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Revisiting the forest transition theory with historical records and geospatial data: A case study from Mississippi (USA)

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ABSTRACT

This study examines forest change processes, within the framework of forest transition theory (FTT), using Mississippi (USA) as a case study. The aim is to evaluate the assumption and theoretical basis of FTT with quantitative data, and to propose changes in forest management policy as a potential driver for reforestation. We compiled a number of historical records, geospatial data, and time series forest mapping products to reconstruct the last 100 years of forest trajectory. Forest changes are studied in relation to changes in society, over a range of temporal and spatial scales. Details of forest dynamics (e.g., the rate and extent of forest gain and loss) were quantified, while considering the ecological properties of the secondary forests. Mississippi forests are intensively managed and fragmented secondary forests, while regenerated entirely through plantation. The quantified forest transition (FT) curve indicated that forest dynamics have been nonlinear and have involved multiple reversals, resulting in multiple periods of forest expansion. The spatial and temporal analysis with time series remote sensing data over the last 30 years reveals that Mississippi forests have experienced very frequent changes and disturbance, even during the period of forest expansion. These change patterns are not apparent when considering total forest area estimates. The result illustrates that the "forest scarcity pathway" of FTT (Rudel et al., Global Environmental Change Part A 15(1) (2005) 23–31) worked to reverse the deforestation trend for the initial FT period. However, regenerated forests have experienced another episode of FT and expansion, and this cannot be explained by the forest scarcity pathway. Rather, the case of Mississippi suggests an alternative pathway (Mather, International Forestry Review 9(1) (2007) 491–502; Lambin and Meyfroidt, Land Use Policy 27 (2010) 108–118), distinct from the previous work, and highlights the importance of changes in policy incentives to account for forest recovery. The conceptual basis of FTT proposed by Mather (Area 24(4) (1992) 367–379) and Grainger (Area 27(3) (1995) 242–251) is revisited, showing how two alternative views are complementary, providing explanation for the repeated patterns of FT. This study presents empirical evidence to understand the theoretical basis and assumptions of FTT and suggests a new path for FT, "forest management policy pathway".

Introduction

Understanding the processes and drivers of land-use land-cover (LULC) changes has emerged as an important interdisciplinary research area. Land use, once considered as a local issue, has become a force of global importance (Foley et al., 2005). LULC is a key component of global environmental systems, and yet represents a missing component when developing policies to address climate impacts (Lambin et al., 2001). In particular, the long term trend and trajectory of forest land cover are crucial parts of carbon cycle analysis and the development of future scenarios for global climate change assessment.

It is only recently that research has progressed to fill in some gaps in monitoring and in developing a theory explaining changes in forest landscapes. One significant progress is related to monitoring technologies based on remotely sensed data. Most forest monitoring work has been concentrated on tropical regions, due to their global significance (Tucker and Townsend, 2000). However, repetitive and continuous monitoring of forests has been rare, due to limitations in resources, scientific methods, and institutional support (DeFries et al., 2005). Significant progress has also been related to the emergence of land use science. Spatial data available from remote sensing have helped explain observed patterns and processes of LULC, and develop analytical frameworks to quantify and predict future land use. However, modeling changes in forests has rarely been the focal point, as most studies have concentrated on predicting the location, intensity, and pattern of urbanization.

In conjunction with other social, economic, and biophysical factors, forest transition theory (FTT) can help bridge this knowledge

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gap by offering insights into changes of forest landscapes, because it offers a conceptual framework to explain long-term trends of forestlands. FTT describes how changes in population, industry and technology, economic market, and public perception and values affect the regional or national forests over the long run, based on historical observations mostly from the Organization for Economic Co-Operation and Development (OECD) countries. Historical records dating back to the 19th and 20th centuries show a slow transition in forest cover after changes in industrial sectors and technology brought dramatic shifts in population and land use demand in rural and urban areas. While there has been a shrinkage of forest cover associated with agricultural expansion, at the last stage of development a U-shape increase in forest cover occurs naturally or artificially associated with population shifts to more urban environments (Mather, 1992; Rudel et al., 2005; Perz, 2007). Lately, there has been a growing interest in explaining the drivers and processes of forest change within the FTT framework, using land-cover data derived from remote sensing data, especially in tropical developing countries (Rudel et al., 2002; Lambin et al., 2001; Perz and Skole, 2003). These studies have pointed out many challenges and limitations in the FTT. The idea of FTT has been put to test to develop a comprehensive understanding of forest land changes and alternative pathways to forest transition (FT).

