
<td>77.79%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Physical fragility</td>
<td>Thematic indicator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support capacity</td>
<td>Handling</td>
<td>L=1,0; M=0,0; H=0,0</td>
<td>16.67%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vulnerability</td>
<td>L=0,9; M=0,2; H=0,0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anthropization balance</td>
<td>Anthropic pressure</td>
<td>L=0,7; M=0,4; H=0,2</td>
<td>46.43%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Environmental potentiality</td>
<td>Thematic indicator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecological relevance</td>
<td>Successional state</td>
<td>L=0,0; M=0,4; H=0,6</td>
<td>74.39%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Environmental singularity</td>
<td>Thematic indicator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultural and environmental relev.</td>
<td>Cultural relevance</td>
<td>L=0,0; M=0,0; H=1,0</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Environmental relevance</td>
<td>Thematic indicator</td>
<td>64.28%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Membership to the Primitive Zone
Conflicts and disputes derived from government decisions delay projects, or are settled in long litigation. Disputes are usually on the aggregation of variables; with petitions argue that the projects partially meet the legal criteria.

This work proposal aggregates indicators, integrating the partial results in the form of a tree, reflecting the various interpretations of experts and stakeholders with a proposal for a general understanding for what the ecosystem can be classified.

The study results show that the "Mata do Ganso" can be classified as a primitive zone in accordance with the definition of the working group set up, and to which indicators are used, with the weights and the aggregation methodology defined for the case. There is a possibility that the ecosystem is not classified as primitive, but with little value.

6. CONCLUSIONS

The presented method was intended to be a contribution to both the transparency and the enlargement of participation in decisions on zoning in conservation units. It was applied and tested in a restinga area that belongs to the State of Santa Catarina – Brazil, where the area of a new environmental park is to be established.

Also, the hypothesis that the ecosystem known as “Mata do Ganso” would fit into the category of “primitive zone” was confirmed.

Moreover, this study can be regarded as a model for further zoning tasks in this conservation unit and, also, it be adopted in other places as an aid to the planning of conservation units (CUs), to handling management and to other areas of relevant ecological interest.

By this method, we intend to provide society, CUs managers, and researchers, with another effective tool for the environmental analysis and as support for zoning decisions.

REFERENCES


