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Land-use changes assessed by overlay or mosaic methods: Which method is best for management planning?

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ABSTRACT

Environmental planning must determine management practices for a given territory based on the landscape processes that have occurred over time and their consequences. Therefore, environmental planning decisions must be based on strong empirical evidence that can be easily understood by all involved parties. Several studies have highlighted the methodological deficiencies that occur when obtaining and interpreting such issues, particularly in heterogeneous landscapes with complex interactions. In this paper, we evaluated two methodological approaches that are used in management planning, land use/cover change (LUCC) and mosaic change (MC) to compare their effectiveness and suitability for supporting decision-making. We applied these methods to the coastal landscape of São Sebastião Island, Brazil, which has undergone many changes in the last 50 years. For two years, land use/cover maps were produced using GIS and assessed according to changes in landscape elements (LUCC) and boundaries (MC). Overall, the LUCC failed to identify sets with similar structural heterogeneities in the landscape. However, the LUCC is easier for stakeholders to understand and apply than the MC. The MC method better presented the evolution of the relationship between the landscape elements and heterogeneity.

1. Introduction

Most coastal landscapes in Brazil are heterogeneous and complex, undergoing rapid changes throughout history leading to major conflicts between social agents. One great difficulty faced by planners and decision makers is how to begin planning interferences that will prevent chaos (Santos and Caldeyro, 2007). In this case, it is important to define territorial units for management actions, which is usually performed by zoning and is often based on land cover, land use and physical environment maps that do not consider the driving forces and changes with time (Silva and Santos, 2011).

The zoning procedure and the territorial units that result from it must be based on the ecological functions of the territory, which should be used by planners when deciding what to preserve. Thus, not only the internal nature of the territorial units is important but also their spatial arrangement, which is identified by the boundaries between them (Hardt et al., 2013).

Although much has been written about these issues, it is difficult to choose a methodological tool that represents the forces, their directions, intensities on each territorial unit, their relationships with neighboring areas (Bürgi et al., 2004; Conrad et al., 2011; Hazeu et al., 2011; Lambin et al., 2003). Although the methods that define zoning are static, new proposals have been presented to include driving forces, land change time analyses (Bertolo et al., 2012; Hersperger and Bürgi, 2009; Schmitt-Harsh, 2013; Wang et al., 2008), to define so-called land flows (Haines-Young and Weber, 2006) or assess landscape value changes depending on land-use changes over time (De Pablo et al., 2011).

One of the most commonly used approaches is the land use and cover change (LUCC) approach. Since 1994, LUCC has been used as a fundamental methodological tool for assessing the environmental and ecological consequences of human activities on natural resources (Flamenco-Sandoval et al., 2007). In addition, LUCC is

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one of the most frequently cited topics in environmental planning literature aiming to predict and map land-use changes through biophysical and human dynamics by using robust, globally applicable, regionally sensitive models (Lambin and Geist, 2006; Parker et al., 2003; Turner and Meyer, 1994). This strategy has been adopted by most Brazilian environmental agencies as an established method for executing environmental plans that rely on zoning (Santos, 2009).

Several authors have attempted to improve LUCC-based models to better represent the movements, trends and causes of temporal transformations. For example, according to Kadıoğulları (2013), to understand the dynamics of change using LUCC and to assist in the development of better planning and environmental policies for landscapes, one should quantify the change rates and directions of each land-use type with time. However, the LUCC approach only considers the landscape as a set of land cover surfaces, regardless of their spatial arrangement or of the matter and energy flows supporting them. Furthermore, landscape structural features based on land cover patch traits are used as indicators when interpreting spatial heterogeneity (Bonfanti et al., 1997; Biswas and Wagner, 2012; Wagner and Fortin, 2005), which is especially problematic in environments with multiple uses that are quickly altered.

The patch-corridor-matrix model is thought to overcome the above-mentioned limitations by defining different functional roles (matrix, patch and corridor) for different elements; however, this model has limitations for expressing spatial heterogeneity (Gustafson, 1998; McGarigal and Cushman, 2005) and ignores the interactions and flows between their elements. Some authors have proposed models that highlight landscape differences to express heterogeneity by using additional analysis factors. For example, Biswas and Wagner (2012) used models representing different types of spatial heterogeneity (homogeneous, binary, gradients and mosaics) associated with dispersal, species interactions and metapopulation habitat limitations.

