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Longitudinal analysis of the road network development and land-cover change in Lop Buri province, Thailand, 1989–2006

Risa Patarasuk*, Michael W. Binford

Department of Geography, University of Florida, PO Box 117315, Gainesville, FL 32611, USA

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A B S T R A C T

Land use and land-cover change (LUCC) is mainly a consequence of human activities such as road network development. In Thailand, the explicit objective of road network development has been to foster economic and social development. The extent of change in roads and land-cover change in Lop Buri between 1989–2006 is analyzed. We hypothesized that road development is a key driver of land-cover change and will cause, substantial changes in areas of forest cover, cultivated food and cash crops. We used land-cover classifications of Landsat imagery and resultant class trajectories to measure change. We then analyzed the relationships between roads, land-cover types, and land-cover trajectories. Overall, cash crops increased while forest and food crops declined between 1989–2006. The relationships between distance to roads and land- cover trajectories indicate that as the distance to roads increase, there are fewer changes in LUCC. The results suggest that in this case study, an increase in road network contributes to an increase in upland crops. In turn, the increase in upland crop production is one of the factors linked to economic development.

Introduction

Land use and land-cover change (LUCC), mainly a consequence of human activities, is a major contributor to global environmental change. LUCC is driven by combinations of social, biophysical, and economic factors (Lambin et al., 2001; Meyer & Turner, 1994). Economic development activities such as road building can lead to LUCC, whether intentional or not (Cropper, Griffiths, & Mani, 1999; Forman & Alexander, 1998; Geist & Lambin, 2002).

Road network development is usually a result of a public policy to serve several purposes. In most cases, the development of road networks aims to foster social and economic development by increasing linkages within a region, facilitating movement of people, goods, and services. In other cases, such as the Thai-Laos Friendship Road/Bridge, roads were built to enhance the relationships between the neighboring countries, and the Interstate Highway System in the USA was built to support national security (Australian Agency for International Development (AusAID), 2009; Caldwell, 1974; Muscat, 1990).

Although roads are built or enhanced for several purposes, they can drive economic development. In Malaysia, improved roads helped the economy of the local residents increase their household aggregate income by increasing the sales of export crops (e.g. rubber, pepper, and cocoa) (Windle & Cramb, 1997). On the other hand, in developed countries such as the USA or in Europe, economic activities such as housing development projects often incur road development (Krugman, 1999; Ralston & Barber, 1982; Stanilov, 2003).

Studies such as Geist and Lambin (2002), Vickerman et al. (1999), and Forman and Alexander (1998) have shown that road network development that aims to enhance economic development can result in LUCC. Thus, it is important to understand road and land-cover interactions in terms of the influence of roads on the landscape. Roads influence regional land cover because they enhance access to land for human activities (Nelson & Hellerstein, 1997; Pfaff, 1999). These influences can be, for example, a conversion of forest to agriculture, including both crop cultivation and livestock. In specific regions, road building in northeast Thailand (Panayotou & Sungsuwan, 1994), northern and central Thailand (Cropper, Puri, & Griffiths, 2001a), Belize (Chomitz & Gray, 1996), and Rondônia, Brazil (Alves, Pereira, Sousa, Soares, & Yamaguchi, 1999; Soares-Filho et al., 2004) led to conversion of forests to crop production or cattle grazing. Initial development of roads in the Rondônian rainforest in Brazil in particular illustrates an increase in access to the rainforest for humans which resulted in a large-scale conversion of forest to agricultural land (Alves et al., 1999; Stone, Brown, & Woodwell, 1991). Another common

* Corresponding author. Tel.: +1 (352) 392 3198; fax: +1 (352) 392 8855.
E-mail addresses: risajook@ufl.edu (R. Patarasuk), mbinford@ufl.edu (M.W. Binford).

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landscape transformation that road networks can influence is the conversion of agricultural land to built-up areas, although the literature does not explicitly reflect that roads are the cause of such conversions. Nevertheless, rapid urban growth and conversion of agricultural land to urban areas or built-up areas occur closer to road networks in as disparate locations as the Kansas City Metropolitan area in the central USA (Underhill, 2004), Puerto Rico (López, Aide, & Thomlinson, 2001), and the urban expansion of Beijing (Zhang, Wang, Peng, Gong, & Shi, 2002). Land-cover conversions usually happen along the road network because roads facilitate mobility and access to jobs, markets, or city centers, thus increasing incentives for land conversion.

During the 1980s to early 1990s, Thailand experienced rapid economic growth by transitioning from an agriculture-based economy to a more industrial economy (Dixon, 1999; Yokakul & Zawdie, 2009). Despite the rapid industrial transition, agriculture is still the largest economic sector in terms of workforce (LePoer, 2007). Agriculture expansion in Thailand has moved rapidly toward commercial farming and intensification of cropped area (Ekasingh, Sungkapitux, Kitchaicharoen, & Suebpongsang, 2007; Intarakumnerd, Chairatana, & Tangchitpiboon, 2002). In 1997, the Asian Economic Crisis hit Thailand and reduced the GDP by 9% (Rosegrant & Ringler, 2000). The investment in public infrastructure such as a road network development was delayed during the crisis (Ministry of Construction, 1999). The economy recovered by 2003 but the investment in the transportation sector has never returned to the pre-crisis position (Economic and Social Commission for Asia and the Pacific (ESCAP), 2005, 2009).

