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Research Paper

# A parcel-based graph to match connectivity analysis with field action in agricultural landscapes: Is node removal a reliable method?

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ABSTRACT

Patch-based graphs are widely used to display and quantify landscape connectivity. They are specially relevant for decision support in land planning and biological conservation. Matching connectivity analyses with practical actions in agricultural landscapes involves considering management units rather than habitat patches. However, at a local scale, the classical method for prioritizing graph elements (node removal) using connectivity indexes such as delta IIC could be viewed as a highly contrived approach with respect to the actual changes in land use. Here we address the relevance of this method compared to simulations likely to display these land-use changes in a more realistic way. Prioritization as determined by the removal method is tested here against simulated land-use changes in four scenarios (e.g. replacing grasslands by croplands) for an agricultural area in the Jura massif (eastern France) where field actions are undertaken to combat the spread of grassland rodents. The results obtained by ranking all the parcels ("enumerative" approach) show that the removal method provides rankings similar to those obtained with the land-use change scenarios, except for the planting of hedgerows. However, defining a limited number of key parcels ("cumulative" approach) results in different rankings whatever the scenarios. This shows that when applying parcel-based graphs to practical actions, the reliability of the removal method depends on the way the connectivity analysis is conducted. Simulating land-use changes, which is more realistic but more time-consuming, proves relevant if only a few key parcels need to be identified for actions to be conducted in the field.

## 1. Introduction

The conservation of biodiversity involves preserving wildlife habitats and their accessibility, maintaining flows of individuals across landscapes, and ensuring population viability. Research dealing with this issue in landscape ecology and biological conservation has mainly focused on landscape connectivity, defined as the capacity of landscape to enable individuals to move across space (Taylor, Fahrig, & With, 2006). Many studies of functional connectivity have been carried out for several decades now, either seeking to observe and better understand real flows in the field in order to characterize actual connectivity (Baguette, Blanchet, Legrand, Stevens, & Turlure, 2013), or using modeling approaches to represent potential connectivity (Calabrese & Fagan, 2004).

Among several methods capable of representing ecological networks and analyzing potential connectivity, landscape graphs are widely used because they offer a functional vision of these networks and do not require large amounts of ecological data, unlike individual-based models (Calabrese & Fagan, 2004; Galpern, Manseau, & Fall, 2011; Urban, Minor, Treml, & Schick, 2009). As landscape graphs are spatially explicit models characterized by a very simple structure, they are suitable for providing decision support in conservation planning and landscape management. From this operational perspective, they can be used (1) to prioritize the most vulnerable elements (e.g. habitat patches) requiring protection so as to preserve the functioning of ecological networks; and (2) to identify the most relevant locations for action in the field so as to improve landscape connectivity (Foltête, Girardet, & Clauzel, 2014). Many authors have outlined the efficiency of landscape graphs in addressing these operational issues. Some have focused on identifying locations for reforesting agricultural land (García-Feced, Saura, & Elena-Rosselló, 2011), for creating and restoring ponds for amphibians (Clauzel, Bannwarth, & Foltête, 2015), or for changing agricultural practices so as to stem the spread of rodent species (Foltête, Couval, Fontanier, Vuidel, & Giraudoux, 2016). Other studies have addressed the design of wildlife corridors (Loro, Ortega, Arce, & Geneletti, 2015; Zetterberg, Mörtberg, & Balfors, 2010) or wildlife crossings along linear infrastructures (Girardet, Foltête, Clauzel, & Vuidel, 2016; Gurrutxaga & Saura, 2013; Mimet, Clauzel, & Foltête, 2016).

One strong point of graph-based methods applied to landscape is

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that they capture a complex array of elements and relationships within a simple structure composed of two sets of objects: nodes representing habitat patches and links representing functional distances between patches. This simple structure can be readily used in numerous procedures such as computing connectivity metrics and simulating changes in the network. As a result, these procedures provide outcomes that can be translated in terms of decision support in response to operational issues (Foltête et al., 2014). One of the most popular procedures is the removal method consisting in simulating the removal of each node successively and quantifying the impact of such modifications on connectivity, with the aim of identifying the key patches. The removal method was first applied to landscape graphs by Keitt, Urban, and Milne (1997) and is the basis for computing the *PC* index (Saura & Pascual-Hortal, 2007) and *IIC* index (Pascual-Hortal & Saura, 2006), two widely used network-level metrics. Beyond identifying key patches for prioritizing conservation measures, the search for the best locations for carrying out field actions such as landscaping to increase (or sometimes decrease) connectivity can be based on the same principle (Foltête et al., 2014).

The method consisting in simulating patch removal in landscape graphs is a relevant way of investigating operational issues. However, in practice, the use of this method for taking concrete action in the field is facilitated when the elements to be analyzed (i.e. the nodes of the graph) correspond to management units belonging to private or public landowners. Such a situation could perhaps be encountered in the case of specific habitat patches characterized by their small size and their being "naturally" fragmented, for example a set of ponds. But in many cases, such correspondence is impossible because habitat patches usually considered as the nodes are defined on the basis of ecological criteria alone. In a recent study applied to an agricultural landscape, the difficulty in making a patch-based graph operational arose from the mismatch between the large size of the grassland patches involved in the connectivity analysis and the small size of the parcels managed by farmers on which actual actions could be conducted (Foltête et al., 2016). Such a situation can be illustrated by a fictitious example in which both options (patches vs parcels) are compared (Fig. 1). This leads us to consider connectivity graphs based on spatial units defined by management criteria and to question their relevance for operational issues.