An obvious limitation of the FTT is related to understanding the extent and rate of FT as well as missing details on the FT curve itself. The theoretical basis and assumptions of FTT have been generalized based on analyses of historical documents and observations from the OECD countries, mostly in the temperate forest biomes (Rudel, 2001). Data have been aggregated at the national or regional level, which may not show the actual LULC processes happening at the local scale because historical data are often scattered and sparsely available. They could include inconsistent information, and misinterpretation of these data could exaggerate FTT, as shown in the case of the USA (Ramankutty et al., 2010). Furthermore, in order to test and refine the underpinning theoretical assumptions and to address their implication for local ecosystems, FT processes in OECD countries should be examined in a geographical context, which has rarely been done. Even if there is information available from remote sensing data, the time periods for monitoring are often too limited to provide the change trajectory over a long period or to illustrate the details of short-term forest dynamics (Perz and Skole, 2003). As a result, we have not fully grasped how the FT and the following trajectory would take place, how they would affect the local ecosystems, and how they are related to regional land dynamics and the species composition of forest covers (Barbier et al., 2010). These challenges are greater in regions with tropical forests, because these regions not only have limited data, but also very complex forest dynamics, with a rapid growth of secondary forests and extensive disturbances.

The purpose of this paper is to examine forest change processes in Mississippi (USA), based on forest transition theory (FTT). More specifically, the goal is to evaluate FTT assumptions and theoretical basis with quantitative data, and to show that changes in forest management policy represent a potential driver for reforestation. We have compiled a number of historical records, geospatial data, and time series forest mapping products to reconstruct the last 100 years of forest trajectory. Forest changes are studied in relation to changes in societal factors (i.e., population dynamics, agriculture, and regional land use change) over a range of temporal and spatial scales. The rate and extent of forest gain and loss are quantified, while considering the ecological properties of the secondary forests. Mississippi forests are highly managed and fragmented secondary forests, which were regenerated largely by establishing plantations (Fickle, 2001). The quantified FT curve indicates that forest dynamics have been highly nonlinear and have involved multiple reversals resulting in several periods of forest expansion. The details of the FT curve have been examined within the conceptual framework of FTT (Mather, 1992; Grainger, 1995), to test and improve the assumptions on FT driving mechanisms (Rudel et al., 2005). Mississippi provides a unique laboratory setting, with valuable historical datasets to study changes in the tropical biome, unlike previous FTT studies. Mississippi belongs to the Southern region of USA, which provides the largest amount of timber to the World (Fox et al., 2007), and the study of forest changes in this region provides important insights to understand contemporary plantation forests. This region in the 1930s (the crucial period prior to FT) resembled a contemporary developing country in terms of physical, socio-economic, and demographic conditions (Rudel, 2001).

Background

Forest transition theory

The concept of FT and its underlying processes and key mechanism were first explained by Mather (1992), who described FT as "areal" transition, a turning point from shrinking to expansion, and identified the key factors that triggered FT. They include changes in population trend, industry and technology, economic market (e.g., demands for forest products, ecosystem services), and public perception toward and values of forests. Historical records dating back to the 19th and 20th centuries (and earlier) have shown a slow transition in forest land from net loss to net gain, after changes in industrial sectors and technology brought dramatic shifts in population, labor, and land demand in rural and urban areas. FT occurrs at the last stage of development, as the rural population decreases and natural and vegetative cover increases, naturally or artificially, from abandoned agricultural fields (Mather, 1992; Rudel et al., 2005; Perz, 2007) (Fig. 1a). While this view considers FT as a one-phase process, Grainger (1995) conceptualizes FT as a two-phase process, separating deforestation from reforestation, and argues that deforestation is related to the national land use change process, while reforestation (i.e., replenishing period) occurs separately, in response to changing demand for wood and depletion of environmental services supplied by forests, after a long transitional period (Fig. 1b).

Two general pathways have been proposed to describe the mechanisms that trigger FT: "economic development path" and "forest scarcity path" (Mather, 2007; Rudel et al., 2005). The first mechanism assumes that increases in forestlands are brought on by recovering forests from abandoned agricultural fields, following the migration of rural populations to urban areas. The second one assumes that FT occurs in response to shortages of forest products and other ecosystem services. For example, scarcity of forest resources would increase prices for forest products, ultimately leading to increases in forest cover to meet demand. The forest scarcity path often involves artificial regeneration through plantation, while the economic development path results from natural forest regeneration. However, Farley (2007) had demonstrated that these two theories failed to explain FT in the case of Ecuador, which experienced FT from grasslands to forestlands through extensive pine plantations. Afforestation and pine plantation were parts of strategies to promote economic development as a result of forestry, economic, and global climate policies. Therefore, FT brought by intense forestry management can be conceived as a "reverse" economic development path. Recently, Lambin et al. (2001), and Meyfroidt and Lambin (2008) have observed similar patterns in other developing countries, using remotely sensed data, and have proposed the alternative pathway of "agricultural intensification". This pathway is characterized as a rapid turnover of forestlands by extensive plantation after a large-scale