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Research Letters

Where matrix quality most matters? Using connectivity models to assess effectiveness of matrix conversion in the Atlantic Forest

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ABSTRACT

Great interest has been devoted to understand how agricultural matrix managements affect species flux in the patchy landscapes and agroforestry systems are known to enhance connectivity for forest dwelling species. In the Brazilian Atlantic Forest, high degree of fragmentation makes the implementation or the conservation of the existing agroforestry systems keystone to connectivity conservation. We located places in the Atlantic Forest where agroforestry restoration is more effective in terms of connectivity conservation using a multi-scale approach. We conducted a large scale regional analysis to identify regions in which matrix conversion has larger effect on bird functional connectivity. Furthermore, we conducted two separate local analyses in the landscape which accounted for high restoration effectiveness in the regional analysis. One was the overlap with the Forest Code debt map to assess where and how much land-owners must restore as obligated by law. The second local analyses consisted in locating areas which least cost path trajectories density is larger within the selected landscape. Matrix restoration effort would be largely maximized by acting on specific places, and multi-scale and interdisciplinary models that account for the biological response of biodiversity and contextualizes under environmental laws will foster effective conservation policies.

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Introduction

Connectivity concerns the capability of the landscape in facilitating species flux and is vital for conserving biodiversity in patchy environments (Taylor et al., 1993). Through landscape connectivity, recolonization can balance local extinction, a process called “rescue effect” (Brown and Kodric-Brown, 1977) maintaining populations in space and time. Because, around one third of the terrestrial ice-free surface of the world is covered by some kind of agricultural system (Ramankutty et al., 2008; Foley et al., 2011), great interest has been devoted to understanding how different agricultural managements influence landscape connectivity (Perfecto and Vandermeer, 2008). Agriculture is also considered the single greatest cause of biodiversity loss (Green et al., 2005). Furthermore, the footprint of agriculture is predicted to increase in the near future, increasing the cultivated area, degrading soil and water and negatively affecting ecosystems services (Laurance et al., 2014). According to the classical definition, matrix is the largest land-use type in a given landscape (Forman, 1995). In degraded and fragmented regions the matrix is often composed by anthropogenic habitat, and generally agricultural managements (Perfecto and Vandermeer, 2008). Therefore, in many landscapes, habitat patches are embedded in agricultural matrices, and organisms inhabiting such patches often present metapopulation dynamics (Perfecto and Vandermeer, 2008). These agricultural matrixes may serve as a conduit or a barrier to species dispersal depending on the type of management they are subjected to (Perfecto and Vandermeer, 2008). Agroforestry systems are known to facilitate flux of species in the matrix (Perfecto and Vandermeer, 2008; Asare et al., 2014). On the other hand, intensive agricultural systems such as pasture and other monocultures act as barriers to dispersal of forest species (Robertson and Radford, 2009).

Connectivity is composed by two elements: structural and functional (Uezu et al., 2005). Structural connectivity concerns the proximity among habitat patches, the presence of corridors and matrix permeability. On the other hand, functional connectivity refers to the species-specific response to this structure (Uezu et al., 2005). In the Brazilian Atlantic Forest region, both structural and functional connectivity are important for species conservation (e.g. Uezu et al., 2005).

The Atlantic Forest biome occurs in Brazil, Argentina, Uruguay and Paraguay and it has being considered global priority site for conservation (Myers et al., 2000). Between 11 and 16% of the original cover remains and most of the forest patches smaller than 50 ha which increases the risk of extinction for many forest species (Ribeiro et al., 2009). Because of this extremely high species richness and high degree of fragmentation, it is expected that local and global extinction events take place among Atlantic forest birds in a near future (Metzger et al., 2009). Therefore policies that act implementing agroforestry systems in anthropogenic matrices are keystone to biodiversity conservation in the biome. Financial resources for conservation are scarce, hence conservationists must define areas in which conservation policies are optimized, identifying where conservation actions intensively affects more species (Sarkar and Illoldi-Rangel, 2010; Jenkins et al., 2010). Finally, conservation actions must be contextualized in the legislation and policy issues in order to move from theory to practice. Concerning this aspect, any restoration management in the Atlantic Forest, as well as in other Brazilian biomes, must be rooted on the New Forest Code (Soares-Filho et al., 2014).

