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Averna Valente, Roberta; Coelho de Souza Petea, Felipe; Vettorazzi, Carlos Alberto
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Roberta Averna Valente[1], Felipe Coelho de Souza Petean[2], Carlos Alberto Vettorazzi[2]

MULTICRITERIA DECISION ANALYSIS FOR PRIORITIZING AREAS FOR FOREST RESTORATION

Keywords:
Urban watershed
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Weighted Linear Combination
Riparian zone
Connectivity

ABSTRACT: Urbanization process transforms original landscapes into an anthropic mosaic, causing impacts on hydrologic cycles and on landscape structure and functions. Aiming at the maintenance of the water resources and biodiversity, in an urbanized watershed, the objective of this study was the definition of priority areas for forest restoration. We used a Multicriteria Evaluation (MCE) method, following the steps: criteria definition, identification of the criteria importance, and criteria aggregation through Weighted Linear Combination (WLC). According to the experts, consulted in the context of the Participatory Technique, only two criteria represented the studied landscape: proximity to drainage network and proximity to forest patches. The first criterion was considered twice more important than the second, and through the pairwise comparison matrix, it was obtained respectively the criterion weights of 0.83 and 0.17. The priority map was obtained through the criteria aggregation, using WLC, that considered the criterion weights. The result was a priority map, indicating 5.06% of the study area with very-high priority for forest restoration; 5.22% with high priority; 5.76% with medium priority; 5,42% with low and; 78.53% with very-low priority. We can say that the framework predefined for the study proposed a scenario for priority areas that allowed driving the actions in order to obtain a landscape restoration, beginning through a forest corridor in the riparian zone. Thus, we concluded that the definition of priority areas for forest restoration is possible in an urbanized landscape, using the traditional WLC Multicriteria method.

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ANÁLISE MULTICRITERIAL PARA PRIORIZAÇÃO DE ÁREAS À RESTAURAÇÃO FLORESTAL

Palavras chave:
Bacia hidrográfica urbana
Ecologia da Paisagem
Combinação Linear Ponderada
Zona ripária
Conectividade

RESUMO: O processo de urbanização transforma paisagens originais em um mosaico antropizado, causando impactos no ciclo hidrológico, na estrutura e função destas paisagens. Visando à manutenção dos recursos hídricos e da biodiversidade, em uma bacia hidrográfica urbanizada, o objetivo deste estudo foi a definição de áreas prioritárias à restauração florestal. Utilizou-se um método de Avaliação Multicriterial (AMC), seguindo as etapas: definição de critérios, identificação da importância dos critérios e, agregação de critérios por meio do método da Combinação Linear Ponderada (CLP). De acordo com os especialistas consultados, no contexto da Técnica Participatória, apenas dois critérios representavam a paisagem estudada: o proximidade à rede de drenagem e o proximidade aos fragmentos florestais. O primeiro critério foi considerado duas vezes mais importante do que o segundo e, por meio da matriz de comparação pareada, foram obtidos seus pesos de critério, respectivamente, de 0,83 e de 0,17. Estes pesos foram considerados na agregação dos critérios, por meio da CLP. O resultado foi um mapa de priorização de áreas, o qual apontou 5,06% da área de estudo com prioridade muito alta para restauração florestal; 5,22% com alta prioridade; 5,76% com prioridade média; 5,42% com baixa e; 78,53% com prioridade muito baixa. Pode-se assim dizer que a estrutura do processo decisório possibilitou a obtenção de um cenário à priorização de áreas, que direciona as ações de forma a se ter a restauração da paisagem, iniciando-se pela formação de um corredor florestal na zona ripária. Dessa forma, conclui-se que a definição de áreas prioritárias à restauração florestal é possível em uma paisagem urbanizada, utilizando o tradicional método da CLP de análise Multicriterial.

Correspondência:
roavalen@ufscar.br

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[1] Federal University of Sao Carlos - Sorocaba, São Paulo, Brasil
[2] University of Sao Paulo - Itapeva, Piracicaba, Brasil

INTRODUCTION

Urbanization process transforms original landscapes into an anthropic mosaic, causing impacts on hydrologic cycles and on landscape structure and functions. Commonly, one main consequence is the conversion of the native forested areas into patches. Ferraz et al. (2014) highlighted the importance of forest areas in the watersheds, considering that those areas are responsible for maintaining the ecosystem balance.

