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# Natural disasters and economic development drive forest dynamics and transition in China

Kerong Zhang [a,*], Conghe Song [b], Yulong Zhang [b], Quanfa Zhang [a,*]

[a] Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan 430074, PR China
[b] Department of Geography, University of North Carolina, Chapel Hill, NC 27599, USA

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ABSTRACT

China has been implementing the world's most ambitious afforestation and forest conservation programs and undergoing rapid forest expansion since 1990s, thus, understanding the forest dynamics in China has global implications for sustainable forest management. Through analyzing forest area, biomass dynamics, and factors influencing deforestation and forest restoration, we found that the natural disasters and economic development drove forest dynamics and transition in China. The growth of the economy and population drove up demand for forest products, facilitating deforestation. The booming economy also boosted government's investment in forest restoration and conservation programs. Natural disasters damaged and frequently destroyed forests, but they also served as stimuli for the authorities to adopt remedy forestry policies and programs that ultimately led to forest increase. Nationwide, increasing peaks of annual afforestation were observed in the late 1950s, early 1980s, and early 2000s, and the newly increased area closed for forest restoration reached the peak in 1998. All these peaks were closely associated with peaks of natural disasters (i.e., floods, drought, and dust storm events). Based on the dynamics of forest area, biomass and forest consumption over the past 40 years, forest transition occurred during the late 1980s to the early 1990s, and it also strengthened the carbon (C) sink function of forests in China (with an increasing rate of 0.137 Pg C $yr.^{-1}$ during 1994–2008). Overall, our study highlighted the influences of natural disasters and economic development on the forestry policies and forest C dynamics in the newly industrialized country.



## 1. Introduction

The growing awareness of the roles that forests play in climate change mitigation has raised global interest in understanding the processes that lead to deforestation and forest restoration (Foley et al., 2005; Chazdon, 2008; Harris et al., 2012), and multiple factors from natural and human systems are drivers of the processes (Geist and Lambin, 2002; Meyfroidt and Lambin, 2011; Hansen et al., 2013; Miyamoto et al., 2014). For instance, forests could be disturbed or completely destroyed by natural disasters (i.e., drought, hurricane, wildfire, flood, ice storms, etc.) (Boose et al., 1994; FAO, 2010; Zhou et al., 2014). Furthermore, as a consequence of climate change, global forests may face rapid alterations in intensity, frequency, and extent of natural disasters (Dale et al., 2001; Zhou et al., 2014). Meanwhile, economic development and population growth are strongly driving deforestation, especially in developing countries or newly industrialized countries (Mather et al., 1999a; Geist and Lambin, 2002). However, empirical studies found economic development might also promote forest growth as income grows following the environmental Kuznets curves (Mather et al., 1999b). Currently, two pathways have been recognized from worldwide studies to explain forest transition from net loss to net increase (Rudel et al., 2005). One is the 'economic development' pathway, where farm laborers decrease due to urbanization and economic development, and agricultural lands are abandoned and then reforested. Another is the 'forest scarcity' pathway, where scarcity of forest products prompts afforestation and reforestation (Rudel et al., 2005; Mather, 2007).

Although global deforestation rate remained high during the past few decades (FAO, 2010; Hansen et al., 2013), forests in some developing countries or newly industrialized countries (e.g., China, India, Vietnam, Bhutan, Costa Rica) show net increment as many European countries and USA experienced in the past (Mather, 2007). The causes, pattern, environmental implications (e.g., carbon budget, biodiversity conservation), and sustainability of forest transition in these countries remain inadequately understood and has attracted widespread attentions (Meyfroidt and Lambin, 2009; Pan et al., 2011). A better understanding of the forest dynamics and its relevance with various natural and socioeconomic factors in these countries could provide critical guidance for articulating policies and strategies of forest management and climate change mitigation, e.g., the REDD+ (Meyfroidt et al., 2010; Phelps et al., 2010; White, 2011; Maraseni et al., 2014; Ituarte-Lima et al., 2014).

* Corresponding authors.
*E-mail addresses:* kerongzhang@wbgcas.cn (K. Zhang), qzhang@wbgcas.cn (Q. Zhang).

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China possesses the largest annual net increment of forest area (FAO, 2010) and the world's most ambitious afforestation and forest conservation programs such as the Natural Forest Protection Program (NFPP), Grain for Green Program (GFGP), Three-North Protective Forest Program (TPFP),and Forest Shelterbelt Programs in Key Basins (Yangtze River, Pearl River, etc.) (FSRB). Meanwhile, China has been undergoing profound economic and social transformation since 1970s, and the growing economy associated with increasing demand for forest products has brought huge pressure on forests (Xu and White, 2004; Liu and Diamond, 2005). Additionally, China is a country with frequent and severe natural disasters (Ting, 2007), which may also affect forests profoundly. Thus, forest dynamics in China may be closely linked to natural disasters and socioeconomic variables.

The major goal of this study is to answer the following questions: (1) Did natural disasters and economic development affect forestry policies and forest dynamics in China? (2) How has the forest biomass changed, and which factors influenced the changes? To address these questions, we analyzed the temporal trends (from 1970s to 2000s) in forest dynamics (including area and biomass), forest destruction (including forest consumption and commercial timber yield), afforestation & forest conservation (including annual area of afforestation, area closed off for forest restoration, ratio of forest designated for conservation, and capital investment in afforestation &forest management), natural disturbances (e.g., natural disasters, forest area affected by fire, diseases and insect pests), and socioeconomic indicators (e.g., Gross domestic product (GDP), per capita GDP, urbanization, population, government revenue). We also explored the potential relationships among these variables.

