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Updating the habitat conservation institution by prioritizing important connectivity and resilience providers outside

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ABSTRACT

Maintaining biodiversity is vital for ecological processes. Yet, present static protected areas seem to be inefficient in biodiversity conservation. In this study, we use a set of indicators to evaluate topological features, landscape connectivity and resilience of the current habitat conservation institution, and apply the node addition method to prioritize habitats that play roles in improving connectivity and resilience outside the protected areas. Wanzhou District, Chongqing (SW China) is selected as the study area as it is a biodiversity hotspot in Three Gorges Reservoir Area. The results show that, in current conservation institution, average clustering coefficient and average weighted degree rise with the increasing dispersal distance of species; besides, landscape connectivity is rather low, while long dispersers have larger connectivity degree and resilience compared with short ones. Furthermore, how those patches could function as connectivity providers in different aspects (e.g. stepping-stone effect) is also presented by partitioning the connectivity indicator into three parts. However, it is interesting to find that, patches with good performance in improving connectivity may not have the equal efficiency in enhancing resilience, and the possible reasons are elaborately discussed. Prioritized patches are suggested to be placed under protection, and to update the habitat conservation institution. Our indicators and method can extend the knowledge of the importance of linking protected areas with surrounding habitats, and it can serve as a supporting tool for conservation planning or land use planning.

1. Introduction

Biodiversity loss has become a pervasive picture worldwide (Mossman et al., 2015), and over the past decades, the establishment of habitat conservation areas has been considered as a cornerstone for maintaining biodiversity (Asaad et al., 2017; Rodrigues et al., 2004). However, the validity of this concept has been in a crisis due to the excess of conventional “conservation islands” effect (Boardman, 1981; De Montis et al., 2016), which results from lacking the consideration of landscape connectivity. Landscape connectivity is defined as the degree to which the landscape facilitates or impedes movement among habitat resource patches (Taylor et al., 1993), and is a major concern for species survival, as well as reduction of extinction risk (Kramer-Schadt et al., 2004). The designation of habitat conservation areas should be viewed as a non-permanent guideline that needs to be updated, and reinforced in its connections with the rest of landscape elements, rather than a static and finished product (Drechsler, 2005; Meir et al., 2004; Rubio et al., 2015). Recent studies have also suggested that, outside the protected areas there might be also valuable habitat sources that contribute to support species survival and persistence (Hansen and Defries, 2007; Pulliam, 1988), and the protected areas may experience functional isolation when surrounding unprotected habitats get lost (Hoekstra et al., 2005; Xun et al., 2017). Hence, prioritizing habitat conservation outside protected areas is rather necessary when planners are to re-assess the conservation institution (Bengtsson et al., 2003).

In this scientific context, the landscape graph (also known as ecological network) approach has gained growing attention and been regarded as a prominent tool for biodiversity conservation, because it could help to detect the response of ecological processes wherein habitat mosaics to land management actions with relatively low data demand (Opdam et al., 2006; Urban and Keitt, 2001). We have identified some most-asked questions in conservation applications of

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Abbreviations: EN, ecological network; CHA, core habitat area; PHA, potential habitat area; *d* value, median dispersal distance; *PC*, probability of connectivity; λ_M, metapopulation capacity; BC, betweenness centrality

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landscape graphs: (1) what the network topology is like in the landscape, and what the implications in connectivity and resilience are? (2) To what extent the landscape is connected (Galpern et al., 2011)? And (3) how resilient the network is (Moore et al., 2016)? The first one measures the topological features such as graph density and graph diagram, and some scholars assess the node centrality to shed light on the topology implications. For instance, the betweenness centrality (BC) could be a measure of the short-cut, or traffic hub role (Bodin and Norberg, 2007; Urban et al., 2009). Second, connectivity could be categorized as structural and functional connectivity, the former concerns maintenance of the spatial structure of diverse ecosystems, while the other focuses on the spreading of species. Third, the resilience is also critical as it indicates the ability of the network system to absorb shocks and continue to develop (Hughes et al., 2003; Liu et al., 2007). One category of resilience is termed as "engineering resilience", focusing on the ability of a system to absorb shocks and return to the previous stable state (Pimm, 1984), while another category "ecological resilience" is mainly concerned with the ability of a system to reorganize from one stability to another stability after a shock (Holling, 1973). In this study, we primarily focus on functional connectivity and ecological resilience.

