LANDSCAPE HIERARCHICAL ZONING USING OBJECT-ORIENTED IMAGE ANALYSIS

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ABSTRACT:

In this work, the geon concept (Lang, 2008) and a hierarchical zoning approach are adopted as an integrative framework for Geographic Object-Oriented Image Analysis (GEOBIA) for landscape analysis and monitoring. This paper objective is to implement GEOBIA methods and techniques to the hierarchical landscape zoning in a study area at the South Region of Brazil and to discuss the potential role of such innovative techniques in this field of research. The approach based on GEOBIA multiresolution segmentation of geomorphometric data, compatibilization with rural census tracts and multivariate data analysis appeared to be a way to semi-automate landscape zoning according to hierarchical scale principles.

KEY WORDS: GEOBIA, Regionalization, Landscape Ecology, Environmental planning.

1. INTRODUCTION

Linking object-oriented image processing and landscape analysis can offer a set of useful tools for environmental and territorial planning, dealing with the complex interactions between nature and society (Zonneveld, 1989, Wu, 1999), provided that the landscape objects can be appropriately represented. In this work, the geon concept (Lang, 2008) and a hierarchical zoning approach are adopted as an integrative framework for Geographic Object-Oriented Image Analysis (GEOBIA) for landscape analysis and monitoring. It is applied to the analysis of the fragmented landscape of the Upper Uruguay River Basin in the states of Rio Grande do Sul and Santa Catarina (Brazil).

Landscape ecology provides integrated methods of analysis and synthesis since its origins and precedents (Freitas, 2009) with contributions to the landscape integrated theory and application as the geosystems approach (Zonneveld, 1989; Monteiro, 2001; Bertrand and Bertrand, 2002) and the hierarchical patch dynamics paradigm (Wu, 1999). Various denominations and concepts were presented for hierarchic landscape zoning and hierarchy; e.g. geosystems and geocomplex (Bertrand and Bertrand, 2002), land units (Zonneveld, 1989), holons (Monteiro, 2001). The common point of all these concepts is the search for the landscape regionalization based on integrated methods that: (a) deals with the complex interactions between nature and society, (b) are designed for landscape diagnosis, planning and management and (c) can be used in landscape dynamics modelling concerned about simulations and prognosis (Monteiro, 2001).

A similar way of thinking is presented by the geon concept that is an integrative framework based on GEOBIA for the regionalization, analysis and monitoring according to spatial variables for providing a plurality of solutions oriented to the policy decision support due to the inherent complexity of landscape and real world phenomena (Lang, 2008).

2. METHODOLOGY

2.1 Study area

The study area is part of the Upper Uruguay River Basin at Rio Grande do Sul and Santa Catarina States (Brazil) with an approximated area of 12.000 Km² and composed by 18 municipalities (Figure 1).

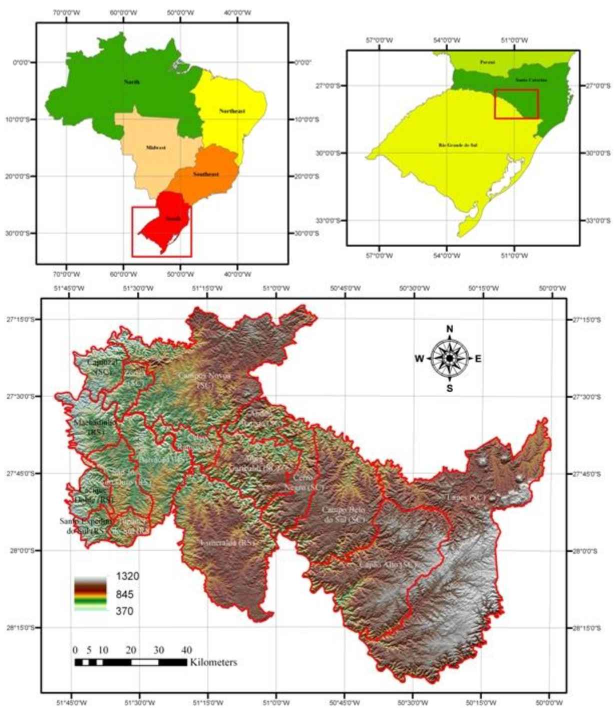

Figure 1: Maps of (a) Brazil and its five regions, where the country’s Southern Region is shown in red; (b) location of study area (red) in the border of the Rio Grande do Sul and Santa Catarina states; (c) study area showing the municipal limits (red lines) with elevation data in meters.