The transformation of forested areas into patches can cause changes in the ecosystem interaction, especially in the dispersal of populations and the genetic material flow, leading to demographic stochasticity (ALBUQUERQUE; RUEDA, 2010; CEREZO et al., 2010; HEINKEN; WEBER, 2013).

Attanasio et al. (2012) highlighted the influence of forest patches in the maintenance of water resources, thinking in the interception process of rain by the trees. According to Yang et al. (2016), the replacement of riparian forest by urban and/or agricultural land uses causes a decrease in the water quality due to the bank erosion, increasing the nutrients and sediments loading into the rivers.

Forest restoration through the landscape perspective has been considered one feasible solution for maintenance of the biodiversity and water resources (ARONSON; ALEXANDER, 2014). This approach requires the knowledge of landscape structure, aiming at the restoration of the different process as the reduction of forest fragmentation and hydrological flows.

Multicriteria Evaluation (MCE) is one approach that has efficiently been used in the forest restoration process, due to their ability in incorporate the landscape perspective, i.e. with the MCE we can aggregate the criteria, which represents the critical characteristics of landscape structure (VETTORAZZI; VALENTE, 2016).

According to Malczewski and Rinner (2015), MCE has been largely applied to decision analyses and management situations in a variety of application domains. The authors highlight the compensatory methods, especially the Weighted Linear Combination (WLC).

WLC was incorporated in different Geographical Information Systems (GIS) but can also be implemented through the GIS calculator, proposing adequate solutions for the studied problems. Related to forest restoration, Geneletti (2007) determined forest conservation areas in an agriculture landscape; Geneletti and Duren (2008) defined protected area zoning for conservation; Chandio and Matori (2011) planned land use and land cover; Lade et al. (2012) used MCE to solve water supply problems; Amiri et al. (2013) planned watershed land use and land cover; and Vettorazzi and Valente (2016) defined priority areas for forest restoration considering the conservation of water resources.

In this context, the objective of this study was the definition of priority areas for forest restoration in an urbanized watershed, aiming at the maintenance of the water resources and biodiversity.

MATERIAL AND METHODS

Study Area

The study area was the Quilombo river watershed in Americana municipality, central-eastern of São Paulo state, with approximately 4000 ha (Figure 1). Americana was originally covered by Atlantic Forest, that suffered from the agricultural and industrial development. Nowadays, the municipality has a well-established textile hub.

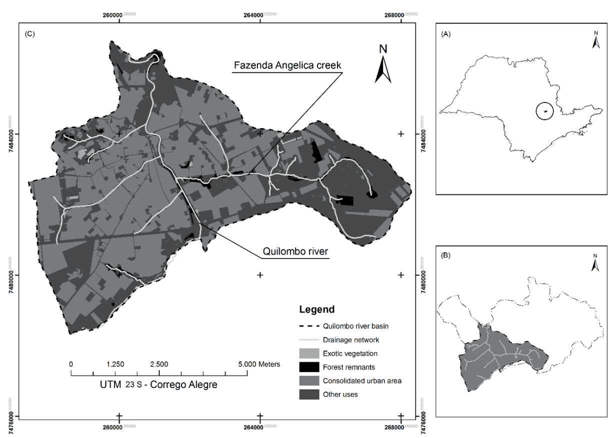

FIGURE 1 Land use and land cover in the Quilombo river watershed (São Paulo state, Brazil).

The Quilombo river runs 7,270m through the municipality, having the Angelica Farm stream as its largest tributary. The authors observed that there are 26 springs in the watershed, although the main problem is the presence of pollutants in the water (MEDEIROS et al., 2009). Quilombo river is part of Piracicaba river basin and it is important for the Americana drainage system. The Americana Municipal Plan (2015) highlights the pollutants problem as a consequence of the urbanization process.

