Spatial uncertainty analysis of GIS-based multicriteria weights of factors that influence in landscape connectivity

Rodrigo Pinheiro Ribas[1]

[1]Departamento de Geografia – Universidade do Estado de Santa Catarina (UDESC)
CEP – 88.035-001 – Florianópolis – SC – Brazil

rodrigo.ribas@udesc.br

Abstract. *Methodologies that assist in identifying locations suited to connectivity are of great worth for a more effective management of areas in need of protection, mainly in very large areas with regional scope. This study was developed in a mosaic of protected areas of approximately 1.9 million hectares, encompassing 19 protected areas within its boundaries. A Multicriteria Analysis procedure for investigation of relationships among selected variables was applied. To analyze the robustness of the result, a spatial uncertainty analysis using the Monte Carlo method was performed. This investigation allowed the identification of five areas with the ability to serve as connectors between habitats in the landscape.*

Resumo. *Metodologias que auxiliam na identificação de locais adequados à conectividade são de grande valia para um gerenciamento mais efetivo das áreas que necessitam de proteção, principalmente em áreas muito extensas com abrangência regional. Este estudo foi desenvolvido em um mosaico de áreas protegidas de aproximadamente 1,9 milhão de hectares, abrangendo 19 áreas protegidas dentro de seus limites. Um procedimento de análise multicritério para investigação das relações entre as variáveis selecionadas foi aplicado. Para analisar a robustez do resultado, foi realizada uma análise de incerteza espacial usando o método de Monte Carlo. Esta investigação permitiu a identificação de cinco áreas com a capacidade de servir de conectores entre habitats na paisagem.*

1. Introduction

Preservation of natural areas is the most primary form of biological diversity conservation. There are throughout the planet areas set aside for preservation due to their singularity, beauty, threat level, among other parameters that characterize the need for effective management and sustainable handling of the natural resources in them. According to IUCN (1994), a protected area is characterized as a land or sea area especially dedicated to protecting and maintaining their associated biological and cultural diversity. They are managed through legal instruments. Often, these protected areas are created or may become isolated fragments in areas that have already succumbed to anthropic pressure. In a more realistic scenario, biodiversity preservation's success hinges on biotas' survival capacity in landscapes fragmented by human intervention (Bennett 2003). According to Noss and Csuti (1997), efficient planning models that try to conciliate human occupation and continuity of natural communities should be elaborated for areas in advanced stages of fragmentation.

In spite of there being different types and categories of protected areas throughout the planet, oftentimes, the setup of these areas is not accompanied by an effective management process. Therefore, there is the need to use updated planning concepts or even a radical shift in understanding biological diversity conservation. Presently, there is a tendency that protected areas' planning and management be coordinated and integrated and not individual. Long-term success in protected areas must be seen in light of the search for more sustainable development standards (Davey et al 1998). Management of protected areas in an isolated manner is not enough for conservation, being a policy for the management of a mosaic of protected areas necessary since these areas are strongly influenced by the surrounding matrix (Metzger 2000). Understanding consequences of changes in habitats and developing effective strategies for biodiversity maintenance in modified landscapes is one of the greatest challenges for scientists and environmental managers nowadays.

Landscape connectivity is made evident from the spatial arrangement of habitat fragments (Forman and Baudry 1984). In this way, it demonstrates landscapes' capacity to make biological flows and the intensity of organisms' movements among habitats easier. Lang and Blaschke (2009) affirm that a landscape's structural characteristics are observable, describable and quantifiable and also indicative of processes that contributed to how the landscape is. Structural analysis of a landscape relates to the study of the landscape mosaic that appears as a pattern and specific spatial ordering of landscape units in a determined research section. Generally, evaluating landscape connectivity consists of identifying and characterizing aspects that make connection between the different elements in the landscape easier or more difficult. Increasingly, this kind of analysis has been used in environmental planning and implementation of biodiversity conservation policies.

