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Progressive landscape fragmentation in relation to cash crop cultivation

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A B S T R A C T

Cash crop cultivation has been a critical driver of land use change in many countries around the world. However, few efforts have been made to quantify the relationships between cash crop expansion and the subsequent landscape pattern changes. This paper characterized the process of cash crop expansion across Tiaoxi watershed (China) from 1985 to 2009 using multi-sensor and multi-temporal remotely sensed imageries. Correlations were identified between indicators of cash crop expansion (total area and total production of cash crops) and a family of landscape fragmentation metrics (patch density, edge density, landscape division index, effective mesh size, splitting index, Shannon's diversity index, and aggregation index). Results showed that Tiaoxi watershed experienced profound cash crop expansion and progressive landscape fragmentation. The cash crops spread in accessible and productive areas at the expense of paddy and forests. Social drivers of cash crop expansion included population growth, labor structure changes and market incentives. Indicators of cash crop expansion presented linear relationships with landscape fragmentation metrics. These findings evidenced that cash crop cultivation would significantly fragment landscapes. Our study contributed to understanding on the enlarging cultivation of cash crops and the associated modifications of landscape patterns in subtropical regions.

Introduction

Cash crop plantation, such as the rubber, hazelnut, tea, and fruit, has been a critical driver of land use change in many countries around the world (Fox & Vogler, 2005; Gibreel, Herrmann, Berkhoff, Nuppenau, & Rinn, 2014; Li & Fox, 2012; Ziegler, Fox, & Xu, 2009). It brings profit for local farmers and strengthens regional finance stability (Manivong & Cramb, 2008; Zhang, Kono, & Kobayashi, 2014). However, cash crop expansion would greatly modify traditional landscape patterns (Abdullah & Nakagoshi, 2008; Godone, Garbarino, Sibona, Garnero, & Godone, 2014), affecting ecosystem services and human welling (Dong et al., 2013; Yi, Cannon, Chen, Ye, & Swetnam, 2014). For example, landscape fragmentation can substantially affect biodiversity, carbon stocks, and hydrological circulation (Girvetz, Thorne, Berry, & Jaeger, 2008; Uuemaa, Mander, & Mander, 2013). Within this context, characterizing the landscape pattern changes associated with cash crop cultivation should advance our understanding of regional land use change process and help mitigate the adverse ecological consequences.

China provides a typical case for this endeavor. More than 20% of China's territory is covered by agricultural land and they have been managed by traditional farming systems for a long history (Ellis & Wang, 2006). Since the land use policy of 'Household Responsibility' was implemented in 1980s, agricultural land use has shifted from field cropping to cash crop growing in pursuit of economic profit (Gibreel et al., 2014; Qin, Kong, Zhang, Miao, & Liu, 2007). This land use change process is accelerated by the expanded transportation networks and increasing consumer demand (Li, Ma, Aide, & Liu, 2008). Spreading of rubber, fruit, and tea widely occurred in tropical and subtropical China during the last decades (Dong et al., 2013; FAO, 2007; Yi et al., 2014; Zhang et al., 2014). Majority of previous studies focused on the farming practice or socioeconomic issues associated with cash crop cultivations (rubber in particular) in tropical regions. Few efforts have been made to characterize the process of cash crop expansion and to investigate the subsequent modifications of subtropical landscape patterns.

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Monitoring the distribution of cash crops is essential to document their expansion and to understand the implications for ecological processes. Methodologies for deriving land use information from remotely sensed imageries are well demonstrated and have been gradually been applied to map cash crop distributions (Dong et al., 2013; Yi et al., 2014; Zhang et al., 2014). Landscape metric analysis, combined with geographical information systems (GIS), has become a popular tool in resource management, land use change studies, and other ecological applications (Abdullah & Nakagoshi, 2008; Sayer et al., 2013; Su, Ma, & Xiao, 2014). It provides a pathway for analyzing the association between landscape pattern changes and land use activities (Mander & Jongman, 2000). Therefore, we applied remote sensing, GIS and landscape metric analysis into a typical subtropical landscape of China. We attempt to address the following three questions:

(1) What is dynamic process of cash crop expansion in time and space?
(2) Does the cash crop cultivation fragment landscapes?
(3) How do landscape patterns change in relation to cash crop expansion over time?

Materials and methods

Study area

The Tiaoxi watershed is located within Zhejiang Province, eastern coastal China (Fig. 1). It is an important part of the Taihu Lake Basin, which is a legend in China for its long history of traditional agriculture and dense population density. Tiaoxi watershed extends from 119° 14′E to 120° 13′E, and from 30° 07′N to 31° 11′N. Its total area covered about 6000 km^2. Summer and winter seasons are long, and spring and autumn seasons are short. Tiaoxi watershed is characterized by a typical subtropical landscape in China. Forest coverage is high and paddy rice dominates the farming system. Since the 1980s, Tiaoxi watershed has been experiencing rapid agricultural commercialization, shifting from traditional subsistence farm production to market oriented cash crop cultivation. Tea was the major cash crop for most households in this area. Many farmers also converted their cropland into fruit orchard. The spreading cash crop cultivation has become a major trend of land use change, which would pronouncedly modify the landscapes in Tiaoxi watershed. This watershed provides a good case for characterizing the landscape pattern changes in relation to cash crop cultivation.

