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A Framework for Setting Local Restoration Priorities Based on Landscape Context

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Abstract

Landscape structure is known to affect species persistence and to influence restoration outcomes, especially in fragmented landscapes. Restoration planning should thus incorporate landscape characteristics in decision-making processes in order to optimize efforts and maximize biodiversity conservation. Here we propose a methodological framework that allows comparing candidate sites for restoration in accordance with their importance for increasing local landscape connectivity. The proposed method is based on graph theory analysis and on multiple local habitat removal and restoration simulations. For demonstration purposes, the method was applied for seven 1 ha candidate restoration sites from São Paulo state, Brazil, analyzing habitat connectivity contribution in a surrounding landscape with 1 km of radius. The proposed method allows setting local priorities, and by using local relative importance values, permits also comparing sites situated in different landscape contexts. This method can be used to establish restoration prioritization at a local scale, after a regional prioritization, contributing to a multi-scale restoration planning.

Key words: Restoration Planning, Landscape Connectivity, Graph Theory, Multi-Scale Approach.

Introduction

Restoration of degraded areas is an important strategy to avoid the loss of biodiversity and ecosystem services, and was recognized as one of the world's top priorities during the United Nations Rio +20 conference (UN 2012). Due to the large amount of degraded areas and high restoration costs, there is an urgent need to prioritize areas and set realistic restoration goals in order to optimize restoration efforts (Menz *et al*. 2013).

When aimed at biodiversity persistence, restoration programs should focus on increasing landscape connectivity, and thus reducing the deleterious effects of habitat loss and fragmentation, which are recognized as the main threats to biodiversity (Ewers & Didham 2006). Besides affecting species persistence in human modified regions (Metzger *et al*. 2009; Pardini *et al*. 2010), landscape characteristics are also known to influence restoration outcomes (Leite *et al*. 2013), as well as to be associated with ecological resilience (Pardini *et al*. 2010). In this sense, the analysis of landscape pattern when planning restoration can be useful to optimize biodiversity benefits through restoration actions. Ideally, a multi-scale approach should be adopted when prioritizing and planning restoration actions, allowing for the identification of restoration constraints at site, landscape, and regional scales, and maximizing ecosystem services and benefits for biodiversity conservation in the long term (Hobbs & Norton 1996; Bell *et al*. 1997).

Although there are some initiatives that have already considered landscape characteristics while setting restoration priorities at regional (Rodrigues & Bononi 2008; Gama *et al*. 2013; Tambosi *et al*. 2014) and local scales (Holvorcem *et al*. 2011), there are some issues that still need to be addressed. First, regional studies usually present a large number of areas with similar priority values (e.g. Tambosi *et al*. 2014), prompting a need to create a second priority level considering local characteristics of the landscape. Second, studies in local scales must consider landscape and regional characteristics when identifying local priorities (e.g. Holvorcem *et al*. 2011), but they usually lack comparisons among larger spatial contexts. Finally, restoration planning should consider that the great part of the land in question is likely to be private property, and the owners might not be interested in restoring those areas considered as priority by governments or NGOs. Usually each parcel of private property has some percentage of its land as abandoned or degraded, which may be considered as candidate sites for restoration by their owners (Rodrigues *et al*. 2011). Incorporating these available lands in restoration planning and adopting criteria to prioritize these lands for restoration can represent a great

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opportunity to facilitate the implementation and optimize the efforts of large scale restoration projects.

In this study we present a local-scale method to compare and prioritize candidate areas for restoration with the main objective to conserve biodiversity. This method is based on the importance of candidate areas for maintaining (in the case of restoring existing habitat sites) or improving (when creating new habitat sites) connectivity at the local scale, assessed through graph theory analyses. The proposed method allows also a standardized comparison of candidate sites considering landscapes with different initial habitat amounts and connectivity. We applied the method in the state of São Paulo, Brazil, to test the effectiveness of the proposed methodology in comparing sites, considering landscapes with different habitat amounts and connectivity levels.

Methods

For the purpose of this study, a candidate *site* is a small area of a private property (1 ha) selected by the landowner for restoration actions. This candidate site can be an existing degraded habitat patch which will be restored to improve habitat quality (e.g. by removing superabundant lianas, exotic invasive species or improving the population of late successional species through reintroduction actions, Brancalion *et al.* (2012)), or a non-habitat area that will be restored in order to create a new patch or extend an existing patch inside the property. All candidate sites from different properties need to be analyzed to set priorities for receiving support from institutions financing ecological restoration, like governments, NGOs, private companies and research agencies. The considered size of candidate sites adopted in this study is compatible with the scale of current abandoned areas by small landowners in the Atlantic forest (Rodrigues *et al.* 2011).