Spatiality in an inherent environmental systems' characteristic and, thus, spatial analysis methods can provide great effectiveness in the search for knowledge and solutions (McHarg 1969). Methodologies that mix Geographic Information Systems (GIS) applications to Multicriteria Decision Analysis (MCDA) techniques have vast applicability in environmental planning. Their integration tends to evolve in the sense of providing users methods for evaluating different alternatives based on multiple criteria and thus observing conflicts that go between objectives (Carver 1991). GIS based-MCDA methodologies aggregate GIS capacity to treat spatial relationships among geographic objects and provide a spatial analysis and visualization on this information due to the great capacity and quantity of techniques directed at decision structuring supplied by MCDA. Application of these methodologies has been very effective in various research areas (Malczewski 2006) and i can find some published results in studies concentrated on landscape connectivity analysis in the literature (Store and Kangas 2001; Marulli and Mallarach 2004; Ferretti and Pomarico 2013). A methodological process known as Sensitivity Analysis (SA) has been researched aiming to quantify uncertainty inherent to the GIS based – MCDA process (Ligmann-Zielinska and Jankowski 2008; Ligmann-Zielinska et al. 2012). This uncertainty may come from inconsistencies in the data used for analysis, incoherencies in evaluating environmental aspects and others. According to Ligmann-Zielinska et al. (2012), GIS based – MCDA models should be carefully evaluated to assure robustness under a wide range of possible conditions and this robustness is defined as the model's minimum response to changes in input values.

In this article, focus will be evaluation of the spatial arrangement of habitat fragments. Therefore, the goal is investigating the landscape structural connectivity in the study area. Striving to reach the objective a GIS based-MCDA methodology will be used to analyze and combine criteria that influence connectivity in the landscape. A Sensitivity Analysis will be applied to estimate robustness of the results reached in this analysis. The area under analysis is the Mosaic of Protected Areas of the "Espinhaço Alto Jequitinhonha - Serra do Cabral", located in the southern portion of the mountain range called "Serra do Espinhaço". It is considered a heritage site by UNESCO called the "Serra do Espinhaço Biosphere Reserve". This mosaic of protected areas was instituted in 2010. It has approximately 1,900,000 hectares and encompasses 19 protected areas within its limits.

2. Spatial uncertainty analysis

The purpose of uncertainty analysis is description and quantification of the risk in a determined chosen decision option (Chen et al. 2011). Simply stated, i can say that the goal of this analysis is to estimate robustness of the results in a multicriteria analysis through observation and control of the effects that changes made to criteria weight can generate in the final decision. In this way, it is possible to estimate the degree of influence of each criterion inserted into a determined analysis, enriching analysis of the investigated environment.

One of the most used methods that provide best results for uncertainty evaluation in decision models is Sensitivity Analysis. There are diverse Sensitivity Analysis methods. Saltelli et al (1999) group these methods in three classes: (1) selection methods in situations in which there are input parameters in great numbers, but only some have a significant effect on output responses; (2) local methods, when analysis focuses on local factors, and (3) global methods, used for analyzing various parameters simultaneously.

Using global sensitivity analysis techniques is indicated when input variables can be affected by uncertainties of different scopes (Saltelli et al. 1999). To evaluate uncertainty impact on weight given to criteria, a global sensitivity analysis that is commonly used in environmental analyses and offers good results is the Monte Carlo Analysis (Zhou et al. 2003; Jeanneret et al. 2003; Carmel et al. 2009; Ligmann-Zielinska and Jankowiski, 2014; Braulio et al. 2014).

According to Vose (2000), the Monte Carlo method randomly selects values according to a defined probability distribution. The Monte Carlo simulation produces intervals with possible results' values distribution. Dealing with these possible distributions of occurrence probabilities of a certain phenomenon, the process's inherent uncertainty tends to more precisely described. In this way, it is understood that the Monte Carlo simulation is a sampling process in which it is interesting to observe the behavior of a variable due to other variables' performance leading to uncertainties. According to Moura et al (2014), uncertainty analysis presents the degree of certainty and uncertainty that exist in a multicriteria analysis and thus inserts greater robustness in multicriteria-based analyses.

3. GIS based-MCDA

3.1. Creating map layers

In this decision problem structuring phase, groups and their constituent factors that will influence the decision were identified. Selected criteria were split into three (3) groups.

They were a biotic factors group, another with physical environment components, and, finally, a group with criteria related to anthropic pressures. A GIS application is used for producing, analyzing and combining spatial data. Criteria utilized in this study present in (Table 1) were selected based on studies by the main author of this text as well as by indications given by a multidisciplinary group of specialists.