Data source and processing

Land use information from 1985 to 2009 was extracted from multi-sensor remotely sensed imageries, including Landsat Thematic Mapper (TM; 1985, 1994, 2005 and 2009), Landsat Enhanced Thematic Mapper (ETM+; 1999, 2000, 2001, 2002, and 2003), and China–Brazil Earth Resources Satellite (CBERS; 2004, 2006 and 2007). The pre-processing included geometrical correlation, false color composition, and resampling of CBERS images to 30 m. We employed visual interpretation using ancillary data of topology, vegetation, soil and high resolution images. Considering the land use patterns and dominant ecosystems, eight land use types were interpreted including paddy, bare land, dryland, water body, sparse woodland, built-up land, dense forest, and cash crops. Given the coarse image resolution and fragmented distributions of cash crops, we did not divide cash crops into sub-level types (tea garden and fruit orchard).

Accuracy assessment followed the approach that recommended by Olofsson et al. (2014). Specifically, the number of reference points, which were selected by stratified random sampling

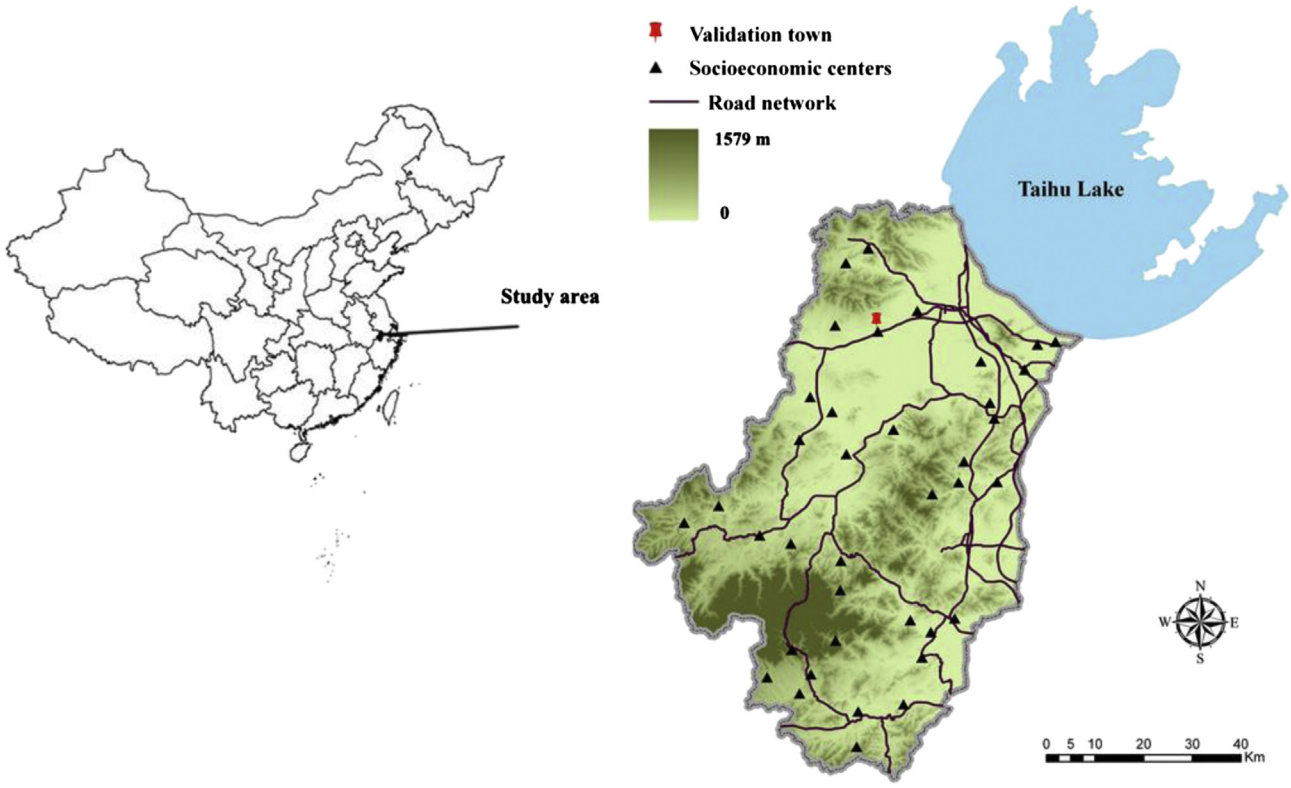

Fig. 1. Location of Tiaoxi watershed (China) and distribution of socioeconomic centers and road networks within it.