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Jean-Christophe Foltête

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HOW ECOLOGICAL NETWORKS COULD BENEFIT FROM LANDSCAPE GRAPHS: A RESPONSE TO THE PAPER BY SPARTACO GIPPOLITI AND CORRADO BATTISTI

Jean-Christophe Foltête

ThéMA, UMR 6049 CNRS / University of Bourgogne Franche-Comté, 32, rue Mégevand F-25030 Besançon, France

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Abstract

Ecological networks are tools for conservation planning that rely on the concept of connectivity. Criticisms leveled at them are that they are widely used in a dogmatic way regardless of how they compare against other tools and that their efficiency is rarely assessed. I propose to include landscape graphs in the debate because they are designed to be operational models of ecological networks. I outline the key features of landscape graphs that can be matched with some of these criticisms: weighting of patches and links to take the landscape matrix into account, integrated metrics dealing with both connectivity and amount of habitat, and the possibility of including them in a decision-support system based on scenario analyses. I conclude that criticisms of ecological networks reveal the lack of diffusion of modeling tools such as landscape graphs, and that approaches such as participatory modeling bringing together scientists and practitioners could be one way to improve matters.

Key words

Ecological networks; landscape graphs; spatial modeling; connectivity; decision support

Highlights

Landscape graphs are mostly comprised of weighted patches and weighted links

Graph-based metrics can deal both with fragmentation and habitat loss issues

Landscape graphs can be readily included in decision-support systems

Participative modeling enhances understanding of ecological networks

1. Introduction: ecological networks in question

A paper published in Land Use Policy (Gippoliti and Battisti, 2017) highlights the weaknesses in the concept of ecological networks as applied to conservation and landscape planning. The authors claim that ecological connectivity, landscape fragmentation and, by extension, ecological networks are subject to semantic ambiguities and are often used dogmatically thereby misdirecting environmental policy. They argue that planners overstate the role of connectivity in maintaining viable populations of target species. They also emphasize the lack of any comparative approach with which to evaluate the gain from connectivity against other conservation strategies such as enlarging the protected areas or reducing disturbances from the landscape matrix. Finally, they suggest including ecological networks in more rigorous project-cycle management with clear objectives and evaluations of their effectiveness.

Given the plethora of studies relying on the "paradigm of connectivity", the paper by Gippoliti and Battisti (2017) provides a useful critical view of ecological networks and of their actual influence on population viability. It should be noted that this debate is not entirely new and was already addressed to some degree by Vimal et al. (2012) who pointed up the excessive focus on a structural and cartographic vision of ecological networks. Moreover, connectivity is not an issue that is restricted to the operational dimension of ecological networks but is also a subject of debate in ecology (Fahrig, 2013).

However, the point is that Gippoliti and Battisti (2017) ignored spatial modeling (specifically, land-use change modeling and landscape graphs) although it can provide useful support in the decision-making processes relating to ecological networks. Accordingly, I propose here to revisit the discussion by including the question of spatial modeling in the debate. More specifically, I suggest that it is worth looking again at some of the misunderstandings about connectivity outlined by Gippoliti and Battisti (2017) but with an eye to landscape graphs, a body of methods recognized to be of use in conservation and landscape planning.

2. Background: theoretical bases for landscape graphs

Let us return to the emergence of the concept of ecological network, in its spatial meaning (Opdam et al., 2006). The concept is rooted in landscape ecology and more specifically in the generalization of the theory of insular biogeography to terrestrial habitats. This resulted in the patch matrix model (Forman, 1995), i.e. a vision of landscape in which discrete homogeneous habitat patches are surrounded by a more or less inhospitable matrix. From that model, the focus on landscape patterns promoted by landscape ecology has favored a cartographic and structural view of connectivity that is very much present in the definition of ecological networks found in spatial planning (Bennett, 1998; Boitani et al., 2007).

On the scientific side, ecological networks were closely associated with functional connectivity (Taylor et al., 2006). Since *actual* functional connectivity cannot be easily measured from field observations, many approaches based on spatial modeling have been proposed for decades to estimate *potential* functional connectivity. These methods include, for example, indices of landscape pattern (Cook, 2002), least-cost modeling (Adriaensen et al., 2003; Gurrutxaga et al., 2010; Théau et al., 2015; Vuilleumier and Prélaz-Droux, 2002), the cost-benefit method (Drielsma et al., 2007), circuit theory (McRae et al., 2008), movement simulations (Tischendorf, 1997; Tischendorf and Fahrig, 2000), graph-theoretic methods (Urban and Keitt, 2001; Urban et al., 2009), and incident function models (Moilanen and Hanski, 2001). Reviews of the operational use of these approaches have outlined the need for a trade-off between their capacity to represent real-world processes and the amount of data they

require (Calabrese and Fagan, 2004; Fagan et al., 2006). It has been concluded that landscape graphs are relevant to conservation planning.