Table 1. Database of criteria

Group	Criteria	Format	Source
Physical	Distance to surface water	Vector	Minas Gerais State Institute of Water Management (*IGAM*)
Biotic	Distance to CU's of full protection	Vector	State Institute of Forests (*IEF*)
Biotic	Distance to CU's of sustainable use	Vector	Thematic Mapper (Ribas, R.P et al. 2014)
Biotic	Distance to forest patches with larger core areas	Vector	Thematic Mapper (Ribas, R.P et al. 2014)
Anthropic	Distance to roads	Vector	Brazilian Institute of Geography and Statistics (*IBGE*)
Anthropic	Distance to urban areas	Vector	Thematic Mapper (Ribas, R.P et al. 2014)
Physical	Slope	Raster	United States Geological Survey (USGS)

According to Moura et al (2014), spatial data can be organized in layers that represent a phenomenon's potential distribution surface or spatial occurrence. To create this potential surface, the first step is data reclassification to create a matrix indicating the theme's presence or absence, defining a common pixel size for all to be created layers. In this study, a 30 meter spatial resolution pixel was used owing to the analyzed area's great extension and the great computational power needed. In a second moment, contact edges among different classes were softened and thus neighborhood influence on transition areas was considered Kernel Density and Focal Statistics were used in this operation.

3.2. Standardization and weighing of criteria

In the data normalization process, each criterion's original value (expressed in its own measurement unit) is converted into a uniform measuring interval. This process permits non-comparable between each other criteria values be normalized into the same scale and makes aggregation between them viable.

Most normalization processes use maximum and minimum values for scale definition. In this study, normalization was done via a linear function since it assumes a linear impact relationship in the value scale attributed to criteria. This normalization method offers the advantage of keeping a ratio relationship between original and normalized values.

The variation interval for criteria values' variation was defined in a 0 to 1 scale. To normalize data it is also necessary to define variables' cost or benefit values. Benefit values occur when the variables' higher values are the more positive and, in return, cost values occur when the variables' lower values are the more positive. Within the criteria used in this study (Figure 1), only the distance between highways and urban areas were defined as Cost.

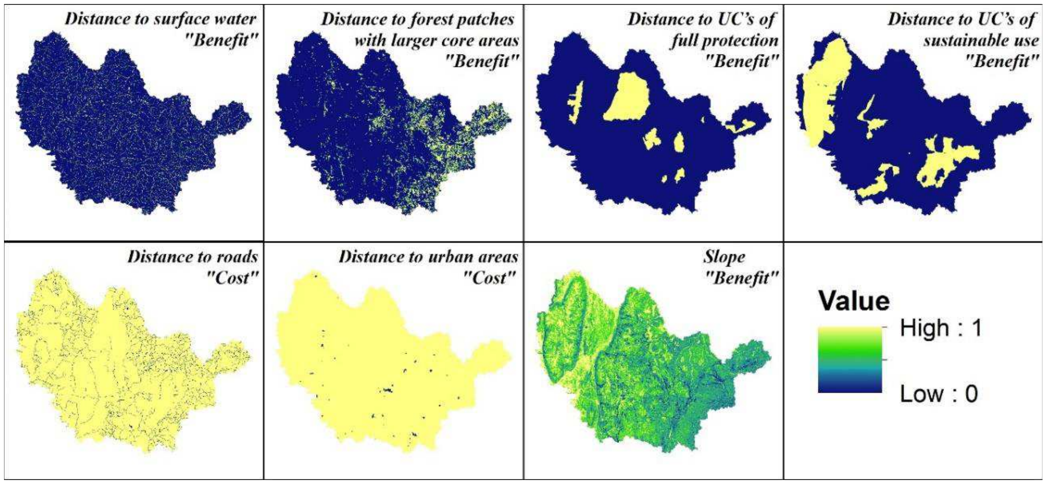

Figure 1. Standardization of criteria

Weighing of Criteria is a procedure that can be reached through the knowledge level of specialists in a determined area or concept or can be derived by approximation using statistical methods. The Delphi method was applied to define weight given to criteria that will be used in the decision process. According to Bonham-Carter (1994), this way of defining weights is called knowledge-driven evaluation. The Delphi method had great repercussion in the beginning of the 60s based on the work developed by Norman Dalker and Olaf Helmer (Estes and Kuespert, 1976). According to Moura (2007), Delphi method application for weight obtainment is based on forming a multidisciplinary group of specialists that know the phenomenon well and the spatial reality where it is located.

Formation of a multidisciplinary group of 15 specialists to apply a questionnaire related to the objective was the procedure adopted. The mentioned group was made up by conservation units in the mosaic region's managers, researchers whose line of research involves biodiversity in the focused region, spatial analysis specialists in multicriteria methods and researchers focused on geomorphologic studies. Members received an on-line questionnaire containing a summary of the project, its objectives and questions about criteria and their importance to connectivity in the landscape. According to the Delphi methodology, the group of specialists remained anonymous so that answers were not influenced by other members.