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This region presents fragmented landscape mosaics composed of a matrix of Mixed Ombrophilous Forest (FOM) or Araucaria Forest and native grasslands as well of patches of traditional land uses (mixed subsistence agriculture and extensive livestock) together with modern land uses (soybeans, wheat, corn and others modern agricultures, silviculture and dams). These landscape mosaics are related to the interactions of physical, ecological and social factors with a high level of heterogeneity and complexity.

Table 1: Thematic, geomorphometric, landscape metric and social variables used for landscape zoning.

Variables	Units/Type
Geomorphology (4 units)	Categorical (binary)
Soils (7 classes groups)	Categorical (binary)
Land use and cover	% of class
Elevation	Meters
Slope	Degrees
Relief	Meters
Surface roughness	-
Patch Area	Sq. meters
Number of Patches	Count
Patch Density	Count/Sq. Km
Edge Density	Meters/Sq. Km
Largest Patch Index	Sq. meters
Fractal Index	-
Shape Index	-
Perimeter-Area Ratio	-
Nearest Neighbor Distance	Meters
Effective Mesh Size	Hectares
Splitting Index	-
Nominal income	Reais (R$)
Average income	Reais (R$)
Mean of study years	Count
Literacy rate	%
Population Density	Pop/Sq. Km
Dependency Ratio	%
Average number of residents	Count
Pop. lower age 15	%
Pop. between 15 and 64 age	%
Pop. over age 64	%

2.2 Landscape variables

We used geomorphometric, social and landscape structure variables (Table 1). Geomorphometric variables were derived from SRTM's (Valeriano and Rosseti, 2011) as Digital Elevation Model (DEM) and slope, then processed by raster filtering operations to generate variables as hill shading, surface roughness (Grohmann et al., 2011) and local range relief (Evans, 1972). Social data were obtained from the 2000's Demographic Census (IBGE, 2000) at the aggregation level of rural census tracts. Landscape metrics at the landscape level based on the land cover patches (Mixed Ombrophilous Forest and native grassland) of the land use and cover classification based on Landsat-TM data of the area of study were based on Freitas and Santos (2010). All variables were input, organized and analyzed in a GIS with vector and raster data.

2.3 Landscape hierarchical zoning

Hierarchy design: We defined the landscape hierarchy based on Holon theory (Koestler, 1978) which conveys the idea that subsystems at each level within a hierarchy are "Janus-faced": they act as "wholes" when facing downwards and as "parts" when facing upwards (Wu, 1999); it also presents a close relation to the multiresolution segmentation technique (Lang, 2005). The Holon theory has already been adapted to geosystems applied studies (Monteiro, 2001; Cunha and Freitas, 2004) providing complex approach for analysis on hierarchical complex spatial systems.

In this study area, we defined two hierarchical basic levels: (a) the landscape geons based on physical and ecological attributes; (b) the lower level, which we called Landscape Planning Units (LPU), based on the compatibilization of the landscape geons with the social units and then divided into two higher hierarchy clusters.

2.3.1 Landscape geons: The landscape geons were based on multiresolution segmentation objects of geomorphometric data (DEM, local range relief, surface roughness and hill shading). We fixed the shape and compactness parameters to 0.5 and varied the scale parameter values (50, 60, 70, 80, 90, 100, 120, 150, 180, 200 and 300). These segmentation levels (Figure 2) were used in an interactive way of grouping in a GIS environment according to the geomorphology, soils and geology maps (RADAMBRASIL, 1986; EMBRAPA, 2005; CPRM, 2006) at low scales and the visual interpretation of the DEM and hill shading (Figure 3).