The land-use/land-cover map (Figure 1) shows the predominance of the urban areas in the watershed, occupying 54.97% of the total area. It is followed by the class "other uses", present in 41.82% of the landscape, which is occupied by pastures (i.e. abandoned areas), crops and roads. The native forest remnants cover only 2.78% of the watershed and there is 0.43% of the area occupied by exotic vegetation, i.e. small commercial forest plots with *Pinus* and *Eucalyptus* and also areas dominated by *Leucaena leucocephala*. The last one is an invasive and very aggressive form of dense woody cover that prevent the growth of other tree species.

The Atlantic Forest patches occur mainly along the rivers, especially the Angelica Farm stream, which runs through rural areas and present 41% of total forest patches (total of 34 patches).

The land-use/land-cover map was generated through on-screen digitizing, based on an aerial photograph (original scale = 1:5000), which was standardized by the datum Corrego Alegre, coordinates system UTM (23 S) and the spatial resolution of 2.4 m. The aerial photograph was provided by the Americana City Hall. The final map was verified through field campaign, representing the real landscape.

Priority areas for forest restoration

We used the MCE, with the WLC method, to define the priority areas for forest restoration, following the steps: criteria definition, identification of the criteria importance and criteria aggregation.

Criteria

Criteria are the basis for the MCE framework, considering that they represent the critical characteristics related with the objective of the study and the main restrictions.

In this study, the criteria were defined through the Participatory Technique, as proposed by Malczewski (1999). Thus, experts in the following areas were e-mailed: Forest Management, Hydrology, and Forest Restoration. They received the land-use/land-cover map and we explained that Quilombo river watershed is urbanized, with only 2.78% of native forest and nowadays it suffers from some problems as erosion in the riparian zone, water with an increase in the sediment level and floods. In this scenario, it is necessary to define priority spots, in order to drive actions and resources. The different point of this study is that we have a simplified landscape, even so, we decided to use a traditional WLC method, as in Geneletti (2004; 2005).

A group of eight experts pointed out criteria sets which were shared with the other participants, who responded by revising or giving further arguments supporting their answers. According to the experts, only two criteria can represent this urbanized and simplified landscape: proximity to forest patches and proximity to drainage network. So, the places considered important for forest restoration are those near to forest remnants and to the drainage network. The only constraint indicated was the watershed limits, assuring the analysis only inside the study area.

In order to produce the criteria maps, we extracted from the land-use/land-cover map the features forest patches and drainage network to individual maps. After, we calculated distances from those features, considering the limits of the study area. The distances values were normalized to a common scale (256 values), using a linear monotonically decreasing function. This way, we assured the allocation of highest-priority areas close to forest patches and drainage network.

Criterion weight

Criterion weight expresses the relative importance of criteria, for the decision process objective (VALENTE; VETTORAZZI, 2008). The experts defined the criterion weights in the context of the Pairwise Comparison Method, developed by Saaty (1980), basing on a continuous scale (Figure 2). The value 1 indicates that two criteria are "equally" important and the value 9 implies that one criterion is "extremely" more important than the other. Comparisons values are entered into a Pairwise Comparison Matrix (SAATY, 1980).

FIGURE 2 Continuous scale used to the pairwise comparison of criteria. Source: Saaty (1980).

The main characteristic of the matrix is to be symmetric, consequently, only its upper triangular part should be complete to produce the best fit set of weights. The procedure was done in a GIS environment, although we could obtain the same result summing the values (between 0 to 9) of the first column; dividing each of these entries in the first column by the "summed value of column"; repeating this for each column, and averaging the weights over the columns.

The ratio, named "Consistency Ratio (CR)", indicates any inconsistencies that may have been done during the pairwise comparison process. CR is designed in such a way that if $CR < 0.10$, then the ratio indicates a reasonable level of consistency in the pairwise comparison matrix; if, however, $CR \geq 0.10$, then the ratio values are indicative of inconsistent judgments; in such cases one should reconsider and revise the original values in the pairwise comparison matrix (MALCZEWSKI et al., 2003). In this context, to obtain the ideal comparison value we considered the criteria ranking, according to the criterion relative importance, previously established by the experts and the value of CR.