Other authors considered that landscapes could be represented as a set of mosaics, with each comprising specific sets of elements and interactions (Cantwell and Forman, 1993; Roldán-Martín et al., 2003). From this perspective, Cadenasso et al. (2003) and Roldán-Martín et al. (2003) showed that it is possible to define each landscape mosaic as a set of patches with similar frequency pattern boundaries that are part of similar interaction networks. These boundaries or transition zones between patches are responsible for ecological flows, which can be altered by changes in their spatial arrangement patterns (Turner and Cardille, 2007). This strategy has become more popular because these mosaics include information regarding the variety of boundaries and patches (land cover or land-use type) that dominate certain portions of territory. Thus, these mosaics expand our understanding of the structural heterogeneity of the landscape and the complex interactions of the landscape's ecological functions. Consequently, these mosaics can be used as management units (de Agar, 2013; Hardt et al., 2013).

In addition, different heterogeneity features in a location can be assessed over time based on changes in the combined conditions of the patches arrangements, boundaries and mosaics (Bertolo et al., 2012; Valverde et al., 2008). The mosaic model appears to be promising for environmental planning because the mosaics can be seen as landscape units (Hersperger, 2006) that have patterns of similar internal structural heterogeneity. The mosaics can be used to make deductions regarding the conservation status, sources of income or habitat support and ecosystem services provisions (Hardt et al., 2013). In addition, mosaics can be valuable for different views of environmental planning (de Agar, 2013). However, it is not easy to apply the mosaic model to large surfaces unless a set of well established spatial analysis software routines are used for recognizing the borders (Hardt et al., 2013; Roldán-Martín et al., 2003). Thus, application is especially difficult for social actors, who usually do not have access to these tools and are therefore unable to take advantage of these results (Sabatino and Santos, 2012; Scarabello Filho and Santos, 2011).

Furthermore, all decision makers must be provided with strong empirical evidence to understand the consequences of landscape change. However, how can LUCC and MC models assist social actors in understanding landscape changes, and how can they complement each other to best represent the conditions that depict the actual landscape with time?

This study compares the effectiveness and complementary nature of two different methods for assisting decision-making in environmental planning processes. Here, the LUCC and MC methods are used to (i) provide units for territorial planning, (ii) represent changes over time, and (iii) evaluate these changes from the perspective of environment protection, i.e. ensuring the natural resources in such away to sustain the human wellbeing.

2. Material and methods

2.1. Study area

São Sebastião Island (a municipality of Ilhabela, Sao Paulo, Brazil), covers an area of 36,000 ha, has an altitudinal range of 1379 m, is covered by 92% forest, and is the Brazilian municipality with the highest ratio of Atlantic Forest to area. This Island is known as a unit that is fully protected by environmental law because it contains a large protected area (Ilhabela State Park) and many natural and historical heritage sites. Nevertheless, highly preserved and highly impacted environments exist on the island and have shown significant changes with time across the altitudinal gradient. Within this area, 16 watersheds (Fig. 1) were selected as having suffered the greatest human pressure over six centuries, primarily due to three driving forces, ruralization, coastal activities and urbanization and tourism (Bertolo et al., 2012).

2.2. Evaluation of land-use changes using LUCC and mosaics

Land-use maps were constructed by visually interpreting panchromatic aerial photographs from 1962 and SPOT 5 satellite images from 2009 [both at a scale of 1:10,000 (Appendix A1)]. Georeferencing was performed using the ArcGIS® 9.2 GIS software with a root mean square (RMS) of less than 12 m. These maps provided a basis for evaluating the LUCC and MC.

Mosaic identification was performed using these land use maps by analyzing the spatial interactions between the patches (M) and boundaries (B). A methodological schema of this process can be found in Appendix A.2. Mosaics were recognized as sets of patches with similar boundary patterns, as described by Roldán-Martín et al. (2003). To identify the mosaics, the frequencies (f) of the types of boundaries between the neighboring patches were recorded and a matrix of patches versus boundary frequencies was constructed for each year (Hardt et al., 2009), as shown in Table 1a. To identify patches with similar boundary patterns, the *patches* versus *boundaries* matrices were analyzed using detrended correspondence analysis (DCA) (Hill and Gauch, 1980). This technique is particularly suitable for frequency data and ensures independence between the ordination axes. Sets of patches with similar coordinates on the ordination axes correspond to the same mosaic. Because the number of patches is very high, these sets were identified using multivariate clustering of the patches according to their coordinates on the ordination axes. We used Ward's method to group the patches into mosaics and the Euclidian distance to measure the similarities among patches (Hardt et al., 2013), which resulted in mosaics that were characterized by their boundary