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Functional analysis of landscape connectivity at the landscape, component, and patch levels: A case study of Minqing County, Fuzhou City, China

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ABSTRACT

Maintaining forest landscape connectivity is one of the most effective ways to alleviate natural forest fragmentation and biodiversity loss problems. Recently, graph theory based metrics have been used as powerful tools in the assessment of landscape connectivity. However, the functional features of landscape units at different structure levels, based on which outcomes can be enriched and advice can be given for practical applications, have been overlooked. In this study, a series of graph-based connectivity indices was calculated to 1) evaluate the optimal threshold distance, 2) identify the key landscape units at the component and patch levels, and 3) classify the functional types of components and patches and analyze functional patterns at different structural levels. The relationship between patch size and patch functional performance in maintaining landscape connectivity was discussed. With a natural forest area in Minqing County of China as the study area, recommendations regarding forest conservation and connectivity enhancement were provided based on the research conclusions. This study provides a way to comprehensively analyze habitat fragmentation and functional patterns for local forest conservation.

1. Introduction

Natural habitat loss and fragmentation are serious ecological problems that threaten global biodiversity conservation. One of the main strategies used to alleviate this negative effect is to maintain habitat landscape connectivity (Estavillo, Pardini, & Rocha, 2013; Lindenmayer & Fischer, 2007). Landscape connectivity is a fundamental ecological characteristic of a landscape, and it describes the interaction between landscape structure and the organisms within it (Merriam, 1984; With, 1997) or the degree to which the landscape facilitates or impedes ecological flow movement among resource patches (Taylor, Fahrig, Henein, & Merriam, 1993). Previous studies have shown that the level of landscape connectivity can influence population dynamics and community structure by affecting ecological processes (Dunning, Danielson, & Pulliam, 1992; Lindenmayer & Fischer, 2007). Habitat fragmentation can impede organism movement (D'Eon, Glenn, Parfitt, & Fortin, 2002), such as seed dispersal (Jesus, Pivello, Meirelles, Franco, & Metzger, 2012) and mammal immigration (D'Eon et al., 2002; O'Brien, Manseau, Fall, & Fortin, 2006). For a population of a certain species distributed in a fragmented habitat, the substructure of the population is largely related to the movement of organisms caused by the distribution pattern of source patches (Brooks, 2006; Kang, Lee, & Park, 2012; Launer & Murphy, 1994). The connectivity of fragmented forest habitats can impact local community composition (Martensen, Pimentel, & Metzger, 2008; Zellweger, Braunisch, Baltensweiler, & Bollmann, 2013) and species richness (Guzy, Price, & Dorcas, 2013; Martensen, Ribeiro, Banks-Leite, Prado, & Metzger, 2012). The interaction between landscape structure and the ecological processes in a landscape, which is exactly revealed by landscape connectivity, has been a key consideration in landscape ecology in recent years (Wu, 2014). Thus, more managers and conservation planners are applying landscape connectivity in planning to improve ecological efficiency (Bergsten & Zetterberg, 2013; Correa Ayram, Mendoza, Etter, & Salicrup, 2016; Frazier & Bagchi-Sen, 2015; Ng, Xie, & Yu, 2013; Yu, Xun, Shi, Shao, & Liu, 2012).

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As a key topic in ecological research and planning, the assessment of landscape connectivity has garnered wide interest and rapid investigation (Kindlmann & Burel, 2008; Tischendorf & Fahrig, 2000). Among all of the methodologies used in recent studies, graph theory is receiving increasing popularity because of its suitability for modeling landscape patterns and corresponding ecological responses (Brooks, 2006; Fortin, James, MacKenzie, Melles, & Rayfield, 2012; Galpern, Manseau, & Fall, 2011; Martín-Martín, Bunce, Saura, & Elena-Rosselló, 2013). Graph-based connectivity metrics have correspondingly undergone rapid development (Baranyi, Saura, Podani, & Jordán, 2011; Kindlmann & Burel, 2008; Pascual-Hortal & Saura, 2006; Rayfield, Fortin, & Fall, 2011; Saura & Pascual-Hortal, 2007; Saura, Estreguil, Mouton, & Rodríguez-Freire, 2011, Saura, Vogt, Velázquez, Hernando, & Tejera, 2011), as well as the specific softwares (Foltête, Clauzel, & Vuidel, 2012; Saura & Torné, 2009). Of all the types of graph metrics, the Integral Index of Connectivity (*IIC*) and the Probability of Connectivity (*PC*) are especially suitable for planners because they combine graph theory and habitat availability metrics (Saura & Rubio, 2010). These indices could provide details about the functional partitioning of the landscape connectivity of each patch, and such details are helpful for prioritizing and analyzing particular functions (Blazquez-Cabrera, Bodin, & Saura, 2014; Saura & Rubio, 2010; Saura, Estreguil et al., 2011, Saura, Vogt et al., 2011). As suggested by Bodin and Saura, the index of *IIC*, based on a binary connection model, is suitable for discovering the topology of the habitat network. The index of *PC*, based on a probabilistic connection model, is preferred when studying the actual movement of organisms of specific species (Bodin and Saura, 2010; Saura & Rubio, 2010). When discussing the structure and the general functional connectivity pattern, the index of *IIC* and its fractions are suggested to be selected.

