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Suitability index for restoration in landscapes: An alternative proposal for restoration projects

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ABSTRACT

Forest fragmentation constitutes one of the main consequences of land cover change worldwide. Through this process gaps in habitat coverage are created and the ability of populations in the remaining fragments to maintain themselves is put in doubt. Hence, two options need to be considered: conserving the remaining forest fragments, and restoring habitat in some deforested patches with the aim of reestablishing the connections among the fragments. We established a mathematical index (SIR) that describes the suitability of individual habitat patches for restoration within a landscape. The index considers classes of distances among fragments and categories of habitat quality in the areas surrounding the fragments to assess habitat quality in terms of probability of dispersal and survival of propagules (especially seeds and cutting). In the present study, we created detailed maps depicting SIR values for two periods (1988 and 2011) for Sorocaba region (São Paulo State, Brazil). We derived land cover maps from satellite images for the two years of our study, and then surveyed the transition of land cover categories and landscape metrics between years. A model for the SIR was created using a map of distance classes among fragments and also a map of habitat quality established according to each land cover category. For both 1988 and 2011, pasture was the predominant land cover category. The main land cover transitions were from pasture to urban (10.6%) and from pasture to forest fragments (13.4%). Although the land cover class "wood sites" increased, the data of SIR revealed that the areas of habitat categorized as excellent and good both decreased, while habitat classes categorized as poor and very poor increased. Our model has the potential to be applied to other regions where the forest is fragmented. Hence, local policy makers will be able to use this model to determine local patches of high value for conservation and also the most ideal locations for restoration projects.

1. Introduction

Land cover is the observed (bio)physical layer on the planet's surface, describing both vegetation and man-made features (FAO, 2000). Land cover change is a spatial property observed at the scale of a landscape over time (Lambin et al., 2003; Renetzeder et al., 2010). Forest fragmentation is a process related to land cover change, in which large forest patches are broken into smaller pieces (EPA, 2003). Forest fragmentation affects both the structure and function of the landscape (Turner, 1989; Botequilha Leitão and Ahern, 2002). Generally, landscape structure is related to the number and spatial distribution of forest patches, while landscape functions refer to the flow of ecological processes (i.e. community dynamics, biogeochemical cycling (nutrients and water), and energy flow) among such forest fragments (Bélisle, 2005).

For landscapes already fragmented, we currently have two practical options: (a) conserving the remaining natural or semi-natural fragments, because of they are imperative for maintenance of biodiversity (Palmer et al., 2004), and/or (b) restoring portions of deforested lands, in order to generate new forested areas and, by consequence, increase the areas of remaining fragments. If placed properly, new forested areas have the role of serving as a connector between two or more fragments, which also may help populations in the remaining forest fragments. For both goals, landscape concepts and metrics should be the starting point (Ribeiro et al., 2009).

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Normally there is a scarcity of information available on the biology, ecology or the present distribution of a species, group of species, or populations, limiting our ability to analyze and model environmental degradations caused by anthropogenic activities from the perspective of individual species. Landscape ecological-based procedures can diminish some of these problems, because research focuses not on the organisms (animal or plant species, for example), but on the habitats and functional associations, for which data can be frequently easier to find and/or produce, e.g. land use/land cover digital maps elaborated from satellite images (Botequilha Leitão and Ahern, 2002).

The spatial patterns of a landscape are usually quantified through landscape metrics which are regarded as fundamental ecological planning tools. Landscape metrics might provide important aid for land planners and policymakers, because they can quantify the arrangement of landscape components in time and in space (Botequilha Leitão and Ahern, 2002; Herold et al., 2002; Schneiders et al., 2012; Syrbe and Walz, 2012). In the context of a fragmented forest, the area of each fragment is recognized as the main metric to be evaluated (Bell et al., 1997; Holl et al., 2003). Further, the perimeter and the ratio between area and perimeter are also of high value (Patton, 1975; Cook, 2002). The latter can be expressed by the K shape index (Schumaker, 1996) which assesses whether a given shape deviates from a perfect circle.

In terms of effects, forest patching has four mainly influence on habitat patterns: (1) reduction in habitat proportion, (2) augmentation in number of forest fragments, (3) decrease in fragment size, and (4) augment in fragment isolation, changing the habitat configuration. Habitat isolation, in particular, drives the composition and abundance of biological species. Landscapes constituted by isolated forest fragments, whether they are protected or not, have reduced biodiversity and lower species population sizes (Fahrig, 2003; Hilty et al., 2006).