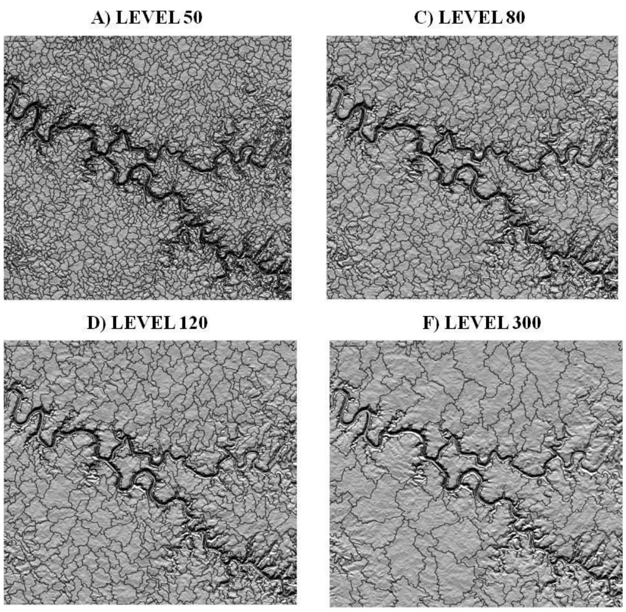

Figure 2: Examples of multiresolution segmentation levels based on geomorphometric data.

This approach can be related to a process of refinement of the Brazilian geoecological mappings, which in most cases are present at lower scales than the actual remote sensing data available. This process is based on the landscape interpretation looking for similarities between the physical and ecological data using a basis of Landsat-TM colour composites, DEM and derived products.

2.3.2 Landscape planning units (LPU): The LPU map was generated by GIS operations of intersection of the rural census tracts and the landscape geons followed by a compatibilization of both mostly based on visual interpretation of land use and cover classification of 2008 year. This compatibilization procedure was grounded on the rural census tracts of 2000 Demographic Census that are provided by IBGE due to Modifiable Area Units Problem (MAUP) and ecological fallacy issues (Openshaw, 1984; Wrigley et al., 1996) inherent when dealing with spatially aggregated data. This compatibilization approach is also adopted in urban planning for generating Planning Units (UP) according to the aggregation of similar urban census tracts (França et al., 2008).

In this case, the major compatibilization procedures were: a) we merged the little rural census tracts related to rural districts headquarters with the belonging bigger census tract; b) we divided the rural census tract of Lages municipality (an aggregation of 172 urban census tracts) according to rural or urban characteristics and replaced the data with the peripheral urban census tracts information; c) in some cases, due to very different landscape features, we divided the rural census tract.

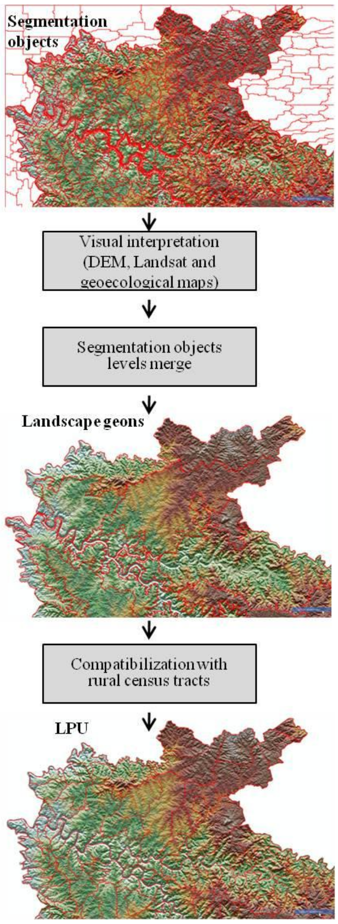

Figure 3: Procedure of landscape geons and LPU delimitation.

2.4 Multivariate analysis and LPU clusters: We made a multivariate analysis on the resulting LPU due to necessity of a statistical analysis to find hierarchical landscape patterns according to different degrees of homogeneity and dissimilarity. The major techniques used in landscape zoning studies are the clustering methods (Silva et al., 2007; Freitas and Carvalho, 2009). In this case, we introduced categorical variables (groups of soils classes and geomorphologic units) alongside geomorphometric, social, landscape structure and distance continuous variables (Table 1).

We used the auto-clustering procedure of the TwoStep cluster algorithm (Zhang et al., 1996; Chiu et al., 2001) that defined 3 clusters which were adjusted based on landscape visual interpretation to 5 LPU clusters. We used the Canonical Correspondence Analysis (CCA) to check the two final clusters results separate and together, producing ordination diagrams with the remaining variables of a manual forward selection based on a Monte Carlo F-like test ($\alpha = 0.05$) (Lepš and Smilauer 2003).