3.3. Mapping the suitability for the connectivity

To generate a sustainability map of connectivity, a multicriteria evaluation using the "Multicriteria Evaluation for Discrete Set of Options" toolbox of Professor Piotr Jankowski of San Diego State University (Ligmann-Zielinska and Jankowiski 2012; Ligmann-Zielinska et al. 2012) was carried out. The Weighted Sum for Feature Class tool carries out a multicriteria evaluation through points' vector archives.

Observing this characteristic of the tool, a vector points grid was created with the same dimensions of columns and lines of normalized layers in raster format. Thus, value extraction for each raster layer pixel for vector points was done. Weight used (Table 2) for each criterion in the present multicriteria evaluation corresponds to the average (AW) extracted from the ponderings of the 15 interviewed specialists. The result of the multicriteria evaluation provided by the Multicriteria Evaluation for Discrete Set of Options tool in a vector archive was converted into raster and permits creation of a connectivity sustainability map (Figure 2).

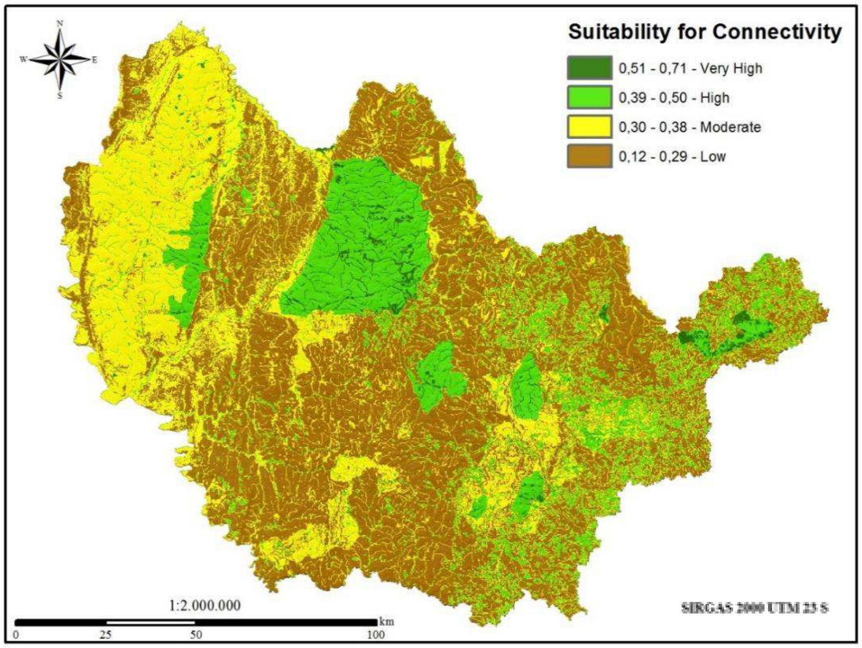

Figure 2. Map of the suitability for the connectivity

4. Spatial Uncertainty and Sensitivity Analysis

For analysis of the uncertainties inherent to a multicriteria evaluation procedure and a reading of the robustness of the evaluation model in case of changes in variables combination, the Multicriteria Evaluation for Discrete Set of Options toolbox of Professor Piotr Jankowski of San Diego State University was also used through the process named Sensitivity Analysis to Land Suitability Evaluation (Ligmann-Zielinska and Jankowiski, 2012; Ligmann-Zielinska et al. 2012). The Monte Carlo statistical method was applied using the "Monte Carlo Weighted Sum" tool. The analysis is based on building possible results by attributing different intervals of maximum and minimum values in relation to the average value attributed to each criterion. Intervals are groups of random values generated by a probability density function (PDF) and are defined using the Standard Deviation (STD) regarding the average. This is a symmetrical distribution and values closer to average will present a higher occurrence probability.

A Monte Carlo simulation with a greater number of iterations will have a more reliable answer but will demand higher computational resources. In this study, 100 iterations between indicated weights intervals were done. The interval of minimum and maximum weights attributed to each criterion varied due to weights attributed by the specialists (Table 2). As proposed by Moura et al (2014), i can observe the difference between the lowest and highest value among the specialists, being that, if opinion variation on criterion is low, it is feasible to opt for 1 STD for each side of the average value. However, if there is great variation in specialists' opinions regarding a determined criterion, STD is used twice for each side of the average value because a broader range will be analyzed for criteria that generated more doubts.