Another important landscape metric is the distance among the forest fragments. When the fragments are located near each other there is usually a low level of isolation, usually providing better environmental quality in the landscape. Consequently, for forested fragments located far each other in many situations, the high level of isolation reduces the number of places with suitable environmental quality in the landscape (Fahrig, 2003). Isolation of forest fragments constitutes a filtering process dictating the kind of dispersal mechanism that might happen successfully (Hill and Curran, 2003; Kepfer-Rojas et al., 2014).

One method to quantify the degree of isolation of the fragments is analyzing the inter-patch distances among fragments. Currently, Geographic Information Systems (GIS) based models can quantify forest fragment distances and other landscape metrics from land cover imagery. However, measuring only the distance among the forest fragments results in an incomplete answer to this issue (Gurrutxaga et al., 2010).

Native vegetation fragments play a fundamental role in the resilience of human-altered areas (Alberti, 2005; Angold et al., 2006; Lopes et al., 2012). On the other hand, ecological restoration usually is a kind of service that can be complex, expensive and time-consuming (Holl et al., 2003). To mitigate the costs of landscape-related projects, GIS-based models and approaches should be used by the decision-makers, managers and other environmental-related professionals (Del Moral et al., 1991; Holl et al., 2003; Gurrutxaga et al., 2010).

It is nearly impossible to restore completely, in ecological terms, a landscape that has experienced intensive human occupation and modification, especially if the land has been used for multiple purposes. Hence, specific restoration sites should be carefully selected to maximize the ecological functions while minimizing the resource inputs (Ribeiro et al., 2009; Rudnick et al., 2012).

Policies regarding forest conservation and/or restoration often call for the establishment of corridors, which are usually linear narrow patches, and/or stepping stones that facilitate the movement of organisms between forested fragments which supports dispersal among fragmented populations and promotes genetic exchange (Chetkiewicz et al., 2006; Rudnick et al., 2012). Nonetheless, the degree to which these strategies increase connectivity may depend of how the corridors are formed and also on the composition of the surrounding matrix (Baum et al., 2004).

The land cover of the surrounding matrix defines how much a landscape resists or promotes dispersal of propagules. The quality of the matrix might be diminished by barriers and inhospitable habitats. The perception of an environment is species specific, each species will recognize it as a percolating or not (i.e., one that is more or less connected).

Some models can be used to predict when an environment that is in a state of fragmentation will begin to lose characteristics such as connectivity (Farina, 2001). Depending on the type of land cover that occurs between forest fragments, movement of organisms among fragments might be difficult. For example, if planted or commercial forests (*Eucalyptus*, for instance) are embedded among natural forest fragments, this would be a better scenario for dispersal than whether when urban settlements occur within natural forest fragments, even taking into account the different environmental features that each species requires to survive. However, if the analysis involves only the quality of neighboring fragments regardless of the context of distance, then an assessment of habitat quality is incomplete.

Therefore a more comprehensive technique of examining land cover fragments is needed to determine correctly the quality of the habitat existing among the forest fragments. The integration of the two features: fragment distance and quality of land cover of adjacent area of the forest fragments, might provide a cartographic product that clearly indicates gradients of landscape quality, showing areas that would require low investments for restoration and simultaneously provide high potential for adequate reestablishment of ecological conditions similar to that one verified in the fragments. Such areas would be of high interest and priority for restoration and such information would improve land management decisions (Gurrutxaga et al., 2010).

The establishment of new forested areas increases the forested area of a region and, according to the placement of the new patches, such reforested areas will also help to conserve the remaining fragments if they successfully connect each other.

In this study we assumed that (1) if forest fragmentation is directly related to land cover change, then carrying out a temporal study considering land cover change from two periods will provide an understanding of the rates and patterns of changes in this region; and (2) if forest fragmentation and isolation are directly related to distance of fragments from each other and the quality of surrounding matrix, then it is possible to establish a mathematical index that describes the potential for restoration.

Hence, the goals of the study were (1) to analyze the landscape pattern in two years: 1988 and 2011, (2) analyze landscape-related metrics for study area, and (3) present a mathematical model that permits the user to generate a map that shows the spatial variation restoration suitability, showing areas ranging from low quality of dispersal to areas with high quality of dispersal. The main usefulness of the map is to guide managers and policy makers and focus efforts and investments on restoring areas with high quality for restoration. The reasons that justify this rationale will be discussed ahead, but we highlight here that the main property that makes the model attractive is the simplicity of execution, as well as the possibility of inclusion of regional and specific data for adequate establishment of each component of the model. Furthermore, the