3. RESULTS

The resulting LPU and its clustering (Figure 4) allowed a hierarchical understanding of the landscape with the identification of two hierarchical levels (holons) of LPU groups. The higher level (3 clusters) represents: (a) areas dominated by urbanization, large-scale agriculture and silviculture expansion processes (holon A1); (b) areas related to mixed semi-subsistence agriculture traditional practices and the bigger remaining forest patches (holon A2); (c) areas dominated by native grasslands with the permeation of silviculture, large-scale and mixed agriculture activities in some areas (holon A3). At the lower level (5 clusters): (a) we divided the holon A1 in the large-scale agriculture (holon B1) and silviculture and urbanization (holon B5) processes; (b) the mixed agriculture holon A2 was reshaped; (c) the holon A3 was divided in the areas with the advancement of agricultural activities (holon B3) and a conserved native grassland area (holon B4).

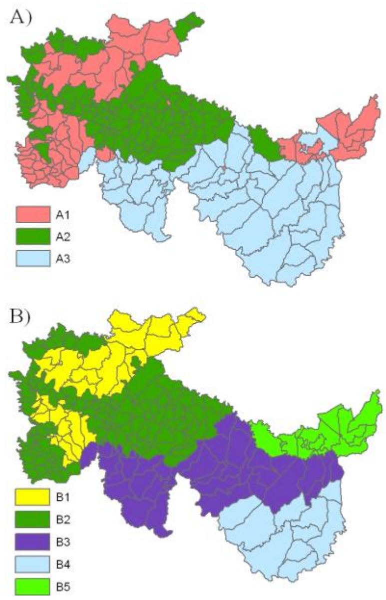

Figure 4: LPU hierarchical clustering results (holons). Holons hierarchy: A1 (B1, B5), A2 (B2) and A3 (B3 and B4).

The results of CCA analysis, i.e. the selected variables and the ordination diagram (Figure 6) revealed a clear distinction between the LPU hierarchical clusters with the variance explained by the independent variables ranging around 75%. The selected variables revealed that an interaction of land use an cover, geomorphometric, landscape and social variables is closely related to the landscape zoning.

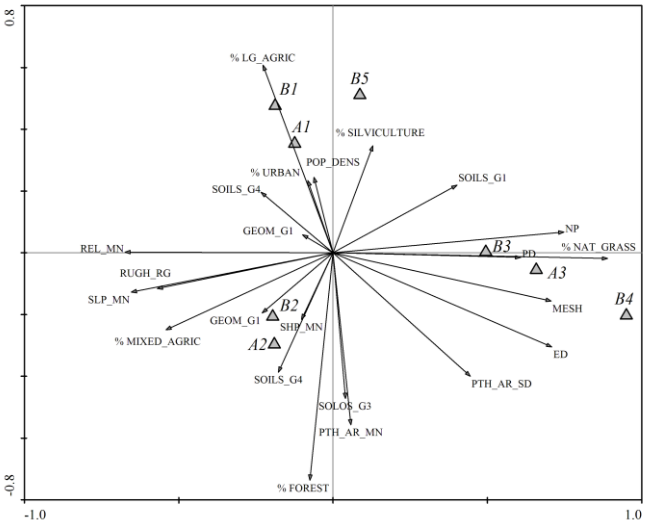

Figure 5: CCA ordination diagram with the two hierarchical levels together and the significant variables. % LG_AGRIC: large-scale agriculture percentage, % MIXED_AGRIC: mixed agriculture percentage, % NAT_GRASS: native grassland percentage, % FOREST: forest percentage, % SILVICULTURE: silviculture percentage, % URBAN: urban percentage, POP_DENS: population density, SOILS G4: Oxisols + Paleudalfs, SOILS G1: Dystrochepts + Hapludolls, GEOM G1: convex lowland relief, GEOM G4: dissected tabular relief, REL_MN: average internal relief, SLP_MN: average slope, RUGH_RG: surface roughness range, PTH_AR_MN: patch area average, PTH_AR_SD: patch area standard deviation, ED: edge density, MESH: effective mesh size, NP: number of patches.

4. CONCLUSION

The approach based on GEOBIA multiresolution segmentation of geomorphometric data, compatibilization with rural census tracts and multivariate data analysis appeared to be a way to semi-automate landscape zoning according to hierarchical scale principles. The necessity of a holistic view of the physical, ecological and social landscape factors was confirmed by the CCA results that revealed complex interactions between these variables on the landscape characterization.

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