Table 2. Criteria for definition de analysis interval

Criteria	AW	SD	PDF	Analysis Interval
Distance to surface water	0.25	0,028	1 x SD	0,222 – 0,278
Distance to UC's of full protection	0.20	0,047	1 x SD	0,153 – 0,247
Distance to UC's of sustainable use	0.05	0,020	2 x SD	0,010 – 0,090
Distance to forest patches with larger core areas	0.20	0,023	2 x SD	0,153 – 0,247
Distance to roads	0.05	0,009	1 x SD	0,041 – 0,059
Distance to urban areas	0.10	0,009	1 x SD	0,091 – 0,109
Slope	0.15	0,016	2 x SD	0,118 – 0,182

5. Results and Discussion

Uncertainty analysis through the Monte Carlo method produces a result indicating a ranking of average classified values (Rank AVG) and a ranking obtained from the standard deviation (Rank STD). The higher values are those that have first positions in the ranking (Figure 3).

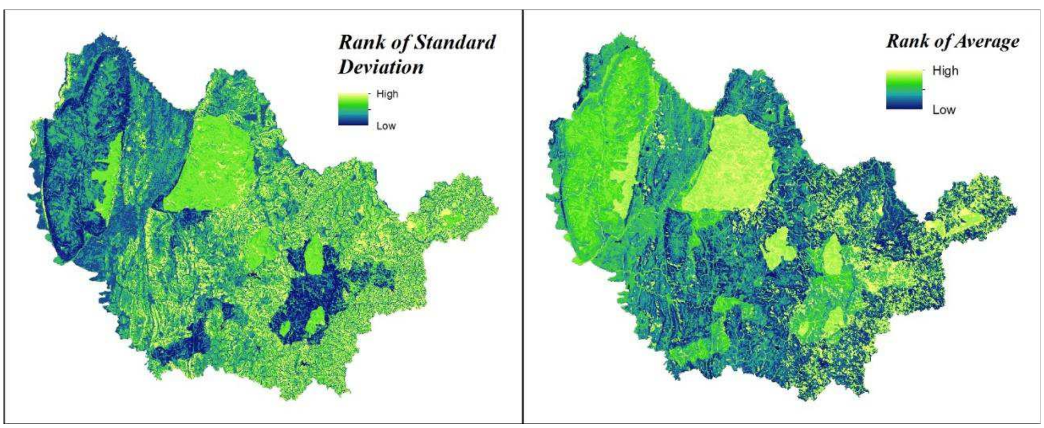

Figure 3. Rank extract by the Monte Carlo analysis

According to Ligmann-Zielinska and Jankowiski (2012), these results allow carrying out an analysis on the area's aptitude level as well as the uncertainty related to this aptitude and a combination of rules is possible for than exploratory analysis of the result. The rules proposed by the authors are as follows:

1. The average's high ranking position and a low ranking position for the standard deviation point to a more suitable location with less aptitude related uncertainty.

2. The average's low ranking position and a low ranking position for the standard

deviation point to less suitable locations as they have low aptitude and low uncertainty regarding this situation.

3. The average's high ranking position and a high ranking position for the standard deviation point to locations with a great suitability potential, nevertheless it needs further studies because of the related high uncertainty.

4. The average's low ranking position and a high ranking position for the standard deviation point to low aptitude locations that, however, have a lot of related uncertainty, being liable to more analyses.

Striving for a better analysis of results, a results combination in a thematic map demonstrating simulated possibilities of connectivity suitability was done (Figure 4).