The proposed method to prioritize candidate sites considers their relative importance to maintain or improve landscape connectivity at a larger scale, using dispersal capability of forest dweller bird species during the analyses. This method can be divided in the following five steps (Figure 1): i) delimitation of landscapes for local analysis (hereafter focal landscapes, FL); ii) division of FL in 1 ha hexagonal cells; iii) habitat removal experiments to calculate the importance of each habitat cell to maintain connectivity; iv) habitat creation experiments to identify the importance of each non-habitat cell for improving connectivity through restoration; and v) determining the relative importance of the candidate site when compared to surrounding cells in the same FL.

Step 1 – Delimitation of focal landscape

The FL was delimited considering a 1 km radius from the candidate *site* cell. The adopted radius was considered by Boscolo & Metzger (2009) as a relevant landscape context that influences birds' species occurrence, which are important biological indicators in the Atlantic Forest (Banks-Leite *et al.* 2011). We also considered an extra buffer to include the information of landscape composition in the 1 km radius around the inner circle (Figure 1A), thus each FL was represented by a 2 km radius (view supplementary material** for more comments on FL size). In the case of adopting a different ecological group with different dispersal capabilities, other criteria should be used to define the size of FLs (refer to supplementary material for more information).

Step 2 – Division of focal landscapes

The central area of the FL, delimited by the 1 km radius around the candidate site, was divided in hexagonal cells (Figure 1B) with the same size of the candidate restoration site (1 ha), which were used to conduct the habitat removal (step 3) and habitat creation (step 4) experiments in order to identify the relative importance of each cell to maintain or increase landscape connectivity.

All connectivity analyses were based on graph theory due to its simplicity, robustness, and capacity to incorporate species functional attributes (Urban & Keitt 2001). We used the software Conefor Sensinode 2.5.8 to conduct the analysis and adopted the Probability of Connectivity (PC) index, which is considered a robust index to detect changes in landscape connectivity due to creation or removal of patches (Saura & Pascual-Hortal 2007).

More details about habitat map used on analysis, tools used to divide landscape in hexagonal cells, cells size, PC formula and calculation are shown in the supplementary material.

Step 3 – Habitat removal experiments

First the PC index for the FL was calculated considering all existing habitat patches. Then habitat removal experiments were simulated by removing each hexagonal cell occupied by habitat and then recalculating the PC index. The variation in the PC index (ΔPC) promoted by the removal of a cell represents the importance of that cell for the FL connectivity (Figure 1C). Those cells that presented higher ΔPC were considered to be the most important to maintain FL connectivity and should be considered priority for restoration actions focused in increasing habitat quality.

Step 4 – Habitat creation experiments

The habitat creation experiments consisted in simulating the creation of habitat inside each non-habitat hexagonal cells and recalculating the PC index (Figure 1D). Those hexagonal cells that, when restored, promoted the larger

