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Ecosystem Services and landscape change associated with plantation expansion in a tropical rainforest region of Southwest China

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ABSTRACT

Rapid plantation expansion and its associated impacts on habitat fragmentation and landscape connectivity in many tropical areas has raised increasing concerns as to its impact on Ecosystem Services (ES). Using the InVEST modelling suite, we evaluated critical ES dynamics in four zones of varying plantation expansion intensity (high, medium, low and no plantation expansion) in Xishuangbanna prefecture in Southwest China from 1976 to 2012. Based on these results, we also exmained the relationship between ES and landscape pattern and connectivity derived by the "probability of connectivity" model. We found that during the study period, plantation area increased more than 20 times in Xishuangbanna prefecture as a whole, while broad-leaved forest cover decreased by nearly 30%. The impact of plantation on ES was substantial at both the regional and local scale. Carbon stocks and water yield services decreased by 15.48% and 10.85%, respectively, from 1976 to 2012 throughout the region as a whole. Within the selected study zones, carbon stock and water yeild decreased by 45% and 32%, respectively, from the no plantation to the high plantation zones in 2012 specifically. Plantation expansion has also resulted in a decrease in natural forest cover and a high level of habitat fragmentation. Landscape connectivity decreased by a range of 54.64–95.58% throughout the study area, with 134.58 km^2 of forest patches of high importance reduced to medium or low importance during the study period. Correlation analysis showed that carbon storage was more closely correlated to landscape connectivity than forest habitat percentage, large patch index or cohesion index. Together, these results highlight that habitat configuration with a high connectivity level between fragmented patches is important for maintaining critical Ecosystem Services.

1. Introduction

The conversion of natural forest to agricultural land has been increasing worldwide in recent decades, particularly in developing countries, where rapid economic expansion has put continuous pressure on the environment and natural resources (Lamelas et al., 2009; Li et al., 2007; Qiu, 2009). In South America, millions of hectares of dry forest have been converted towards the generation of soy products (i.e., *Cerrado*, *Chaco*) (Grau et al., 2005). In Southeast Asia, the demand for oil palm has led to the deforestation of 10.7 million ha of tropical forest between 1990 and 2002 (Li et al., 2007). In Southwest China specifically, large forested areas have been replaced by plantations due to the increasing demand for monoculture rubber (*Hevea brasiliensis*) trees, tea and sugar (Li et al., 2007; Qiu, 2009; Smajgl et al., 2015).

Studies show that forest conversion has led to many negative ecological consequences, such as local habitat fragmentation, changes in community structure and biodiversity loss (Burgess and Dawson, 2004; Lamelas et al., 2009; Qiu, 2009). In addition to these ecological consequences, tropical forest conversion also threatens the sustainability of a wide array of Ecosystem Services (ES), such as water purification; flood abatement; carbon storage; the provision of wood, pharmaceuticals, and other forest products; and the fulfilment of other cultural services (Chazdon, 2008). Ecosystem Services modelling tools are proved to be useful to quantify the ES provision, understand spatiotemporal changes due to land

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use changes (Nelson et al., 2010). Many studies used InVEST model to analyze, quantify and balance different Ecosystem Services for various land use change issues (Nelson et al., 2009; Leh et al., 2013). Undermining these Ecosystem Services results not only in adverse ecological impacts, but also potentially adverse economic impacts at both the local and regional levels.

The prefecture of Xishuangbanna in Southwest China has been especially subject to forest conversion due to plantation expansion. With diverse landscapes and a high level of biodiversity, Xishuangbanna is located within the Indo-Burma biodiversity hotspot, containing more than 11,700 plant and animal species (Cao and Zhang, 1997; Myers et al., 2000). From 1976 to 2003, forests in Xishuangbanna were cleared at an average rate of almost 14,000 hectares per year, shrinking forest coverage to less than 50% of the original forest cover. During this time, rubber plantations increased to cover about 400,000 hectares of the prefecture's land. While many studies conducted throughout Xishuangbanna have focused on forest cover change and landscape fragmentation, insufficient attention has been paid to quantifying the ecological impacts of plantation expansion on local ecological processes and Ecosystem Services.

Landscape connectivity has become a key issue in maintaining wildlife dispersal in order to sustain key ecological processes, such as biodiversity levels and functional ecological networks. These ecological processes, in turn, promote many important Ecosystem Services, such as soil formation, carbon sequestration, nutrient cycling, seed dispersal and pollination (Wood et al., 2016). Landscape connectivity is, therefore, one of the major issues related to the maintenance of ecological processes as well as the provision of several important Ecosystem Services (Mitchell et al., 2013).

