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Forest fragmentation and landscape connectivity change associated with road network extension and city expansion: A case study in the Lancang River Valley

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ABSTRACT

Human disturbances contribute significantly to the decrease in the quantity and connectivity of the natural habitats. Taking Lincang City in Lancang River Valley as a case study, we focused on the forest fragmentation and habitat connectivity loss associated with its road network and expansion in the past 15 years. Our findings show that, from 1991 to 2006, its forest habitat (>25 ha) decreased to 18.3% of the total area due to fragmentation. Landscape fragmentation indices (NP, PLAND, and LPI) changed more than the landscape shapes and the aggregation indices (SHAPE, FRAC, and DIVISION). Habitat loss occurred more often in the lower elevations and in areas near the city and road network. Landscape connectivity loss was 91.3%, which showed a more significant decrease than did the landscape pattern changes. With sensitivity analysis of different animals' dispersal abilities and landscape resistance consideration, our study reveals that landscape connectivity could be more effective in showing the potential ecological effects caused by city and road network extension.

1. Introduction

Landscape fragmentation as a breakup of a continuous habitat into smaller, less connected patches can impose devastating and irreversible consequences on the regional biodiversity (Trakhtenbrot et al., 2005; Brooks et al., 2006). Transportation infrastructures built in line with a city's expansion, particularly road networks, cause both direct and indirect losses of habitat, which, in turn, influence the abundance and distribution of plant and animal species (Geneletti, 2003; Eigenbrod et al., 2007).

Most studies of the effects of roads on biodiversity are carried out separately on different scales, with little effort to integrate the results of these multiple scales (Laurance et al., 2004). On a local scale, biodiversity characteristics such as mortality, movement, distribution, and species richness are more often investigated (Gibbs and Steen, 2005). At the landscape level, fragmentation and land cover changes can be quantified using GIS methods for habitat changes. However, biodiversity evaluations on a small scale due to road construction are far from comprehensive due to the lack of related knowledge, especially the species' behaviors, while landscape-level analyses such as pattern and spatial analysis often have limited ecological meanings for biodiversity conservation given the absence of focal species (Fu et al., 2010; Li et al., 2010).

Landscape connectivity is a major concern for the maintenance of wildlife populations and is considered important for ecological processes such as the movements of genes, individuals, species, and populations over multiple scales, especially in fragmented landscapes (Saura et al., 2011). Currently, landscape connectivity is viewed both structurally (spatial arrangement of the habitat) and functionally (focal species to the physical structure of the landscape) (Saura and Torné, 2009). Many indices have been developed and those based on graph theory (e.g. Probability of Connectivity) perform well in practical landscape analysis (Bodin and Saura, 2010; Pascual-Hortal and Saura, 2006). These new indices with underlying ecological processes overcome the limitations of small-scale empirical indices and large-scale landscape pattern indices (Fu et al., 2010). However, studies on the ecological effects caused by road network expansion mainly focus on pattern analysis (Liu et al., 2011).

China's road network has been growing rapidly during the past three decades, in accordance with the government's reform policy. Landscape fragmentation and the subsequent effects of roads are widely studied in many countries, but similar studies have just been initiated in China (Forman et al., 2002; Li et al., 2010). As China continues to develop its western provinces, many high-level roads are being constructed, especially in Yunnan Province where highways account for 93% of the total transportation routes. In Yunnan, there