**see supplementary material available at abeco.org.br.

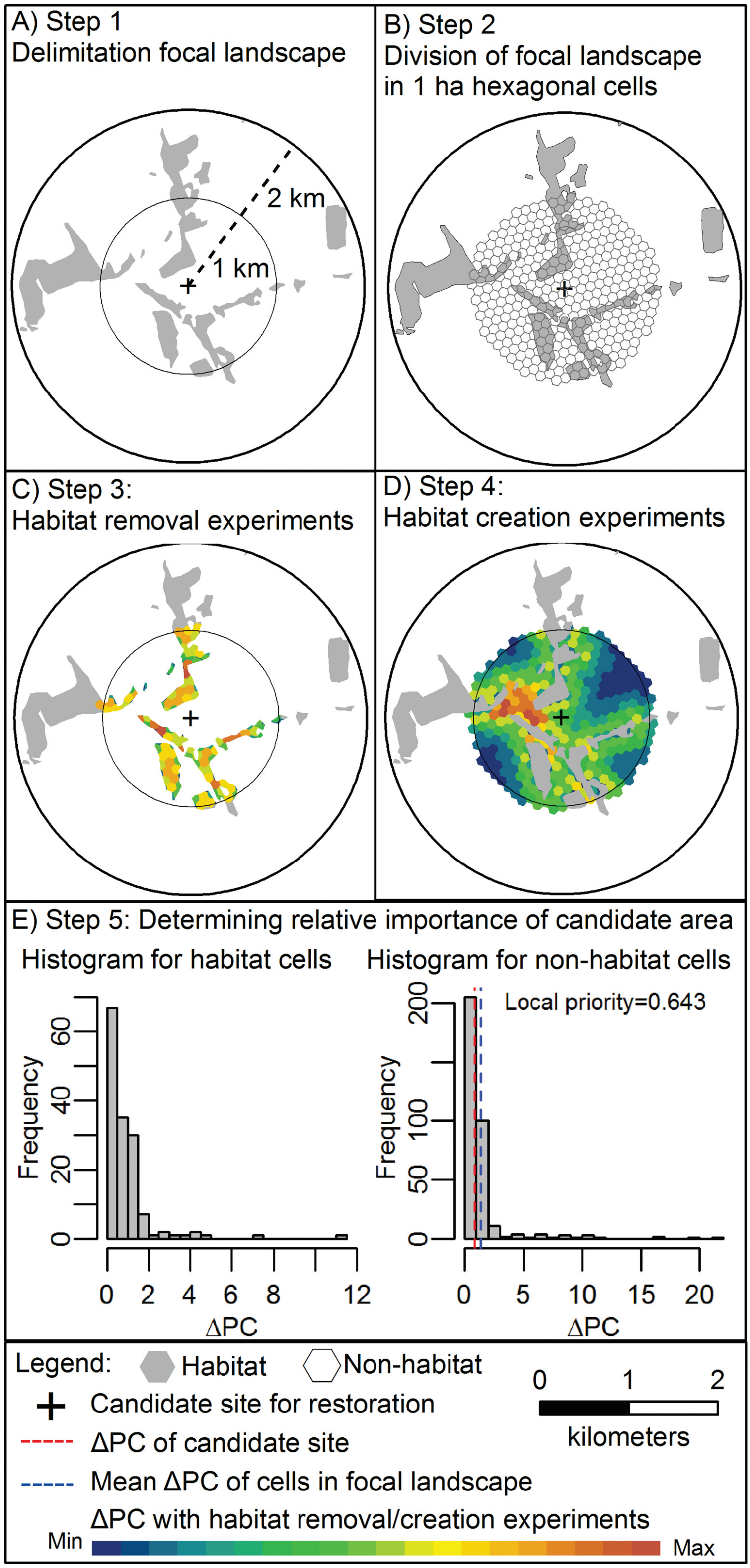

Figure 1. Representation of the five main steps of the proposed method to set local restoration priorities based on landscape context. A) delimitation of focal landscape (FL) based on a 2 km radius from the candidate site for restoration; B) division of the central region of FL (1 km radius) in 1 hectare hexagonal cells to conduct habitat removal (C) and habitat creation experiments (D) to identify which regions in the FL would promote greater variation in the Probability of Connectivity index (ΔPC) of the FL when restored. E) Definintion of local relative priority for restoration by dividing the ΔPC value of the candidate site (red dashed line in histogram) by the average ΔPC value of all cells in the 1 km radius (blue dashed line in histogram). The histograms show the number of cells in each class of ΔPC value.

ΔPC can be considered the most important for increasing landscape connectivity.

Step 5 – Determining the relative importance of candidate area

Due to the index formula, the PC and ΔPC values are extremely dependent on the amount of habitat in each FL. In order to allow the comparison of FL with different habitat amount, we determined the relative importance of a candidate site, when compared to their surrounding cells. The relative importance was calculated by dividing the ΔPC value of the candidate site cell (red dashed line in Figure 1E) by the average value of ΔPC from all cells in the 1 km radius (blue dashed line in Figure 1E). The surrounding cells average considered only habitat cells when the candidate site was a habitat site and only non-habitat cells when the candidate site was a non-habitat cell (Figure 1E). The higher the ratio value, the highest is the importance of the candidate site when compared to its surrounding cells, and thus, highest restoration priority. Values above 1 indicate sites with contribution above the average in the surrounding 1 km.

The proposed methodological procedures were applied to seven randomly selected candidate sites in the state of São Paulo, Brazil. These sites were selected to simulate candidate areas for restoration in private properties (central panel in Figure 2).

Results

All candidate sites were located in areas considered of high and very high regional restoration priority (central panel in Figure 2). Sites 1 and 5 were candidates for habitat quality improvement through the restoration of existing habitat patch in the FL, while the other five sites were candidates for creation of new habitat by restoration actions (Figure 2).