Landscape connectivity is defined as the degree to which the landscape facilitates or impedes movement amongst resource patches (Zuazo et al., 2005). Recent advances in graphic landscape connectivity indices make it possible to link spatial landscape organization to animal movement (Liu et al., 2011a). These indices can be applied to calculate functional connectivity (i.e., the permeability of the landscape matrix to movement) – a major concern for ecological processes, such as the movement of genes, individuals, species, and populations over multiple spatiotemporal scales (Chen et al., 2010; Li et al., 2009; Liu et al., 2011a). Estimating functional connectivity is necessary to quantify ecological fluxes and natural dispersal routes for wildlife species moving within the landscape, ultimately enabling the design and implementation of functional ecological networks (Cui et al., 2009; Liu, 2008). In recent years, there have been numerous studies of landscape connectivity application for biodiversity conservation and planning aims (Bodina and Saura, 2010). And some useful metrics, such as integral index of connectivity (IIC) (Pascual-Hortal and Saura, 2006), probability of connectivity (PC) (Saura and Pascual-Hortal, 2007), equivalent connected area (ECA) index (Saura et al., 2011) and the network centrality metric betweenness centrality (BC) (Bodin and Norberg, 2007), were brought out and utilized for different purposes.

Despite recent developments in measuring connectivity, information on the relationship between ES and landscape connectivity is still lacking (Pelorosso et al., 2015). By assessing the impacts of forest conversion on ES and landscape connectivity in Southwestern China, this study attempts to address this knowledge gap. We modelled changes in ES and landscape connectivity from 1976 to 2012 in four study zones in Xishuangbanna. Based on previous studies demonstrating that decreases in connectivity are mainly caused by landscape fragmentation (Liu et al., 2014), we also chose to measure typical landscape pattern indices related to fragmentation for our study. The specific aims of our paper are: (1) to model critical Ecosystem Services in Xishuangbanna, including carbon storage and water yield, and evaluate their dynamics from 1976 to 2012; (2) to measure changes in landscape connectivity due to fragmentation and identify critical habitat patches for maintaining connectivity; and (3) to investigate how changes in landscape pattern and connectivity in the study area affect Ecosystem Services. Overall, our study is intended to contribute to the ongoing exploration of how to improve local connectivity and balance the relationship between biodiversity conservation and agricultural activities in Xishuangbanna through landscape pattern optimization.

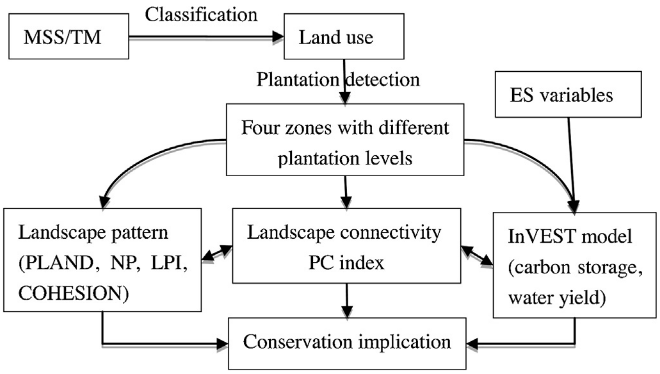

Fig. 1. Methodological flow chart.

2. Material and methods

Our methodological framework included several steps (Fig. 1): (1) selection of four zones with different plantation levels based on remote sensing image classification; (2) ESs estimation in these zones; (3) further landscape connectivity and pattern calculation; (4) relationships between ESs and landscape metrics identification; (5) suggestions of biodiversity conservation.

2.1. Study area

Xishuangbanna (21°08′–22°36′ N, 99°56′–101°50′ E), located in Yunnan Province in Southwestern China, is renowned for its diverse landscapes and natural splendour. The prefecture includes three counties (Jinghong, Menghai and Mengla) covering an area of 19,150 km^2 (Zhang and Cao, 1995). In Xishuangbanna, approximately 95% of the region is covered by mountains and hills, with an elevation ranging from 2429 m in the north to 477 m in the south (Cao and Zhang, 1997). The area has an annual precipitation of 1493 mm, of which 1256 mm (84%) occurs between May and October. The combination of geography and climate in Xishuangbanna has created a transition zone with the highest flora and fauna level in China (Liu et al., 2002). The common forest types include tropical seasonal rain forest, mountain rain forest, subtropical evergreen broad-leaved forest and coniferous forest.

Four zones (10 km × 10 km) with different plantation expansion rates (high, medium, low and no plantations) were selected to evaluate the effects of expansion on landscape connectivity (Fig. 2). Plantation coverage rates in 2012 in Zones 1, 2 and 3 were 56.2%, 32.6% and 10.5%, respectively. As a control group, no plantations have been established in Zone 4. All of the zones contain a sufficiently large number of forest patches (at least 5 patches) for connectivity analysis.

2.2. Sources of data

Land-use/land-cover change was determined using two Landsat Multi Spectral Scanner (MSS) images, a Landsat Thematic Mapper (TM) image and a Landsat Enhanced Thematic Mapper (ETM) image. All images were acquired during the dry season between February and April. Landsat MSS and TM image data of 1976,