Landscape graphs are spatially explicit models of ecological networks designed from environmental data and specifically from land cover maps. They may be built in various ways to represent a network of habitat (Galpern et al., 2011) and can be described as a set of nodes representing the habitat patches of a focal species and a set of links representing the potential connections between those nodes. As spatial graphs (Fall et al., 2007), they are a suitable framework for computing connectivity metrics at different levels (Laita et al., 2010; Rayfield et al., 2011). These metrics provide a helpful diagnosis for prioritizing habitat patches worth preserving, for identifying the best locations for field actions to influence the functioning of ecological networks (e.g., to improve connectivity), and for assessing the ecological impact of new developments (Foltête et al., 2014). They are thus appropriate tools for providing indicators to support monitoring and decision-making.

3. Landscape graphs, a way to combine structural connectivity, functional connectivity, and habitat extent

Like other methods relying on concepts from landscape ecology, analyses and indices derived from landscape graphs make wide use of the term "connectivity". However, their significance should not be restricted to direct connections between habitat patches. They extend beyond the limitations associated with the term "connectivity" as used in Gippoliti and Battisti (2017), in terms of (1) the way the graph elements are defined, (2) the type of computation the graphs underpin.

3.1. Landscape graphs are not merely circles and lines

The binary nature of many graphs in other domains (e.g. social networks) should not make us oblivious to the point that landscape graphs are usually weighted graphs. Even if their cartographic representations are often simplified in the form of topological layout, i.e. circles linked by straight lines, they contain richer information in two respects. First, the nodes may be simple centroids (Galpern et al., 2011) but more often than not they are two-dimensional objects characterized by a carrying capacity represented by their area or some other environmental attribute defined by their vicinity, e.g. foraging area for bats (Tournant et al., 2013), terrestrial habitat near ponds for amphibians (Clauzel et al., 2015a). Proximity to disturbances is also often included in the delineation of nodes, for instance by eroding habitat patches as in Mimet et al. (2016). Second, the links in the graphs are usually weighted by least-cost or resistance distances, including the landscape matrix as a heterogeneous environment. Consequently, landscape graphs are sensitive to modifications in the landscape matrix and not just to changes on the perimeter of the habitat patches.

3.2. Metrics calculated on landscape graphs deal with functional connectivity and the amount of habitat

All measurements applied to landscape graphs at a global or a local scale are named connectivity metrics for convenience, but they are not limited to topological relationships (Rayfield et al., 2011). The metrics including weighted patches and links have indeed a more general scope than connectivity in the topological sense. This is the case of the Probability of Connectivity index (PC), one of the most popular metrics applied to landscape graphs (Saura and Pascual-Hortal, 2007) which has given rise to several variants (Saura and Rubio, 2010; Saura et al., 2011; Saura et al., 2014; Martensen et al., 2017). The core of this network-level metric is a product reflecting the potential interaction between two patches, given the expression $a_i a_j e^{-\alpha d_{ij}}$, where a_i and a_j are the areas of patches i and j, d_{ij} is the distance separating these patches, and α is a parameter controlling the decline in the probability of movement with distance, usually using a negative exponential function (Saura and Pascual-Hortal,

2007). Considering the patch area (or some other attribute including patch quality) as a proxy for demographic potential, this expression is related both to metapopulation models (Hanski, 1994) and to spatial interaction models in human geography.

By summing all the potential interactions, i.e. all pairs of patches, the PC index also comprises the internal interactions within the patches (Saura, 2018), which are not usually included in the "narrow" definition of connectivity. It can be broken down into fractions so as to distinguish, in the relative importance of a given patch, what pertains to its area and what pertains to its connections with other patches (Saura and Rubio, 2010). As a result, a PC value represents in an integrated manner both the amount of habitat of the target species and how reachable that habitat is, depending not only on connections between patches but also on the size and shape of the patches themselves. The expression "reachability" (or availability) of habitat is thus more appropriate than "connectivity" in explaining what this metric represents. Finally, the confusion about decline in connectivity and habitat loss mentioned by Gippoliti and Battisti (2017) is certainly present in some studies where connectivity is invoked in a broad sense, but can easily be avoided with a clear modeling approach.

4. Using landscape graphs in scenario-based planning

Gippoliti and Battisti (2017) notice the lack of any comparative approach between the application of ecological networks and other options of conservation or landscape planning. Landscape graphs like many spatial modeling methods are, however, specifically relevant for carrying out this approach via the prospective analysis described in Foltête et al. (2014) and Lechner et al. (2015b). This implies translating planning actions into land-use change scenarios and then assessing their impact on habitat reachability using landscape graphs.

From a conservation planning perspective, the scenarios to be tested may include the extension of core areas of specific patches, for example, or patch creation or restoration. Clauzel et al. (2015a), for instance, apply landscape graphs to simulate the creation of new ponds for amphibians in order to mitigate the impact of a high-speed railway. In their comparison of scenarios of forest conservation, Bergsten et al. (2013) include not only several levels of area protection but also forestry practices. In another context, Lechner et al. (2015a) compare the connectivity of conservation scenarios implemented from a public participation GIS.