The FL's varied in percentage of habitat cover (from 10.9 to 37.2%) and PC index (from 0.012 to 0.139, Figure 2).

The comparison of the relative importance of each candidate site, showed that site 2, when restored, will promote an increase in the PC index that will be 13.7 times greater than the mean increase caused by alternative restoration of its surrounding cells and can be considered the most important for restoration actions inside the FL (Figure 2).

All other candidate sites presented ΔPC values smaller than the average values of their surrounding cells (local priority <1, Figure 2). Despite the low habitat cover and connectivity in the FL, sites 7 and 1 were considered the second and third local priority for restoration (local priority = 0.643 and 0.539, respectively) due to their contribution to landscape connectivity (Figure 2).

Although FL from site 6 presented the highest habitat cover and connectivity, the candidate site for restoration was located far from existing habitat patches and would result in small contribution to landscape connectivity, and was considered the lowest priority among all sites (0.004, Figure 2). The high isolation of candidate sites 3 and 4 also resulted in low local priority for restoration.

Discussion

The comparison of the candidate sites for restoration with other sites in the same FL allowed identifying the relative importance of each candidate site for improving FL connectivity. By using the ratio *candidate site ΔPC/average ΔPC of surrounding cells*, it was possible to compare sites situated in different landscape contexts.

Setting restoration priorities can be a controversial issue since some authors suggest prioritizing more degraded sites (Crossman & Bryan 2009) while others suggest prioritizing intermediate degraded sites to optimize cost benefit ratios (Pardini *et al*. 2010). Although higher degradation levels are associated with higher restoration costs and lower restoration outcomes (Hobbs *et al*. 2009), in disturbed landscapes, with low connectivity, several species can still be present in the vegetation remnants due to the short time since perturbation (Metzger *et al*. 2009) and they can be lost if no action is taken to improve habitat quality and quantity (Tilman *et al*. 1994). In these situations, when the main objective of restoration is to conserve biodiversity, actions to improve habitat quality and connectivity are of primordial importance.

For this reason, the proposed method did not include the degradation level or the restoration cost (and effectiveness) in the prioritization process. The decision to support restoration in more or less degraded conditions can thus be taken *a posteriori*, considering a complete new set of parameters (disturbance history, endangered or endemic species occurrences, opportunity cost, for example).

Besides optimizing the improvement of connectivity due to restoration actions, considering the position of candidate sites in the landscape can avoid prioritizing non-optimal actions such as the creation of isolated habitat patches and the improvement of habitat quality in small and isolated patches. These non-optimal sites can present important constraints to restoration outcomes, impeding the recovery of several ecological processes due to high isolation of restored areas (Pardini *et al.* 2010; Leite *et al*. 2013), and will also result in very small ΔPC values when compared to their surrounding regions. The optimal candidate cells are those highly connected habitat patches that can increase habitat quality and also facilitate biological fluxes in existing routes, and also non-habitat cells that will improve habitat area and also connectivity creating new routes among patches. Thus, restoration of both optimal cells will increase functional connectivity, and consequently, habitat availability and should be considered as priorities.

Moreover, the habitat creation and habitat removal experiments based on a graph theory approach also revealed