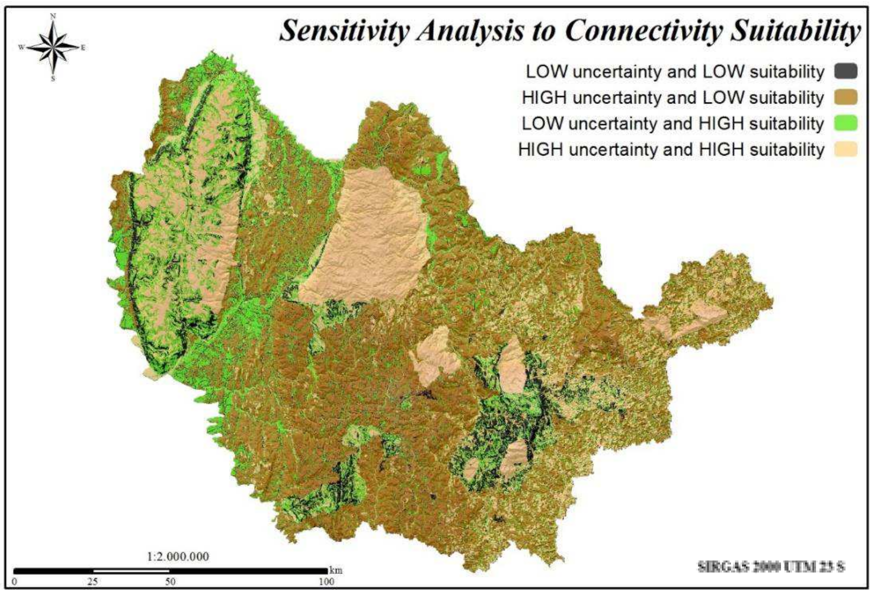

Figure 4. Sensitivity Analysis to Connectivity Suitability

Areas presenting better suitability for connectivity among protected areas are those that have a low ranking position for the standard deviation (low uncertainty) and a high ranking position for the average (high suitability) as indicated in Rule 1. Such areas correspond to 19.82 % of the mosaic's total area (Table 3). Highly suitable areas, however, also have high uncertainty and can also be considered important to foster connectivity though they need a more detailed analysis of associated uncertainties. These areas correspond to 28.73% of the mosaic's total area.

Table 3. Sensitivity Analysis to Connectivity Suitability

Sensitivity Analysis	Rule	Area (ha)	Percent (%)
LOW uncertainty and LOW suitability	Low STD - Low AVG	150,82	7,97
HIGH uncertainty and LOW suitability	High STD - Low AVG	822,69	43,48
LOW uncertainty and HIGH suitability	Low STD - High AVG	375,06	19,82
HIGH uncertainty and HIGH suitability	High STD - Low AVG	543,63	28,73

Areas that present low suitability, but have high associated uncertainty are the landscape's matrix with 43.48% of the mosaic's total area. In these areas there are different land use typologies and, consequently, coexisting habitats. More research on these habitats and their respective species is needed in these areas, striving for a deeper analysis of fragments' real functionality to serve as connectors in the landscape.

It is interesting to note that even integrally protected areas have high uncertainty linked to their connective capacity and thus demonstrate that some agents involved in the multicriteria analysis may harbor doubts on these areas' roles. It is also indicative of little consensus among specialists valuing criteria under analysis.

Taking areas with higher suitability into consideration, or be it, that have low ranking position for standard deviation (low uncertainty) and a high-ranking position for the average (high suitability), 5 principal locations that have patterns capable of allowing connectivity between protected areas were identified.

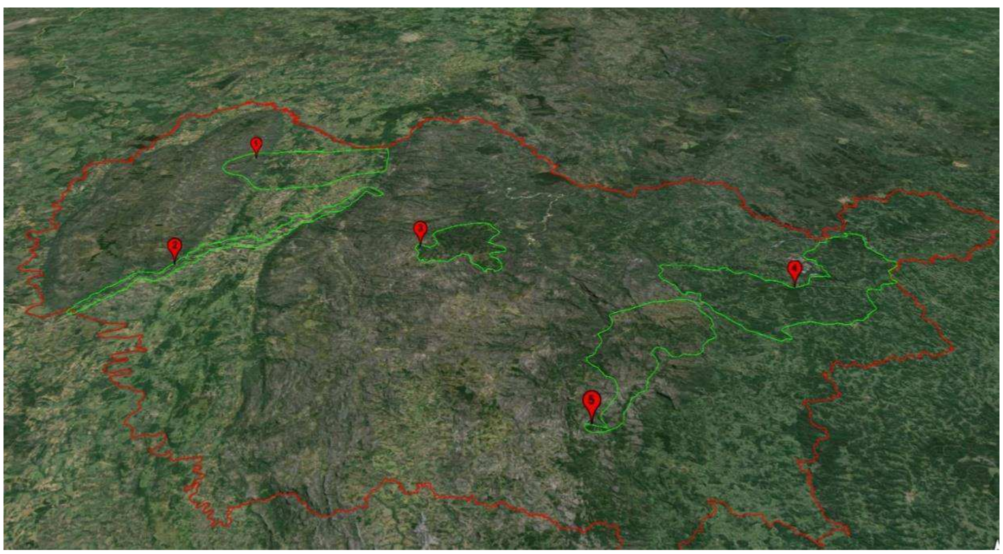

Figure 5. Sensitivity Analysis to Connectivity Suitability

In area 1, located in the mosaic's northwestern portion there are dense patches of vegetation in the landscape and presents a stepping stone pattern that may come to allow connectivity between the northern region of the "Serra do Cabral" and the main face of the "Serra do Espinhaço" near "Sempre Vivas" National Park. Area 2, in the mosaic's western section is shaped to potentially permit connectivity via a typical biodiversity corridor formed by the Curimataí River's riparian vegetation. It allows connection between the southern region of the "Serra do Cabral" and the main face of the "Serra do Espinhaço" near "Sempre Vivas" National Park. Areas 3, 4 and 5 present a landscape mosaic pattern in which the differently shaped habitat fragments have the potential to permit connectivity in the landscape. Within the methodology presented here, these areas must be the object of a more detailed evaluation to implement environmental management policies, striving to preserve biodiversity through the establishment of connectivity among habitats.