Weighted Linear Combination (WLC) method

Malczewski and Rinner (2015) highlight the Weighted Linear Combination (WLC) as the most popular MCE method, which was developed by Voodg (1983). According to WLC, the criteria are multiplied by their respective criterion weights and after they are summed, as indicated in equation 1. The operation is done pixel by pixel, allowing that the decision-makers to include landscape features with continuous distributions instead of features represented only by classes, where xi is the score of the ith criterion and wi is it criterion weight.

$$S = \sum w_i x_i \qquad [1]$$

In this context, the WLC was employed in the criteria aggregation, producing a priority map at a 256-values continuous scale for Quilombo river watershed, that was reclassified into five priority levels: very low, low, medium, high, and very high. Firstly, we evaluated the map histogram, thus regions with the same value patterns (homogeneous values) were kept in the same priority classes.

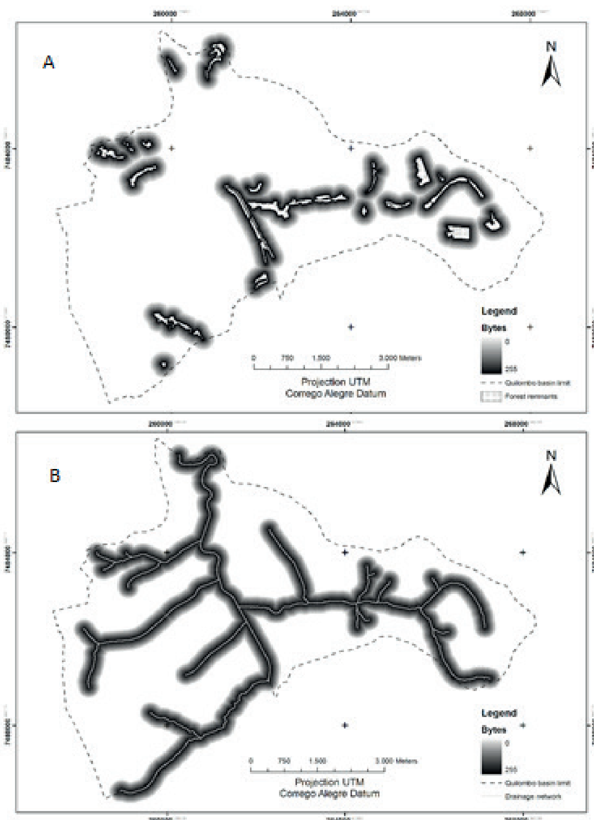

FIGURE 3 Proximity maps: (A) to forest patches and (B) to drainage network, for the Quilombo river watershed (São Paulo, Brazil).

RESULTS

The criteria indicated for prioritization areas for forest restoration in the Quilombo river watershed were, as mentioned, proximity to forest patches and proximity to drainage network (Figure 3).

Proximity to forest patches was justified as important for forest restoration because the spatial distribution of remnants by itself is an indicator of landscape configuration, in terms of their degree of forest fragmentation (TURNER; GARDNER, 1990; YONG; MERRIAN, 1994). The experts highlight the forest connectivity as the only way to obtain restoration at the landscape level (ROY; TOMAR, 2000; KINDVALL; PETERSSON, 2000). In our study landscape, regardless the patch size, the connectivity can be achieved by two ways: through a structural link among forest patches or through a functional connectivity, as mentioned by Uezu et al. (2005).

On the other hand, the experts selected the criterion proximity to drainage network having in mind the priority places to provide the forest connectivity. In this case, it was proposed near to the rivers, i.e. mainly at the riparian zone as also proposed by Forman (1997) and Uezu et al. (2005). This way, the restored areas could have two structural functions in the landscape, the forest connectivity, and the water-quality improvement. Authors as Lima (2005), Lima and Zakia (2006), Mingoti and Vettorazzi (2011) and, Yang et al. (2016) related the effects of riparian zone on the water quality, highlighting that the presence of forest can decrease the sediment production and its amount in the water; and it can also decrease the amounts of sulfates and nitrates.