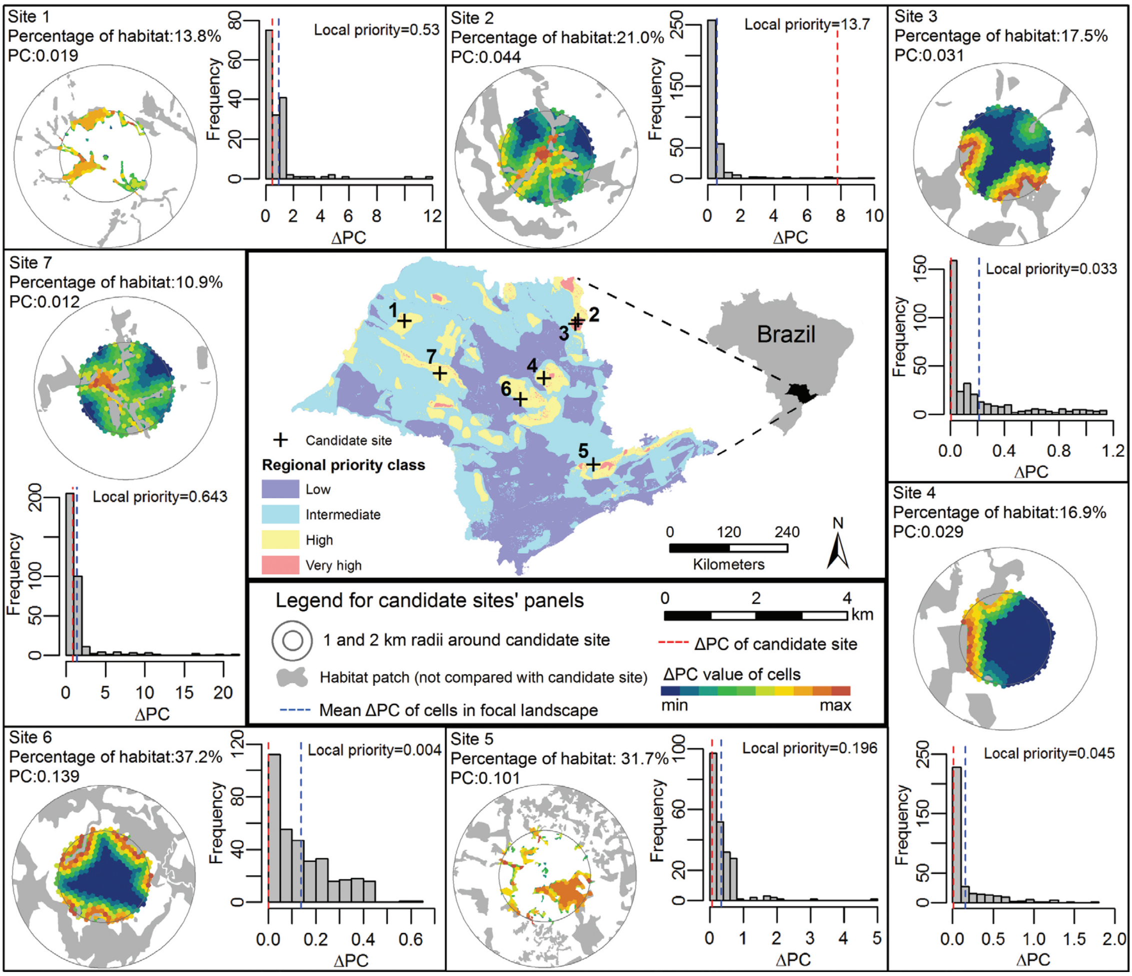

Figure 2. Location of candidate sites for restoration in different classes of regional priority for restoration actions in São Paulo state, Brazil (central panel, modified from Rodrigues & Bononi (2008)). External panels show the focal landscapes in the 2 km radius of each candidate site with the percentage of habitat cover and the Probability of connectivity (PC) index; the variation in PC values (ΔPC) during habitat removal (sites 1 and 5) and habitat creation experiments (sites 2, 3, 4, 6 and 7) in the 1 km radius. Histograms represent the number of hexagonal cells in each class of ΔPC. The candidate site ΔPC value (red dashed line in histograms) was divided by the average ΔPC value of all cells in the 1 km radius (blue dashed line in histograms) to obtain the local restoration priority (values on top of histogram).

the ideal areas for restoration actions that would maintain or increase connectivity inside each FL. Thus, a similar approach can help landowners in reallocating the candidate areas for restoration inside their rural properties.

Finally, the proposed method should be integrated with other larger scale restoration prioritizations (e.g. Rodrigues & Bononi 2008; Tambosi *et al.* 2014), for example summing prioritization at different scales, resulting in a multi-scale approach. Such approach has long been considered essential towards more efficient strategies to restore several ecosystem services and conserve biodiversity (Bell *et al.* 1997; Holl & Aide 2011), but has rarely been applied to restoration actions (Holl *et al.* 2003; Leite *et al.* 2013).

Although requiring very little biological information, the proposed method considered functional landscape connectivity to compare candidate sites in different landscape contexts. These comparisons allowed identifying the ideal restoration areas for improving connectivity and also avoiding restoration in sites where landscape configuration would limit the restoration outcomes. Moreover, the possibility of comparing priorities among areas which are already considered candidates for restoration by their owners and also coupling this prioritization with larger scale methods represents an opportunity to better guide restoration and conservation policies. The proposed prioritization method can be used to rank candidate sites included in payment for ecosystem services programs focused on biodiversity conservation and also to prioritize among candidates for receiving funds for restoration actions.

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