We assessed the response of bird connectivity to agricultural matrix conversion in assess priorities sites for matrix conservation in the Atlantic Forest of Minas Gerais State using a cross-scale framework. We hypothesize that connectivity increment caused by matrix restoration will affect preferably certain landscape configurations, as well as affect species differently according to their dispersal abilities.

Methods

This framework uses a regional and a local analysis for matrix restoration. In the regional analyses we used binary forest and non-forest map of the Atlantic Forest, located places where four endemic bird species occur, simulated the conversion of the matrix into three different land-use (low, medium and high quality) and calculated the increase in functional connectivity caused these conversions (Fig. 1). We selected the following passerine birds, all of them endemic to the Atlantic Forest: *Chiroxiphia caudata* (Blue Manakin), *Xiphorhynchus fuscus* (Lesser Woodcreeper), *Pyriglena leucoptera* (White shouldered fire eye) and *Sclerurus scansor* (Rufous-brested Leaftosser). For further information about these species and why they were selected, see supplementary material. We then identified places where matrix restoration is most effective in terms of functional connectivity conservation for these species assuming homogeneous matrixes types. In the local analyses, we assess areas in which matrix restoration would be recommended at small scale within the region that accounted for highest levels of restoration effectiveness in the regional analyses. To do this we used land-use maps to account for matrix heterogeneity and identify least cost paths trajectories, and the density of trajectories among the largest forest patches. Furthermore, we made a separate analysis which takes into account the Forest Code offset balance to locate where restoration is obligatory by law at local scale.

Regional analyses

The regional analysis consisted in selecting 40,000 ha landscape cells in which the four endemic bird species occur in the State of the Minas Gerais using a binary of forest and non-forest habitat (S.O.S. Mata Atlântica, available at http://www.sosmatatlantica.org.br). Using these maps, we assumed three hypothetical matrix quality scenarios. The matrix quality was assumed to be low (pasture and monoculture), medium (polyculture and home gardens) and high (rustic agroforestry). We used literature records to defy dispersal thresholds for the species in these different matrices and used these values to model functional connectivity (see supplementary material). We calculated functional connectivity (IIC) of the species using Conefor Sensinode 2.2 (Saura and Torné, 2009). Than we subtracted the IIC produced after treatments (matrix permeability scenarios), so that for each grid and for each species, we calculated:

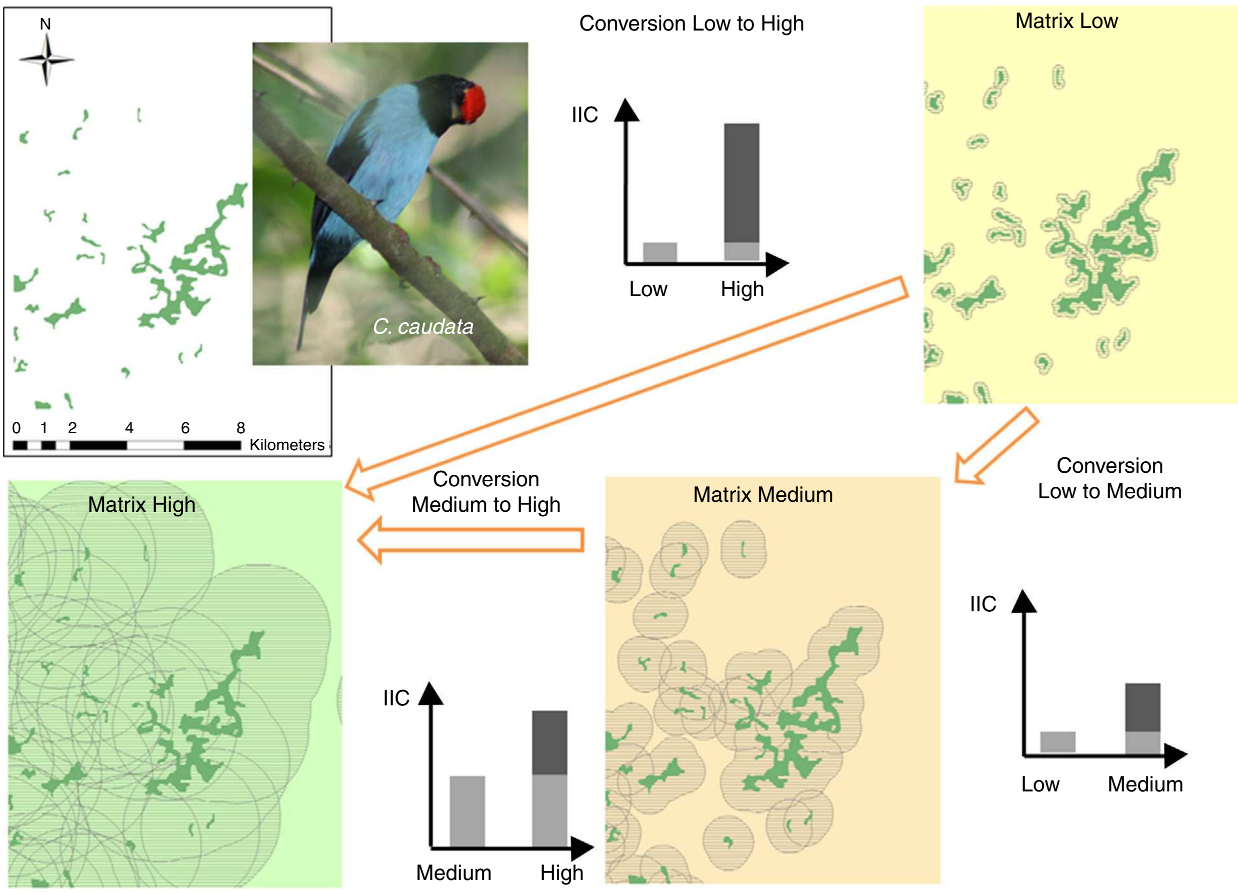

Fig. 1 – Diagram showing the procedures of the macro analyses. On the top left is the original forest cover map (green) of a portion of a landscape cell. Low, medium and high matrix quality are associated to the species dispersal threshold (dashed buffer around forest patches). We used the dispersal threshold for *C. caudata* (Photo by FFG) as an example. For each of the three conversion scenarios (orange arrows), we calculated the increment of the IIC, which is represented by dark gray bars in the graphics.

IIC Increment$_{L-M}$: Increase in IIC by converting matrix management from low to medium
IIC Increment IIC$_{M-H}$: Increase in IIC by converting matrix management from medium to high
IIC Increment IIC$_{L-H}$: Increase in IIC by converting matrix management from low to high

Diagrammatic representation of the procedures of the regional analyses is shown in Fig. 1.

Local analyses

We selected the landscape which accounted for the largest total median IIC increment (concerning all species) to conduct two separate local analyses for matrix restoration prioritization. The first analysis is the prioritization of areas according to the Forest Code debt. This was done using the Forest Code debt map (Soares-Filho et al., 2014) of each watershed with the selected landscape cell. This analysis showed how much and where restoration is obligatory by law. The second local analyses involved locating areas in which bird dispersal routes among large patches overlapped in greater extent. We selected the four largest fragments in the landscape cell and made the entire possible least cost path among their centroids. The cost surface raster was the land-use map (Soares-Filho et al., 2014) associated to the cost values of each pixel given the proportion of the potential dispersal in each land-use type (see supplementary material for estimating cost of each land use type for each bird species). Finally, we conducted a line density analyses to locate areas in with dispersal routes co-occurred.

Results

Species where differently affected by landscape matrix conversion (Fig. 2). *C. caudata* was the most affected species by the low to high conversion when considering species separately and all grids together. This shows that this species could be more positively affected by overall matrix restoration. *S. scansor* and *P. leucoptera* was less affected by low to medium conversions, while *X. fuscus* and *C. caudata* was more affected by such transition. Therefore, if functional connectivity for *S. scansor* and *P. leucoptera* species are to be conserved, medium to high matrix conversions are necessary. On the other hand