In this scenario, the experts considered the second criterion twice more important than the first one, based on the continuous scale (Figure 2), resulting in the pairwise comparison matrix presented in Table 1. Thus, the criterion weights obtained for proximity maps were 0.83 for drainage network and 0.17 for forest patches. The CR was 0.06, indicating that the matrix has a reasonable level of consistency and, that we can use the indicated criteria weights for the Quilombo watershed decision problem.

The result was a priority map (Figure 4), indicating 5.06% of Quilombo river watershed with very-high priority for forest restoration; 5.22% with high priority; 5.76% with medium priority; 5,42% with low and; 78.53% with very-low priority.

TABLE 1 Pairwise matrix for the Quilombo river watershed (São Paulo, Brazil).

Criteria	Proximity to drainage network	Proximity to forest patches	Criterion weight
Proximity to drainage network	1		0.83
Proximity to forest patches	2	1	0.17
Consistency ratio (CR) = 0.06		Total	1.00

We can assume that the solution is in accordance with the predefined framework (criteria and weights), considering that places classified as the highest priority were those near to drainage network and those areas surrounded by forest patches (Figures 3 and 4). Consequently, regions that concentrated forest patches were associated to a higher priority level than those only near to the other forest remnants (zoomed regions A and B). This occurs because the framework was defined by the proximity to drainage network with 83% of importance. Thus, as illustrated by the zoomed regions B, C and D, the forest remnants, that were farther away from the river than others, were placed in the high-priority region.

DISCUSSION

The two criteria selected for prioritizing areas were also considered essential in the restoration process by Valente and Vettorazzi (2008) and Pirnat and Hladnik (2016). They represent the critical features of the landscape, which we would like to re-establish (JESUS et al., 2015; MCDONALD et al., 2016), that are the improvement in the water quality and the biodiversity.

The criteria number is a consequence of the landscape structure, considering that the Quilombo river watershed is an urbanized and simplified landscape. Geneletti (2004 and 2005) and Mello et al. (2014) also used, in urbanized landscapes, a reduced group of criteria in their decision problems, wherein the first author aggregated his criteria through the WLC method.

The traditional MCE method allowed, in this study, to assign the importance to the criteria and this was essential to determine priority areas near to the rivers, i.e. in the riparian zone, and considering another purpose that was the connectivity among forest patches. We cannot lose opportunities that exist in the urban areas to enhance ecological functions, even knowing that the strict restoration in an urban condition is not a realistic goal and that the process implies in a “limited