## 2. Materials and methods

### 2.1. National forest inventory (NFI)dataset

The forest inventory dataset was compiled from China's seven NFIs (Chinese Ministry of Forestry, 1977, 1982, 1989, 1994, 2000, 2005 and 2010, respectively): 1973–1976 (1st), 1977–1981 (2nd), 1984–1988 (3rd), 1989–1993 (4th), 1994–1998 (5th), 1999–2003 (6th), and 2004–2008 (7th). The inventories comprised of more than 250,000 plots (160,000 permanent plots and 90000 temporary plots) (Fang et al., 2001; Zhang and Song, 2006). The plot selection, field investigation, and data analysis both have followed standardized guidelines enacted by China's Ministry of Forestry (Ministry of Forestry, 1982). Systematic sampling with a grid of 2 × 2 km or 4 × 4 km (depending on forest region) was used when selecting plots (Fang et al., 2001).Forest area and timber volume of each forest type were aggregated at provincial level. In addition, other information, such as the land-use, forest consumption, growth rates, etc., was also recorded at provincial scale. Additional details regarding China's NFIs were provided by Fang et al. (2001, 2007).

All forests were classified and reported in five age classes in the NFI dataset, i.e. young, half-mature (middle-aged), near-mature, mature and post-mature forests. The classification of age class has been conducted according to the standardized guidelines enacted by China's Ministry of Forestry (Ministry of Forestry, 1982). The age classes of forests were classified based on the age of dominant tree species and their development stages (See the Appendix Table in Xu et al., 2010).The growth rates, climatic zones, and species have been considered in the age classification guidelines (Ministry of Forestry, 1982; Xu et al., 2010). More detailed information about the age classification criteria for each forest type had been provided by the former Ministry of Forestry of China (1982). Considering that there were some difficulties in classifying the near-mature, mature and post-mature forests accurately in field investigation, forests in these three age classes were pooled as ‘mature forests’ in our present study.

The threshold canopy coverage was set at >30% for a stand to be considered forest in the first four national inventories (i.e., 1973–1976, 1977–1981, 1984–1988, and 1989–1993), while forests with canopy coverage >20% were accounted for in the in the later three inventories (i.e., 1994–1998, 1999–2003, and 2004–2008). We calibrated the first four national inventories to the same criterion (20% canopy coverage) according to the method developed by Fang et al. (Fang et al., 2007; Pan et al., 2011).

We obtained the information of provincial forest area (ha), timber volume ($m^3$), forest consumption (expressed as annual timber consumption from living trees, $m^3$) from the inventory dataset (Chinese Ministry of Forestry, 1977 to 2010, respectively). The provincial forest area affected by climatic disasters (wind, drought, snow, ice, landslides, etc.) was recorded only in the 7th NFI, and was used as Climatic Disasters Index (CDI) of natural disturbance to forests.

### 2.2. Forestry development dataset

Forestry development dataset was composed of annual area of afforestation, newly increased area closed for forest restoration, commercial timber yield, capital investment in afforestation &forest management (IAM), and area of forests disturbed by fire, diseases and insect pests. The information was collected from the China Forestry Statistical Yearbooks from 1987 to 2010 (Chinese Ministry of Forestry, 1987 to 2010, respectively) and publications compiled by Chinese Ministry of Forestry (Chinese Ministry of Forestry, 1990) and State Statistical Bureau from 1949 to 1987 (State Statistical Bureau, 2000). The annual area of afforestation at provincial level was only available after 1978. The information about wood supply, consumption, and foreign trade was obtained from China forestry development reports from 2003 to 2012 (State Forestry Administration, 2003 to 2012, respectively).

### 2.3. Natural disasters and social-economic dataset

The dataset including GDP, per-capita GDP, population, urbanization level, and occurrence of natural disasters was compiled from the ‘Thematic Database for Human-earth System’ (TDHS, http://www.data.ac.cn), ‘National Data Sharing Infrastructure of Earth System Science’ (NSTI, http://www.geodata.cn), China Statistical Yearbooks (State Statistical Bureau, 2008 to 2011, respectively), and other publications (State Statistical Bureau, 2000; State Statistical Bureau, 2009). We used the ratio of the crop area suffered by drought or/and flood to the total area of crops as an index of occurrence severity for drought or/and flood (State Statistical Bureau, 2009). The information about dust storm events was collected from a study of Wang et al. (2005).

### 2.4. Analysis

We analyzed the temporal trends and potential relationships among forest area and biomass, forest destruction, afforestation & conservation, natural disturbances, and social–economic indicators. The temporal dynamics were fitted by polynomial or linear fitting ($P < 0.05$). We estimated the forest biomass for each province (excluding Taiwan due to lack of data) based on the NFI dataset and biomass expansion factor (BEF) using the volume-derived method which was described in detail in previous studies (Fang et al., 2001;Fang et al., 2007; Xu et al., 2007). Briefly, the forest biomass was estimated according to the allometric relationships between forest biomass and forest timber volume for each forest type (Fang et al., 2001;Fang et al., 2007; Xu et al., 2007). Bamboo and economic forests (trees planted for harvesting fruits, oils, ingredients, and medicinal materials) were not included for estimating forest biomass stocks and density. We also analyzed the relationships among changes of forest biomass stocks and density during 1994 to 2008, current forest biomass stocks and density (7th NFI), and potential influencing factors (e.g., investment, afforestation, consumption, disturbances) at provincial level. Taiwan and Tibet were not included in this analysis because their dataset was incomplete. The Climatic Disasters Index (CDI), Forest Fire Index (FFI), Diseases& Insect Pests Damage Index