Notwithstanding the downturn in1997, Thailand's road network had been undergoing extensive development for nearly 60 years as a result of National Economic and Social Development Plans that aim to improve the quality of life through poverty alleviation, enhanced economic development, and increased linkage among different regions (Lop Buri Provincial Office, 2006; Puri, 2006; Rojnkureesatien, 2006). Early studies showed that road network development in Thailand enhanced social and economic development by increasing household income through the production of more cash crops (Dixon, 1999; Hafner, 1970; Hughes, 1971). Although these social surveys were not spatial in nature, they do note that much of the landscape change was from forested areas to agricultural areas, particularly in the central plain and the northeastern regions.

In Lop Buri, a relatively wealthy agricultural province in the central plain of Thailand and about 150 km north of Bangkok, the road network was intentionally designed to drive economic development. The policy responsible for road network development within the province was initiated in the 1930s by General Por Piboonsongkram, who established Lop Buri City as a military town. The road network was developed to facilitate military movements, to enhance economic and social development, and to increase linkages among other regions of Thailand (Caldwell, 1974; Rojnkureesatien, 2006). Piboonsongkram's policy transformed Lop Buri City to the center of economic development in the upper central region of Thailand (Office of Information and Technology: Thepsatri Rajabhat University, 2008). In the past several decades, Lop Buri province experienced major landscape changes, especially in response to the growth of the economy (Oung-youang, 2000).

The purpose of this study is to describe how the road network that was built intentionally to stimulate economic development influenced more broadly distributed land-cover change in Lop Buri province from 1989 to 2006. This period is chosen because we can compare the amount of the road network development and the amount of land-cover change before and after the economic crisis. This study analyzes the change in the road network development and land cover from 1989–1998 and 1998–2006. This paper describes and explains the patterns of the road network development and land-cover change from 1989 to 2006 in Lop Buri province in Thailand by measuring the spatio–temporal changes in road network and land cover in the region. Specific research questions for this study are: 1) How has the road network developed from 1989–1998 and 1998–2006? 2) How has the land-cover changed from 1989–1998 and 1998–2006? and 3) What are the spatial relationships between where roads were developed and where land-cover change occurs? We measured spatial relationships of road network development in terms of distance to roads. As the road network is developed, distance to roads decreases, leading to better accessibility to land. In this study, we presume a direct relationship between the road network development and agriculture expansion as the indicator of the economic development (Alexandratos, 1995). We hypothesize that the 1) agriculture expansion occurs closer to roads at the expense of forest cover, and 2) land area closer to roads devoted to food crops (i.e. rice) will be increasingly replaced by cash crops (e.g. cassava, maize, sugarcane).

Data and methods

The study area

Lop Buri province is located in the central region of Thailand approximately 150 km north of Bangkok, the capital city of Thailand, and is a gateway between the northern, central and northeastern regions (Fig. 1). Lop Buri province is one of the wealthier provinces in Thailand and is ranked 22nd out of 76 provinces in GDP per capita (Lop Buri Provincial Office, 2006). The province's population at a 2006 was 839,397. The province consists of 11 districts (called "amphoe" in Thailand). Amphoe Muang Lop Buri (Lop Buri City) is the most populated district with a 2006 population of 249,907 persons. It is followed by Amphoe Chai Badan (Chai Badan City) with 89,077 persons. These two districts are the most important centers of economic activity in the province.

At approximately 6300 km^2, the province is ranked 37 out of the 76 provinces of Thailand in land area. It is located between 14° 39′ N and 15° 35′ N latitude and between 100° 24′ E and 101° 26′ E longitude. The elevation ranges from 2 to 840 m above sea level (Fig. 2). Approximately 65% of the land area is below 100 m above sea level. These low-lying areas are found in the west and scattered among the northeast. Areas of elevation between 100 and 300 m make up approximately 25% of the province and are scattered in the northern, central, and eastern regions; areas above 300 m make up 10% of the province and are scattered in the central and eastern regions.

Lop Buri has a monsoon climate. The province's rainy season is from May to October, during the southeast monsoon from the Indian Ocean. Rainfall in the province is bimodal. The highest rainfall is in September and the second highest is in May. For the 30-year span from 1961 to 1990, the average May rainfall was 170 mm and September rainfall was 280 mm. In some years, the intense monsoon causes flooding in the province and reduces road quality and access. During November and April, the province experiences the dry northeast monsoon. Average minimum temperature from 1961–1990 was 23.3 °C, and the maximum was 33.3 °C. April is usually the hottest month and December and January are the coldest months.

For the past several decades, the road network in Lop Buri has been developed through road extension, lane-widening, and road surface upgrades. In 2006, Lop Buri had a total road length of 4727 km. However, road density is not evenly distributed throughout the province. In the lower western and the upper sections, the road network is dense compared to the central and the