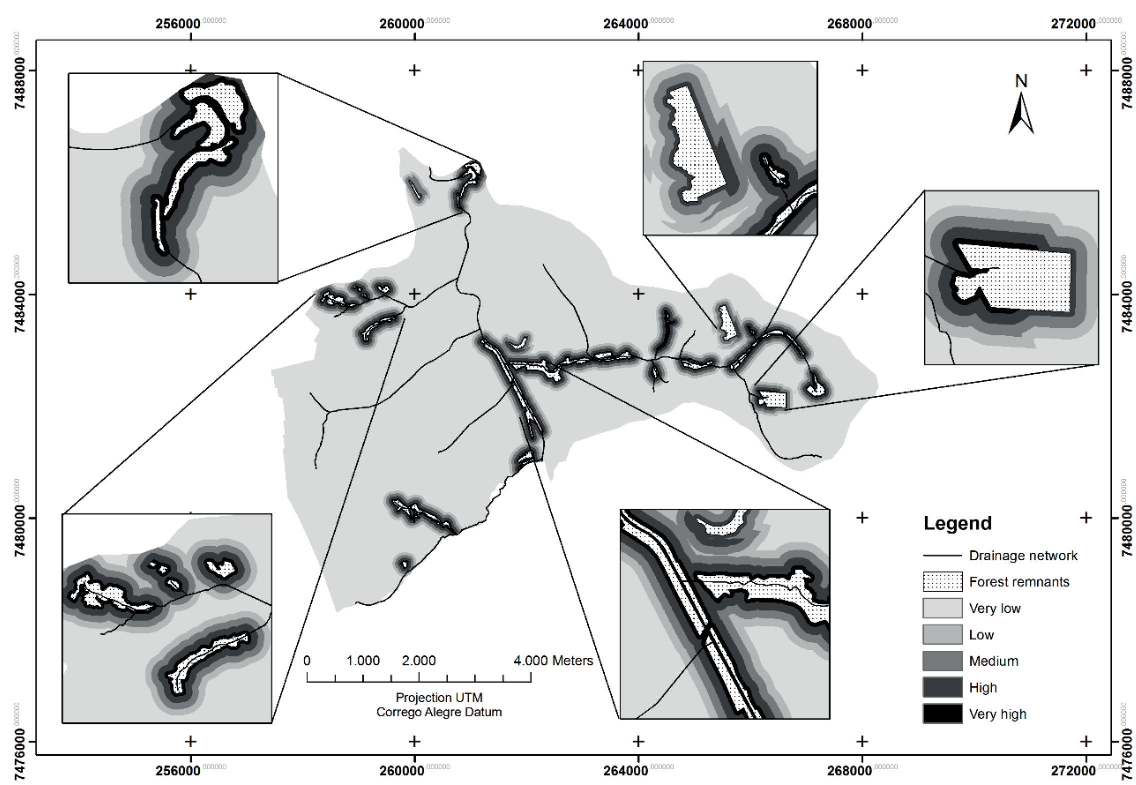

FIGURE 4 Priority areas for forest restoration, aiming at the maintenance of the water resources and biodiversity, in the Quilombo river watershed (São Paulo, Brazil).

mitigation" in terms of ecological, hydrological and aesthetic functions (CADENASSO et al., 2008).

We can mention different positive effects of the riparian restoration, both locally and regionally, such as the control of nonpoint pollution, reduced air and water pollution, prevention of soil erosion, among others (KAUSHAL et al. 2008; VALENTE; VETTORAZZI, 2011; YANG et al., 2016).

The framework predefined for the study (MCE method, criteria, and weights) proposed a scenario for priority areas that allow driving the actions to obtain landscape restoration, beginning through forest corridor in the riparian zone (zoomed regions in Figure 4). The scenario has approximately 11% of landscape associated with the highest priority classes, i.e. the WLC method defined locally the priority areas.

Malczewski et al. (2003), Boroushaki and Malczewski (2008) and Valente and Vettorazzi (2008 and 2011) highlight that WLC is characterized by means, resulting in neutral attitude, i.e. regions classified by medium risk, priority, etc.

The main difference of this decision-problem was the cartographic database, that had the spatial resolution of 2.4 meters, which can be considered as high resolution. Thus, this characteristic contributed, together with the criteria and weights, to minimize the WLC tendency, in terms of the mapping by mean.

The main result was the highest priority placed in order to propose an improvement in the shape and the connectivity of forest patches (Figure 4). In some situations (zoomed region, Figure 4), through the first action we can obtain the second. Thus, the restoration of highest priority areas can result in a forest corridor in this urban landscape, which can promote the forest connection in the urban riparian zone and outside its limits.

In these conditions, we could also have provided an environment for the movement of fauna between disconnected landscapes, in this case, the rural landscapes. Authors as Harper et al. (1992), Forman and Collinge (1997) and Shields et al. (2003) mentioned that the riparian vegetation plays an important role in the maintenance of landscape dynamics, supporting the fauna flow and, consequently, contributes to plant dispersion and forest connectivity.

However, in urban landscapes, the success of the restoration process also depends on the actions related to the protection from the neighborhoods.

CONCLUSION

Definition of priority areas for forest restoration is possible in an urbanized landscape, using the traditional WLC Multicriteria method. We should have in mind that it is not feasible to return the landscape into its original conditions. The restoration process should aim at the maintenance of some important features, which are related to the landscape structure, and commonly have influence in goods and services that directly or indirectly are important for the population.

WLC is a flexible method that is easy to implement, considering the experts or the decision maker opinions through the criteria weights, which in turn can drive the mapping since they represent the importance of the critical feature, i.e. the landscape features related to the decision process purposes.

The priority map of the Quilombo river watershed shows an adequate solution to drive restoration actions, resulting in the establishment of the forested riparian zone.

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