In the case of agricultural landscapes, using management units for conducting connectivity analyses entails building parcel-based graphs instead of patch-based graphs. This assumes that the spatial grain of the analysis is fine enough to include the parcels in the land-use map. In this way, the results of connectivity analyses are expected to be more readily convertible into concrete actions in the field. However, in this case, the removal method may involve overkill with respect to the real situation, because a parcel cannot be simply removed. In the real world, a node (patch or parcel) that is removed is replaced by some other land use and, if this change modifies the resistance of the matrix and also modifies the local topology of the graph, its impact may differ from changes quantified by removal alone. Consequently, the binary mode (presence/absence) of the removal method is better adapted to contexts where the landscape matrix is assumed to be uniform (i.e. when the links are weighted by Euclidean distances), than to cases of heterogeneous matrixes, i.e. when using least-cost or resistance distances. Furthermore, in some cases, the actual changes in land use may affect only a part of the node area, for example if hedgerows are planted in open-habitat nodes. In this case, the nodes are not removed but their quality is altered. For all these reasons, prioritizing actions on the basis of the removal method could prove irrelevant when it comes to properly representing changes in agricultural practices that may correspond to more subtle land-use modifications.

When it comes to transposing the graph-based connectivity analyses from patches to parcels (i.e. to apply these analyses at the scale of the management units), the question is therefore whether the removal method provides reliable results for prioritization compared to simulations of more realistic changes in agricultural parcels. This question has to be addressed in order to detect any potential contradiction between the spatial scale suitable for concrete actions in the field and the prioritization method that could be too coarse for simulating land-use changes.

In this paper, we propose to investigate the relevance of a parcel-based graph in addressing an issue of reduction of connectivity in a grassland network. In the Jura massif (eastern France), the cyclic spread of the montane water vole (*Arvicola terrestris sherman*) causes numerous ecological, economic, and public health problems. Populations of montane water vole spread in grasslands in about cyclic outbreaks over about five decades (Blant, Beuret, Poitry, & Joseph, 2009; Delattre & Giraudoux, 2009). The main determinants of the diffusion of these populations have been studied by Duhamel, Quéré, Delattre, and Giraudoux (2000), Morilhat, Bernard, Foltête, and Giraudoux (2008), and Berthier et al. (2014). These studies have shown that homogeneous

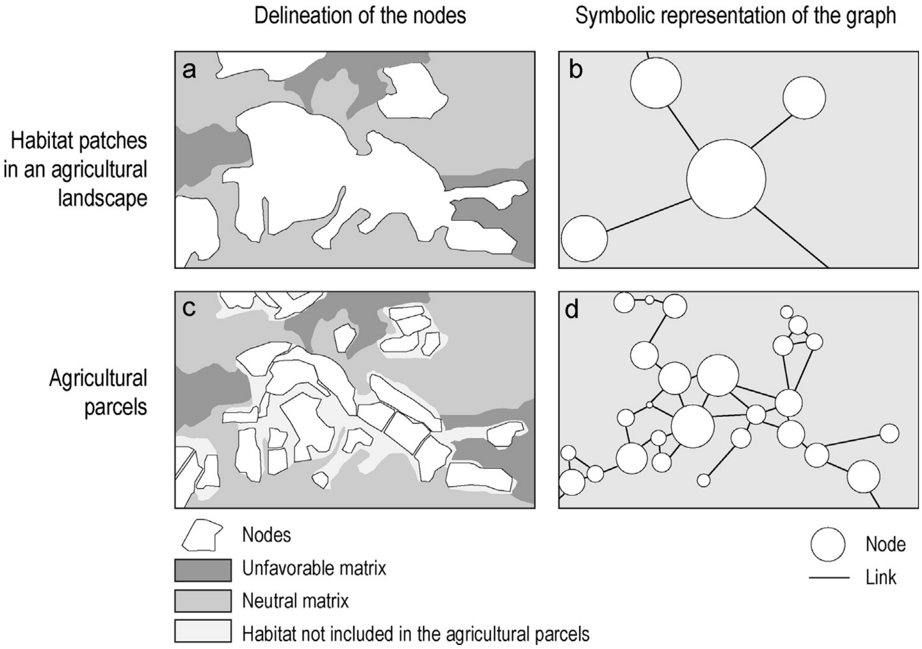

**Fig. 1.** Patches vs parcels, two ways of considering nodes in agricultural landscapes. The classical method for mapping nodes consists in delineating areas corresponding to the preferential habitat of the species under study (e.g., grassland) (a). An alternative is to consider agricultural parcels to be the nodes (b). In this case, the parcels within a given patch may be adjacent or separated by a portion of habitat not included in the parcels. The decision support provided by connectivity analyses differs according to these options. In the case of patch-based graphs (c), the removal method will lead to field actions being contemplated on large zones including several parcels and other areas. This may raise practical problems (e.g., do all the parcel managers agree with changes in their respective parcels?). With parcel-based graphs (d), the connectivity analysis is directly geared to the potential actions in the field and can be applied to the subset of parcels of which the managers are involved.