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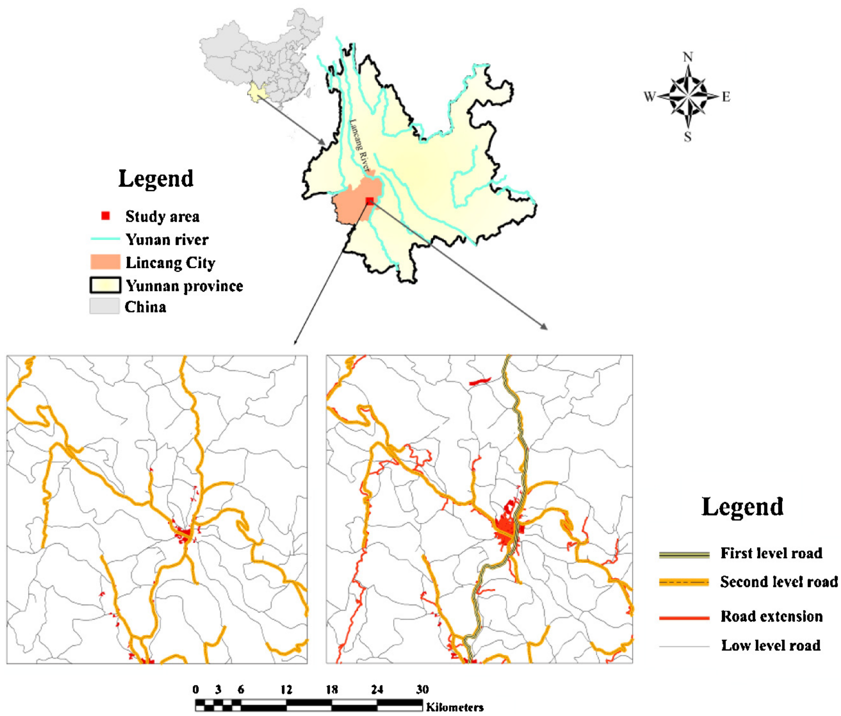

Fig. 1. Study area of Yunnan Province, China.

are more than 18,000 higher plant species (51.6% of China's total), 1836 vertebrate species (54.8%), and 15,000 seed plant species (50%) (Yang et al., 2004). The richness value, endemic value, and endemic rate in biodiversity all rank first in China, although this province accounts for only 4.1% of the country's land area, or eighth largest, with a total area of 394,000 square kilometers (WWF, 1996). Research on the ecological effects of road networks will therefore have significant practical applications in this region.

Although biodiversity includes diversity at the genetic, species, ecosystem, and landscape levels (Lindenmayer et al., 2000), species could benefit from increasing connectivity from a landscape-level perspective. Within this more restricted arena, the indicators of biodiversity should consist of habitat pattern, habitat quality, and connectivity. As landscapes are viewed as at least partially consisting of highly interconnected linear features known as networks, the network properties of connectivity are useful predictors of biodiversity (Forman, 1995). In conclusion, the analyses of habitat fragmentation, heterogeneity, and connectivity at the landscape level should supply additional important information within the context of environmental management for biodiversity conservation.

In this paper, our study was conducted to investigate the degree of habitat change due to road networks and cities' expansion in Yunnan Province. The objectives are as follows: (1) find the relationship between road network and habitat fragmentation and (2) assess the landscape connectivity change by sensitivity analysis of ecological processes. Here, the different dispersal/movement distances are considered broadly representative of ecological processes. The effectiveness of different methods from pattern and process perspectives is also discussed.

2. Materials and methods

2.1. Study area

A 40 km × 40 km square zone (23.7°–24.1°N, 99.8°–100.2°E) in Lincang City in southwest Yunnan Province, located in the middle reach of the Lancang River, was selected as the study site (Fig. 1). Two features of this zone make it suitable for this study: (1) intensive road networks of different levels total 0.54 km km^{-2} with city expansion and (2) biodiversity in this zone has been subjected to severe disturbances by these roads.

2.2. Data acquisition

The road data was digitized based on the transportation maps of Yunnan Province in 1990 and 2010 and rectified by 1:250,000 road databases from the National Fundamental Geographical Information Center in 2002. According to Liu et al. (2008a), the roads are divided into four categories: (1) first level (national roads), (2) second level (mainly county, city-county, city roads), (3) third level (mainly county, city-town roads), and (4) fourth level (mainly town-village and village-village roads). Landsat TM images (#131/043) in 1991 (February 17, 1991) and 2006 (December 11, 2006) were used for landscape mapping after interpretation and supervised classification. We compared our classification of the 1991 images with land-use status maps (Yunnan land use status map in 1990), and the classification of the 2006 images were validated by using the ground truth data (53 points, 2009), which indicated the accuracy level of the land cover map was 83.5%. The images were classified into seven categories: grassland, farmland, shrub land, forestland, water, urban land, and rural residential land.

2.3. Analysis methods

2.3.1. Habitat selection

According to local conditions and animals' behavior, for connectivity analysis, we selected forest land-cover types with a greater than 30% closed canopy dominated by broadleaf and coniferous forests as the habitat. The main forest types are *Lithocarpus glaber* and *Pinus kesiya Royle ex Gordon var. langbianensis (A.Chev) Gaussen*. According to the characteristics of the local environment and referring to previous studies, the minimum ecological threshold patch