In this context, a decision model we can envision after analysis will, besides conciliating natural communities' survival possibilities in fragmented landscapes with human intervention, must have the capacity to direct strategies on a larger scale, or in other words, with greater attention to details. The proposition is that legal instruments be created. They should follow concepts within the scope of Landscape Ecology, which was initially proposed by Forman & Godron (1986). In it, landscape has a three element structure and they are Matrix, Patch and Corridor. Starting from this Landscape Ecology concept, management models based on landscape's structural elements can be created minding greater biodiversity conservation efficiency.

In landscape mosaics in places with a typical matrix pattern, areas in which there is a habitat typology intertwining, such as pasture lands, native forests, monocultures and others, it would be necessary to create policies making economic growth and biodiversity conservation compatible. To do this, it would be crucial to develop matrix permeability studies that contemplate endemic species and their transit capacity in the matrix.

In places with a stepping stone pattern, in which connectivity is reached through short movements among habitat patches dispersed within the matrix, a decision-making model would be to carry out metapopulation research including degree of patches' isolation studies, efficiency of patches' core areas, verification of patches' real functioning as habitats, how species coexist in the habitat and others.

In locations with an ecological corridor pattern, which can be understood as great avenues on which biodiversity moves through habitats, creation and verification of the real functionality of existing policies on riparian vegetation conservation as water networks with preserved riparian vegetation is an efficient ecological corridor. Besides this, constant analyses on possible interconnection locations among habitats must be checked with the aid of orbital images and field teams.

6. Conclusions

One of the characteristics of the multicriteria analysis method is to take into consideration decision makers' opinions and be expressed through criteria and their weighting. However, i observed that in the course of the criteria and weighting definition process, some uncertainties were identified. This situation was satisfactorily resolved in this study through applying sensibility analysis using the Monte Carlo method. This analysis lends robustness to the methodology since it permits analysis of the relationship between weighting, criteria and their propositioning method.

The Protected Areas Mosaic of the Espinhaço corresponds to an area of regional dimensions and that leads to complicated situations regarding territorial management be it due to lack of technical knowledge or because of the territory itself. Under this aspect i conclude that the methodology presented herein was very satisfactory as it allowed identification of areas with great suitability for this theme, which was habitat connectivity in the landscape.

Observing the 5 five suitable areas for connectivity, identified using the presented methodological guide, i propose a continuation of the study by carrying out a detailed investigation into each detected area using images made by higher resolution sensors. We also indicate a review of the questionnaire written for effectuation of the Delphi method including more specific questions since the study's scale tends to be refined.

Keeping in mind the method's integration capacity in a GIS environment and analysis possibilities on different scales, we believe that this method can aggregate to protected areas' management, taking into consideration the definition of apt or vulnerable areas for determined activities and helping in the search for solutions that add to biodiversity conservation.

7. References

Bennett, A. F. (2003). Linkages in the landscape: The role of corridors and connectivity in wildlife conservation. Gland, Switzerland and Cambridge, United Kingdom: The World Conservation Union (IUCN) Forest Conservation Programme, 2, 262.

Bonham-carter, G. (1994). Geographic Information Systems for Geoscientists; modelling with GIS. Ottawa, Pergamon.

Braulio, M.F., Moura, A. C. M & Haddad, M. (2014). Definição de áreas prioritárias para conservação na borda nordeste do Quadrilátero Ferrífero por meio da análise de multicritérios em ambiente SIG com vistas ao processo de Geodesign In. XXVI Congresso Brasileiro de Cartografia, Gramado.

Carmel, Y., Paz, S., Jahashan, F & Shoshany, M. (2009). Assessing fire risk using Monte Carlo simulations of fire spread. Forest Ecol. Manage. 257, 370–377.

Carver, S. (1991). Integrating multi-criteria evaluation with geographical information systems. International Journal of Geographical Information Systems, 5, 321–339.

Chen, H., Wood, M.D, Linstead, C & Maltby, E. (2011). Uncertainty analysis in a GIS-based multicriteria analysis tool for river catchment management. Environmental modelling and software, 26 (4), 395-405.