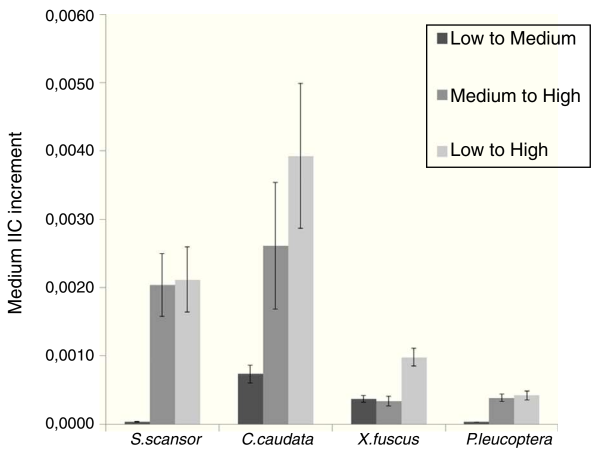

Fig. 2 – Median IIC increment due to matrix conversion in all cells for each species. Error bars stands for first and third quartile.

lower quality transition, such as low to medium may affect positively *X. fuscus* and *C. caudata*.

Landscape cells greatly differed on their median IIC increment (Fig. 3), showing that the influence of conversion on some cells is disproportionally greater than others. Very few cells presented high values of median delta IIC, while in the great majority of the cells, this value is closed to zero. Therefore, matrix conversion affects functional connectivity differently according to landscape configurations. The landscape cell which accounted for largest Total median IIC increment is located in the Municipality of Jequinhonha in the Almenara and Pedra Azul County in the North of the Reserva Biológica da Mata Escura. Fig. 4 shows the local assessment of the restoration priority in this landscape cell according to Forest Code debt (a) and for least cost path trajectories densities (b).

Discussion and conclusion

Species showed different responses to conversion, and *C. caudata* suffered higher increase in functional connectivity caused by matrix conversion, while *P. leucoptera* showed lower increase. Lower quality matrix conversion (low to medium conversion scenario) had little effect on *S. scansor* and *P. leucoptera*. Therefore, if these last two species are chosen as conservation targets, medium to high matrix conversions should be priority. Because most of species treated here may suffer from local extinction (Uezu et al., 2005), matrix agroforestry restoration can in balance local extinction via "rescue effect". Our results show that increasing in the matrix quality