From a landscape planning perspective, it is also possible to simulate land-use changes, such as the implementation of a new transport infrastructure or the extension of a built area. Whatever the context, the variations in connectivity levels between scenarios are suitable for ranking them according to the gain in connectivity (i.e., the increase in terms of habitat accessibility) they provide. Many studies are based on such planning scenarios. Clauzel et al. (2015b), Fu et al. (2010), and Vasas et al. (2009) compare several options for the siting of transport infrastructures. From a more theoretical perspective, Tannier et al. (2012) and Tannier et al. (2016) assess the ecological impact of several patterns of residential development, and Huang et al. (2018) compare actual and counterfactual scenarios of urban growth. All these examples demonstrate that landscape graphs are operationally capable of analyzing scenarios for the purpose of improving, maintaining, or restoring ecological networks.

5. Is there a place for landscape graphs in operational ecological networks?

The previous sections outline that landscape graphs provide many possibilities for operational implementation covering issues of both fragmentation and habitat loss. They offer other advantages, being adapted to a multi-scale analysis of connectivity (Zetterberg et al., 2010) and to multi-species diagnoses (Lechner et al., 2017; Mimet et al., 2016; Sahraoui et al., 2017). Moreover, they can be used

for reducing connectivity, e.g. for controlling pest species (Foltête et al., 2016), and not just for maintaining or improving it. Although these methods have their limitations (Moilanen, 2011) and must certainly be improved to better represent ecological processes, they do offer a framework of analysis that is consistent with some of the five conclusions of Gippoliti and Battisti (2017) about better implementing ecological networks. They will not erase the semantic ambiguity of the term "connectivity" (first conclusion of those authors) and they will not settle the problem of the choice of the target species to be considered (fifth conclusion). But they provide ecological indicators likely to be included in a decision-making approach (second conclusion), they are fully compatible with cost/benefit analyses relying on the comparison of scenarios (third conclusion), and they can be used in an adaptive way to take account of each regional context (fourth conclusion).

This shifts the problem to the way the implementation of ecological networks should be conceived, and to the place of landscape graphs in their design. Since landscape graphs are models linking planning orientations with theoretical and empirical knowledge of ecology, why are these methods devised in the academic sphere diffused so sparingly among planners and why do they so obviously remain "tools of researchers"? Gippoliti and Battisti's (2017) conclusions suggest there is a gap between scientists and practitioners with respect to the implementation of ecological networks. Vimal et al. (2012) mention the difficulty of bringing together scientists and other sources of expertise on ecological networks to product shared knowledge. Other factors could explain this gap:

1. Most spatial models are (1) too complicated to be accepted and used by planning practitioners, (2) designed to answer scientific issues rather than to achieve operational objectives. These arguments are not totally valid for landscape graphs, which are thought to strike a balance between ecological reliability and ease of implementation. Furthermore, Bergsten and Zetterberg (2013) show that environmental managers are not opposed to graph-based methods and even have a clear vision of their strengths, but they have difficulty in choosing the focal species and acquiring spatial and ecological data. However, this problem is not merely a technical barrier, that may eventually be overcome by engineering offices (Vimal and Mathevet, 2011), but also a conceptual difficulty inherent in the simplification used in the modeling approach compared to the real situation perceived by actors in the field.

2. Landscape graphs are part of a very great number of approaches, methods, and software packages developed in the scientific domain. This makes choices difficult for practitioners and dependent on their skills, their technical and human resources, and their connections with scientists. This difficulty increases when the choice is oriented towards more advanced methods that are not yet fully tried and tested. This methodological diversity is inherent in any scientific approach and is explained in part by the variations in the contexts and scales of investigation of ecological networks. It also reflects the lack of consensus about the role of connectivity in ecology (Fahrig, 2013) and the conflict between the landscape fragmentation model and the continuum model (Fisher and Lidenmayer, 2006; Lausch et al., 2015).

3. The participative modeling approaches likely to overcome the previous point are mostly oriented towards system dynamics or agent-based modeling (Voinov and Bousquet, 2010). Although landscape graphs are considered to be tools for decision support, they are rather used as a result provider (e.g. prioritizing protection areas) than as a framework for promoting collaborative modeling. This can be explained by their static aspect and their level of aggregation, making their linkage with biological processes indirect. However, they could benefit from participative construction involving non-scientific stakeholders and, like more complex tools (e.g. individual-based simulation platforms), become "a medium for knowledge sharing between researchers and planners" (Tannier et al., 2015).

6. Conclusion

Some of the weaknesses identified by Gippoliti and Battisti (2017) in the application of ecological networks could be overcome by the use of landscape graphs. Although environmental managers and other practitioners make use of spatial data and GIS software, there is still a gap to cross when it comes to the use of landscape graphs as spatial modeling tools. Participative modeling experiments involving those with a stake in ecological networks (e.g. companion modeling) could be one way to improve things. This would mean promoting an educational approach to modeling instead of considering it simply as a toy in the hands of researchers.

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