Another compelling task for practitioners is to answer: which patches are important for the whole habitats network? Generally, scholars can detect the most important nodes by (1) node removal or (2) node addition method. In terms of removing method, many researchers have used single patch removal to rank the node importance through the variation in connectivity (Bodin and Saura, 2010; Saura and Pascual-Hortal, 2007); besides, De Montis et al. (2016) have tested the change of network resilience under different node removal scenarios, and found that nodes with high BC values are crucial for the ecological network resilience. However, recent studies have suggested that the single node removal may be hard to predict the vulnerability of the remaining landscape to further node removal (Rubio et al., 2015). More importantly, considering our major concern is to update the habitat conservation network by prioritizing the surrounding unprotected habitats, reversing the node removal logic to the node addition should be more reasonable and proper (e.g. Roberts and Stevent (2007)). Regarding node addition method, García-Feced et al. (2011) have used it to prioritize agricultural patches which could improve landscape connectivity for reforestation, and Xun et al. (2017) have explored the impacts of different node additional scenarios on habitat connectivity. Despite their successful applications in enhancing the landscape connectivity for habitat conservation area, the knowledge that integrates network topological features and their implications, as well as resilience, should be extended.

Our primary goal is to further the understanding of the importance of reinforcing the connection between protected areas and surrounding habitats in the landscape. We adopt a set of metrics to quantify topological features, landscape connectivity and resilience of the current conserved habitats network, and apply node addition method to prioritize habitat conservation outside the protected area. In detail, the research objectives consist of: (I) the ecological network construction of Wanzhou District in Chongqing City (SW China), which is a biodiversity hotspot in Three Gorges Reservoir Area; (II) investigating topological features, landscape connectivity and resilience in local current conservation institution, to find out whether it needs to be updated; and (III) detecting which habitats outside conservation areas play roles in improving connectivity and resilience when they are added to update the habitat conservation network.

2. Materials & methods

2.1. Study area

Wanzhou District is located in the center of Three Gorges Reservoir Area (TGRA, SW China, Fig. 1). The area spans 107°55′22″-108°53′25″E and 30°23′23″-31°0′20″N, covering approximately 3456 km^2. In 2014, the proportion of forest takes up 44.3%, and the total area of natural reserves, forest parks, and ecological controlling area accounts for 14.3%. Meanwhile, Wanzhou is inhabited by multiple rare species, such as the large Indian civet (*Viverra zibetha*), the tufted deer (*Elaphodus cephalophus*), the Asian golden cat (*Catopuma temminckii*), and the Fransçois's Langur (*Trachypithecus francoisi*).

As the economic center and the largest migration settlement zone in TGRA, Wanzhou has experienced rapid population growth and built-up land expansion since the planning period of Three Gorges Dam, because of the TGRA migration settlement issue (He et al., 2017). Considering the increasingly serious conflicts between enormous constructive land demands and biodiversity conservation in Wanzhou, the stability of local conservation institution might be in danger and thus there is a need to continuously re-assess the performance of it.

2.2. Data preparation

Multiple datasets are collected from diverse sources and compiled (Table 1). Geographic information and least-cost corridor analysis have been processed through ArcGIS 10.2 in conjunction with MatrixGreen (Bodin, 2010), the visualization and analysis of topological features of ecological network have been performed by Gephi (v0.9.1), connectivity assessment has been conducted in Conefor 2.6 (Saura et al., 2009), and MATLAB R2014b has been employed for resilience calculation.

2.3. Building the ecological network

The ecological network is a set of nodes and corridors used to model the habitat network of the target species. The nodes here are categorized into two types: (1) the core habitat areas (CHAs), and (2) the potential habitat areas (PHAs). We define natural reserves, forest parks, and ecological controlling areas as CHAs, because they are under strict protections by legally binding directives, these areas are ecologically stable, and inhabited by many national protected or local representative species. As far as the PHAs, Given that PHAs should have certain requirements for the area and the distance away from transportation land and densely built-up land (Sunde et al., 1998), only the non-conservation patches that are larger than 0.2 km^2 (Xun et al., 2017), and are at least 1 km away from urban/primary road are defined as PHAs. Compared with CHAs, PHAs usually function as economic forest and they are under less conservation, so their ecological conditions could easily get changed. Yet, they could still function as area favorable to the species migration in case the original CHAs are under exterior pressures and become unsuitable for species inhabiting (Fig. 2).

The median dispersal distance (d value) of the large Indian civet is estimated as 5 km, the tufted deer as 10 km, the Fransçois's Langur as 15 km, and Asian golden cat as 20 km (please see Appendix A for the dispersal distance estimation). This dispersal range could cover most of forest mammals in the study area. Each pair of core areas are connected (calculate from patch edge) through the least-cost path between them based on the least-cost modelling (Adriaensen et al., 2003), please see Table A3 and Fig. A1 in Appendix A for the further details. Moreover, the median dispersal distance of each species is multiplied by the resistance value of their habitat (i.e. forest, resistance value = 1), so that the d value of each species later corresponds to the effective capacity of the species to migrate in the cost surface. Besides, we use the migration probability, which is usually formulated as an exponential function of distance in Eq. (1) (Clark et al., 1999), to consider the intensity of interactions between pairs of nodes.

$$p_{ij} = e^{-\beta d_{ij}} \tag{1}$$

where p_{ij} is the migration probability between patch i and j; β ($0 < \beta < 1$) denotes the impedance coefficient that considers the migration resistance caused by spatial distance, which is usually the