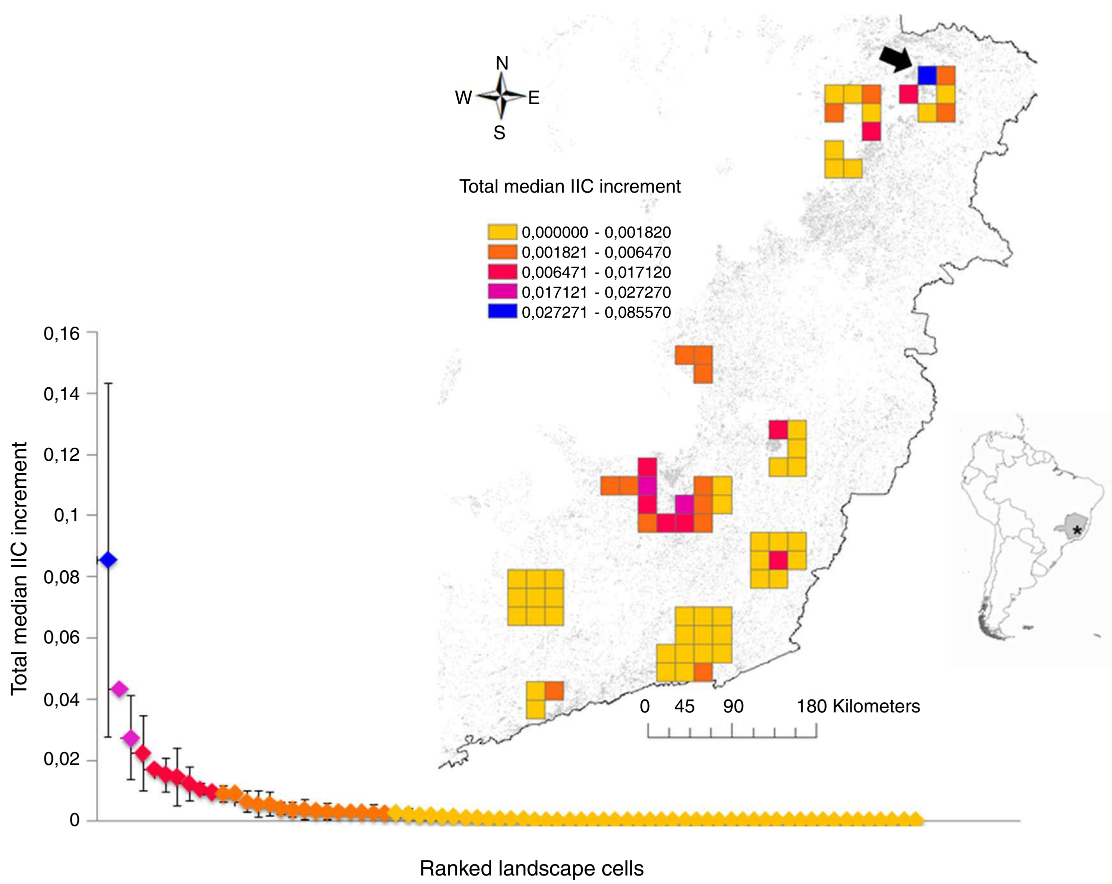

Fig. 3 – Spatial distribution, total median IIC increment and the first and third quartiles in all two non-overlapping conversion scenarios (low to medium and medium to high) for the four species in each cell. Map on the top right showing the median values of the landscape cells. Black arrow indicates the cell with the highest Total median IIC increment and was selected for the local scale anlyses.

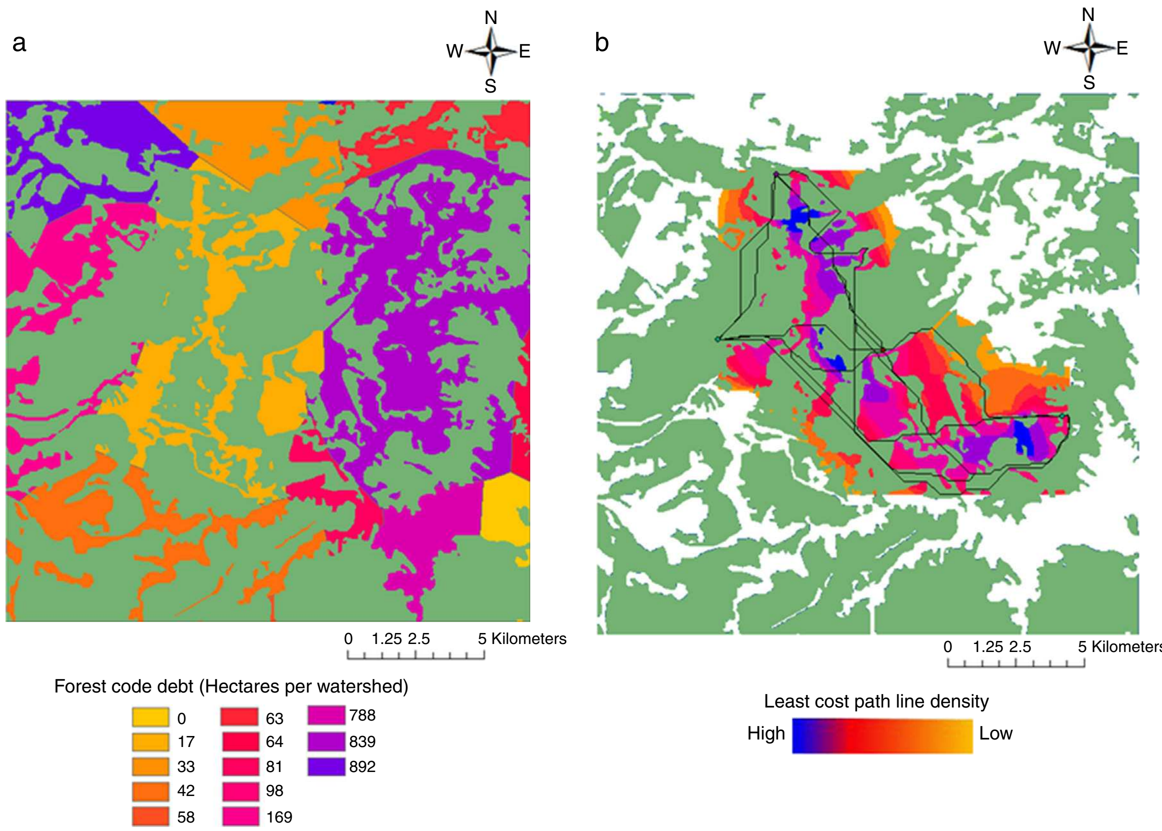

Fig. 4 – Area of the Forest Code debt in hectares per watershed (a) and 12 least cost paths and the trajectory density among the centroid of the four largest forest patches (b).