Davey, A.G. (1998). National System Planning for Protected Areas. IUCN, Gland, Switzerland and Cambridge, UK. 71pp.

Estes, G. & Kuespert, D. (1976). Delphi in industrial forecasting. Chemical and Engineering News, EUA. 40-47.

Ferretti, V & Pomarico, S. (2013). An integrated approach for studying the land suitability for ecological corridors through spatial multicriteria evaluations. Environ. Dev. Sustain. 15(3), 859-885

Forman, R.T & Baudry, J. (1984). Hedgerows and hedgerow networks in landscape ecology. Environ. Manage. 8: 499- 510.

International Union for Conservation of Nature. (1994). Guidelines for protected area management categories. IUCN Commission on National Parks and Protected Areas with the assistance of the World Conservation Monitoring Centre. IUCN, Gland.

Jeanneret, P., Schüpbach, B & Luka, H. (2003). Quantifying the impact of landscape and habitat features on biodiversity in cultivated landscapes. Agric. Ecosyst. Environ. 98, 311–320.

Lang S & Blaschke, T. (2009). Análise da paisagem com SIG. São Paulo: Oficina de Textos.

Ligmann-Zielinska A & Jankowski P. (2008). A Framework for Sensitivity Analysis in Spatial Multiple Criteria Evaluation, Lecture Notes in Computer Science No. 5266, Eds. T.J., Cova, H.J. Miller, K. Beard, A.U. Frank, Proceedings of 5th International

Conference, GIScience 2002, Park City, Utah, USA, September 2008, Springer Verlag, Berlin-Heidelberg 217-233.

Ligmann-Zielinska. A. & Jankowski, P. (2012). Impact of proximity-adjusted preferences on rank-order stability. in geographical multicriteria decision analysis. Journal of Geographical Systems 14: 167-187.

Ligmann-Zielinska, A., Jankowski, P. & Watkins, J. (2012). Spatial Uncertainty and Sensitivity Analysis for Multiple Criteria Land Suitability Evaluation. Journal of Geographical Systems 13, 2–5.

Ligmann-zielinska, A. & Jankowski, P. (2014). Spatially-explicit integrated uncertainty and sensitivity analysis of criteria weights in multicriteria land suitability evaluation. Environmental Modelling & Software, DOI: 0.1016/j.envsoft.2014.03.007.

Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature. International Journal of Geographical Information Science, 20(7), 703–726.

Marulli, J., & Mallarach, J. M. (2005). A GIS methodology for assessing ecological connectivity: Application to the Barcelona Metropolitan area. Landscape and Urban Planning, 71, 243–262.

McHarg, I. L. (1969). Design with nature. New York: Wiley.

Metzger, J.P. (2000). Tree functional group richness and landscape structure in a Brazilian tropical fragmented landscape. Ecological Applications. 10 (4), 1147-1161.

Moura, A.C.M. (2007). Reflexões metodológicas como subsídios para estudos ambientais baseados em Análise de Multicritérios. Departamento de Cartografia. Universidade Federal de Minas Gerais. In: Simpósio Brasileiro de Sensoriamento Remoto, Florianópolis. Anais. Instituto Nacional de Pesquisas Espaciais, 2899-2906.

Moura, A. C. M., Jankowski, P., & Cocco, C. (2014). Contribuições aos estudos de Análises de Incertezas como complementação às Análises Multicritérios - "Sensitivity Analysis to Suitability Evaluation". In XXVI Congresso Brasileiro de Cartografia, Gramado.

Noss, R.F. & Csuti, B., (1997). Habitat fragmentation. In: Meffe, G.K.,Carroll, R.C. (Eds.), Principles of Conservation Biology, 2, 269-304.

Ribas R.P. & Gontijo, B.M. (2014). Análise multitemporal da evolução estrutural da paisagem por meio de técnicas de sensoriamento remoto e métricas de paisagem. Revista de la Asociácion Argentina de Ecologia de Paisajes 5(1):39-44.

Saltelli, A., Tarantola, S. & Chan, K. (1999). A quantitative, model independent method for global sensitivity analysis of model output. Technometrics. 41 (1), 39-56.

Store, R. & Kangas, J. (2001). Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modelling. Landscape Urban Plann. 55 (2), 79–93.

Vose, D. (2000). Risk analysis: a quantitative guide. 2. Ed Susses: John Wiley & Sons Ltd.

Zhou, G., Esaki, T., Mitani, Y., Xie, M. & Mori J. (2003). Spatial probabilistic modelling of slope failure using an integrated GIS Monte Carlo simulation approach. Eng Geol 68(3–4):373–386.