However, further studies are still needed to achieve a richer understanding and better practical applications. Recently, most studies evaluating the graph-based connectivity mainly focus on the patch and landscape levels, while the component level usually lacks analysis (Bodin and Saura, 2010; Laita, Mönkkönen, & Kotiaho, 2010; Saura, Estreguil et al., 2011, Saura, Vogt et al., 2011; Shanthala Devi, Murthy, Debnath, & Jha, 2013). The intermediate level of the landscape (e.g., components or compartments) has been proved to be helpful for habitat conservation and management by providing a useful perspective (Bodin & Norberg, 2007; Gao, Kupfer, Guo, & Lei, 2013; Urban, Minor, Treml, & Schick, 2009). Components and compartments refer to the patch groups in which patches connect with each other. The patches from different components may have weak interaction, while patches from different compartments are strictly separated (Bodin & Norberg, 2007; Saura & Torné, 2009). Thus, compartments could better represent the dynamics of metapopulation, and components are usually taken as structure unit decomposed from the patch-based network (Minor & Urban, 2008; Urban, Minor, Treml, & Schick, 2009). When focusing on the topological and functional structure of the landscape, the components were suggested to be selected as the intermediate structural level. Because the patches that belong to a component are functionally connected, the functions they perform are first presented as the component's functions, which are then reflected within the landscape. The analysis of connectivity focused on components is therefore essential for understanding the overall connectivity pattern.

As landscape structural units, both components and patches have particular functional features of their contributions to overall connectivity, which are rarely mentioned in other studies. According to the model of the metrics of *IIC* and *dIIC*, a patch can have three kinds of functions in maintaining the overall connectivity, which are represented by three fractions of *dIIC* (Saura & Rubio, 2010). In a real landscape, the proportions of these three fractions of patches can be obviously different based on their attributes and locations. The functional performance of a patch can differ substantially from that of other patches. Thus, a classification system based on functional fractions is necessary to unravel the functional characteristics of patches. In this way, analysis at the patch level, which is usually focused only on prioritization ranked by the values of patch importance metrics (Blazquez-Cabrera et al., 2014; Shanthala Devi et al., 2013), can be enriched. Functional classification can be included for the comprehensive understanding of patches by providing information about their functional features, a method that is similar to the analysis of components.

The chosen or calculated threshold distance is of great significance in the application of graph-based connectivity indices. In the index models, the existence or strength of a connection (i.e., potential organism movement) depends on both the length of the actual link and the value of the selected threshold distance (Bunn, Urban, & Keitt, 2000; Urban & Keitt, 2001). Usually, the calculation of the maximum dispersal distance of a focal species is the most common way to determine a reasonable threshold distance (Hernández, Miranda, Arellano, Saura, & Ovalle, 2015; Liu et al., 2014; Szabó, Novák, & Elek, 2012; Teixeira et al., 2014). However, this method may be limited by the lack of representativeness of the temporal ecological characteristics of individual species and the complex community composition of some habitats (Saura, Estreguil et al., 2011, Saura, Vogt et al., 2011; Xun, Yu, & Liu, 2014). Another way to calculate a distance that could manifest the connections and present the features of the landscape network is to identify a critical link threshold (Galpern et al., 2011). Using the connectivity response curves of threshold distance and connectivity indices, the link thresholding experiment could find out the points associated with rapid increases of connectivity metrics (Brooks, 2006; Bunn et al., 2000; Urban & Keitt, 2001). However, this method may still fail to identify the optimal threshold distance value with ecological significance (Saura & Rubio, 2010; Shanthala Devi et al., 2013). In the present study, focal species and response curve methods were applied to calculate the optimal threshold distance. This calculation aimed to combine different evaluation methods of threshold distance to overcome their limitations.

Part of the natural forest in Minqing County of Fujian Province, China, was selected as our study area. The vegetation of Minqing County is mainly a mixture of subtropical evergreen broadleaf and conifer forests. Considering that the identification of important areas by graph-based connectivity indices is rather robust regardless of the scale of the data (Blazquez-Cabrera et al., 2014), the fine-scale-interpreted data of the National Forest Resource Inventory in 2010 was used in this study. The combination of focal species and response curve methods was used to calculate the optimal threshold distance. At the optimal threshold distance, the most important components and patches were identified based on the values of the connectivity metrics. The classification of functional types originally proposed in our study was used to identify the functional features of the components and patches in the study area. Functional analyses at the landscape, component, and patch levels were intended to identify the landscape characteristics of the functional patterns of connectivity. In the discussion, the relationship between patch size and patch functional performance are discussed. Targeted recommendations for local habitat conservation are provided based on the results.

2. Materials and methodology

2.1. Study area

Minqing County is situated northwest of Fuzhou City in the