leads to an increase on the functional connectivity for forest birds in the Atlantic Forest landscapes due to the increase in species dispersal. Despite of this, the influence of matrix conversion greatly differed among landscapes. Very few cells accounted for high values of delta IIC, while the majority of the cells presented low values (closed to zero), which shows that restoration/conservation of agricultural matrix may have very different effectiveness according to landscapes characteristics. IIC is a measure of landscape functional connectivity that is largely influenced by habitat area (Saura and Rubio, 2010). Therefore, as in this case, the area is fixed, the small increment in IIC is exclusively given by reachability increase caused by dispersal threshold augment. Therefore, this small value of IIC increase can be due to underestimation of landscape configuration in the IIC formula. Despite of this, it has shown to be satisfactory as a mean of comparison and for selecting areas which restoration is most effective.

Another issue that raises form the results is the characteristics that foster greater matrix restoration effectiveness. Although this issue is beyond the scope of this paper, this is being assessed by other studies (Goulart, 2012). We hypothesize that intermediate levels of landscape isolation confers high effectiveness in matrix restoration in terms of functional connectivity conservation, although problems with experimental design make this issue rather inconclusive at this point (Goulart, 2012). Another limitation of the regional analyses in not accounting for spatial heterogeneity, which can largely influence dispersal through the matrix (Revilla et al., 2004; Revilla and Wiegand, 2008). The reason for this is the methodological unfeasibility of considering heterogeneity in such a large scale. Therefore, we considered all three matrix conversion scenarios in order to calculate the median increment of all possible land conversion irrespectively of the actual land-use. On the other hand, heterogeneity was successfully addressed in the local analyses in the least cost path analyses.

Concerning the local assessment, most of the watersheds in the selected landscape cell have some debt according to the Forest Code. A recent study on the set-aside strategy for restoration of the Atlantic Forest based on ecosystems services payment showed that less than 10% of the Brazilian agricultural subsidies could support effective restoration in private land (Banks-Leite et al., 2014). Although the authors used a promising framework, the analyses of restoration of the Atlantic Forest without considering the Forest Code (no. 12727 10/17/2012) and the Atlantic Forest Law (no. 11.425) may lead to results which have low applicability for management. Our study shows that in the landscape cell which has largest matrix restoration effectiveness for functional connectivity has a significant Forest Code debt, which makes the restoration obligatory in those areas. This is the first study, that we are aware of, that associates Forest Code new policy with spatial explicit models concerning functional connectivity.

We suggest that this framework be used in other regions and using other organisms.

Finally we delineate, where within the most effective landscape cell in terms of regional connectivity, matrix restoration priority at local scale is. Although most studies on least cost path is related to corridor effectiveness (Pinto and Keitt, 2009; LaRue and Nielsen, 2008), we used the same basic idea for non-linear matrix restoration. By using line density we define areas that are already used as dispersal routes to by restoring these areas, increase the functional connectivity for birds.

This study address where matrix matter most in terms of functional connectivity conservation, and in terms of restoration legislation using a cross-scale framework. Models that associate the biological response of species and the law obligation context at multiple scales can increase the applicability of conservation strategies without losing the ecological bases of management.

Conflicts of interest

The authors declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ncon.2015.03.003.

REFERENCES

Asare, R., Afari-Sefa, V., Osei-Owusu, Y., Pabi, O., 2014. Cocoa agroforestry for increasing forest connectivity in a fragmented landscape in Ghana. Agrofor. Syst., 1–14.

Banks-Leite, C., Pardini, R., Tambosi, L.R., Pearse, W.D., Bueno, A.A., Bruscagin, R.T., et al., 2014. Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot. Science 345 (6200), 1041–1045.

Brown, J.H., Kodric-Brown, A., 1977. Turnover rates in insular biogeography: effect of immigration on extinction. Ecology 58 (2), 445–449.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., et al., 2011. Solutions for a cultivated planet. Nature 478 (7369), 337–342.

Forman, R.T., 1995. Some general principles of landscape and regional ecology. Landsc. Ecol. 10 (3), 133–142.

Green, R.E., Cornell, S.J., Scharlemann, J.P., Balmford, A., 2005. Farming and the fate of wild nature. Science 307 (5709), 550–555.

Goulart, F.F., (PhD dissertation) 2012. Uso de modelos para avaliar a influência da matriz de paisagens fragmentadas sobre aves do Cerrado e da Mata Atlântica. Universidade de Brasília, Brasília.

Jenkins, C.N., Alves, M.A.S., Pimm, S.L., 2010. Avian conservation priorities in a top-ranked biodiversity hotspot. Biol. Conserv. 143 (4), 992–998.

LaRue, M.A., Nielsen, C.K., 2008. Modelling potential dispersal corridors for cougars in midwestern North America using least-cost path methods. Ecol. Model. 212 (3), 372–381.

Laurance, W.F., Sayer, J., Cassman, K.G., 2014. Agricultural expansion and its impacts on tropical nature. Trends Ecol. Evol. 29 (2), 107–116.

Metzger, J.P., Martensen, A.C., Dixo, M., Bernacci, L.C., Ribeiro, M.C., Teixeira, A.M.G., Pardini, R., 2009. Time-lag in biological responses to landscape changes in a highly dynamic Atlantic forest region. Biol. Conserv. 142 (6), 1166–1177.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403 (6772), 853–858.

Perfecto, I., Vandermeer, J., 2008. Biodiversity conservation in tropical agroecosystems. Ann. N. Y. Acad. Sci. 1134 (1), 173–200.

Pinto, N., Keitt, T.H., 2009. Beyond the least-cost path: evaluating corridor redundancy using a graph-theoretic approach. Landsc. Ecol. 24 (2), 253–266.

Ramankutty, N., Evan, A.T., Monfreda, C., Foley, J.A., 2008. Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. Glob. Biogeochem. Cycles 22, GB1003.

Revilla, E., Wiegand, T., Palomares, F., Ferreras, P., Delibes, M., 2004. Effects of matrix heterogeneity on animal dispersal: from individual behavior to metapopulation-level parameters. Am. Nat. 164 (5), E130–E153.

Revilla, E., Wiegand, T., 2008. Individual movement behavior, matrix heterogeneity, and the dynamics of spatially structured populations. Proc. Nat. Acad. Sci. 105 (49), 19120–19125.

Robertson, O.J., Radford, J.Q., 2009. Gap-crossing decisions of forest birds in a fragmented landscape. Austral Ecol. 34 (4), 435–446.

Ribeiro, M.C., Metzger, J.P., Martensen, A.C., Ponzoni, F.J., Hirota, M.M., 2009. The Brazilian Atlantic Forest: how much is left, and how is the remaining forest distributed? Implications for conservation. Biol. Conserv. 142 (6), 1141–1153.

Sarkar, S., Illoldi-Rangel, P., 2010. Systematic conservation planning: an updated protocol. Nat. Conserv. 8, 19–26.

Saura, S., Rubio, L., 2010. A common currency for the different ways in which patches and links can contribute to habitat availability and connectivity in the landscape. Ecography 33 (3), 523–537.

Saura, S., Torné, J., 2009. Conefor Sensinode 2.2: a software package for quantifying the importance of habitat patches for landscape connectivity. Environ. Model. Softw. 24 (1), 135–139.

Soares-Filho, B., Rajão, R., Macedo, M., Carneiro, A., Costa, W., Coe, M., Alencar, A., 2014. Cracking Brazil's forest code. Science 344 (6182), 363–364.

SOS Mata Atlântica, Instituto Nacional de Pesquisas Espaciais, 2008. Atlas dos remanescentes florestais da Mata Atlântica, período de 2000 a 2005. http://www.sosmatatlantica.org.br

Taylor, P.D., Fahrig, L., Henein, K., Merriam, G., 1993. Connectivity is a vital element of landscape structure. Oikos, 571–573.

Uezu, A., Metzger, J.P., Vielliard, J.M.E., 2005. Effects of structural and functional connectivity and patch size on the abundance of seven Atlantic Forest bird species. Biol. Conserv. 123 (4), 507–519.