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Deforestation in Heilongjiang Province of China, 1896–2000: Severity, spatiotemporal patterns and causes

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A B S T R A C T

This study attempts to ascertain the spatiotemporal patterns of de(re)forestation and its causes in Heilongjiang Province, China during the last century. In 1896, there were 308,020 km^2 of forest covering 68% of the Province. Forest area was reduced to 247,256 km^2 by 1949 at an annual rate of 1146 km^2. By 1958 primary forest was reduced to 169,533 km^2 while secondary forest remained at 68,801 km^2. Thus, 9421 km^2 of forest were logged at a rate of 1046 km^2 per annum. From 1958 to 1980, forest as a whole was reduced by 22,326 km^2 at an annual rate of 1014 km^2. The amount of deforestation was reduced to 9211 km^2 for dense forest, but sparse forest gained 831 km^2 during 1980–2000. The net decrease of 8379 km^2 represents an annual loss of 419 km^2. Spatially, deforested areas used to be extensive and expansive, but have become fragmented with thousands of patches that have a shrinking mean size. These deforested sites were located in low-lying flat terrains with a close proximity to rivers and roads. Such land was replaced primarily by farmland and secondarily by grassland. Therefore, the causes of deforestation are identified as demand for timber, population-driven land reclamation up to 1980, and urbanisation in the last two decades.

Introduction

Forests are one of the most significant components of the Earth's biosphere. They play a critical role in regulating the Earth's surface temperature and precipitation, preserving soil nutrients, minimizing flooding, and fixing carbon, in addition to serving as a valuable habitat for wildlife. In spite of these functions, however, forest resources around the world are being depleted for various reasons. Forest depletion or deforestation is a process of removal of a forest or stand of trees that results ultimately in non-woodland uses or tree covers at a reduced density. According to FAO (2005), about half of mature forests in the tropics have been logged. Deforestation has been occurring at an annul rate of 5.8 million ha between 1990 and 1997 (Achard et al., 2002) while 2.3 million ha is degraded annually (Mayaux et al., 2005). This conversion from forest to non-forest covers have contributed to environmental degradation, increased flooding, exacerbated soil erosion, and reduced biodiversity. Deforestation must be timely monitored so that decision-makers can have the most recent knowledge on the status of forest land in order to achieve sustainable forestry, and minimize carbon footprint on the environment.

As a panoramic, systematic, and objective method of detection and assessment, remote sensing enables deforestation to be efficiently monitored. With an ability to faithfully preserve the Earth's surface (Achard et al., 2002), aerial photographs and satellite images have found applications in detecting forest cover change and forest fragmentation (Harper, Steininger, Tucker, Juhn, & Hawkins, 2007). Satellite imagery with a broad coverage, a moderate resolution, and multispectral bands are particularly useful for monitoring deforestation (Baker & Williamson, 2006) owing to its capability of supplying transparent and reliable information on forest cover and condition (Fuller, 2006). Space-borne imagery enables detection and differentiation of forest and non-forest covers (Townshend, Justice, Li, Gurney, & McManus, 1991). Because of its synoptic views, space-borne imagery plays a vital role in identifying and estimating deforested areas (Buchanan et al., 2008). Coarse resolution data such as Advanced Very High Resolution Radiometer (AVHRR) imagery at a resolution of 1 km are well suited to identification of deforestation (Tucker, Holben, & Goff, 1984), assessment of deforestation rate (Gastellu-Etchegorry, Estreguil, Mougin, & Laumonier, 1993), and documentation of land-clearing activities over an extensive range (Stone, Brown, & Woodwell, 1991). The fine temporal resolution of AVHRR images makes them especially valuable in real-time identification and locating of fires, but hampers their utility in estimating burned areas (Setzer, Pereira, & Pereira, 1994). Such a task is more competently achieved from images of a finer spatial resolution

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(e.g., multispectral scanner MSS imagery at 79 m resolution) that are good at determining net forest removal, regrowth, and forest edges (Huang et al., 2007; Westman, Strong, & Wilcox, 1989). New satellite images with improved spatial resolution have become available since then.

Multi-temporal remote sensing data that have been in existence for decades are especially good at detecting changes in land use in general and deforestation in particular. Goldewijk and Ramankutty (2004) reviewed the detection of land cover change over the last three centuries. The areas of historical studies range from regional to country, such as the Nestos delta, Greece (Mallinis, Emmanoloudis, Giannakopoulos, Maris, & Koutsias, 2011) and Belgian Ardennes (Petit & Lambin, 2002). Since earth resources satellites did not come into existence until the early 1970s, the change detection span is restricted to tens of years (Abd El-Kawy, Rd, Ismail, & Suliman, 2011; Gao & Liu, 2010; Hadeel, Jabbar, & Chen, 2010; Masoud & Koike, 2006; Onur, Maktav, Sari, & Kemal Sönmez, 2009). This span can be extended further to the pre-1970s era if coarser resolution data such as AVHRR are used (Laneve & Castronuovo, 2005). Longer period of change detection has to rely on non-remote sensing data (Mallinis et al., 2011). So far the post-classification change detection method is the most popular (Chen & Wang, 2010; Faid & Abdulaziz, 2012; Gao & Liu, 2010). Images are also processed to derive vegetation index that is used for subsequent detection of vegetation-related change (Laneve & Castronuovo, 2005).

Remotely sensed data are indispensable in studying the rapidly changing forest environment and in determining the trend of deforestation (Peralta & Mather, 2000), such as detecting spatial changes in forest cover, and identifying critical areas of forest cover changes (Lele & Joshi, 2009). Once the deforested areas are identified, their spatial patterns can be quantified (Steininger et al., 2001; Wang et al., 2003), their relationship with the size of forest cover analysed (Zhang, Devers, Desch, Justice, & Townshend, 2005), and the reasons behind deforestation explored. After deforestation is analysed from multi-temporal satellite images, and the trend of deforestation rates estimated, it is possible to assess the impact of spatial, cultural, and economic factors on deforestation (e.g., the distance from roads, rivers, research facilities, oil facilities, markets and towns, and land ownership) (Greenberg, Kefauver, Stimson, Yeaton, & Ustin, 2005).

The causal relationship between deforestation and its contributors is most effectively determined via overlay of forestry maps with other physiographic layers in a geographic information system (GIS). This spatial analysis can reveal the significance and magnitude of the relationship between forest cover and environmental variables (Apan & Peterson, 1998). A proposed vegetation classification logic for remote-sensing data (Running, Loveland, & Pierce, 1994) and recent computer advances with GIS make estimation of deforestation repeatable and quantifiable (Iverson et al., 1994). However, no comprehensive studies have been carried out to systematically examine the change between forest and other land covers over a long (e.g., >100 years) period and the causes of deforestation over different periods. Such a long-time frame is essential in order to assess the validity of the forest transition theory that states "over time, forest cover declines, but at some point a transition occurs, such that the decline halts and reverses, and forest cover thereafter expands" (Perz, 2007). This study aims at modifying this theory using the remote sensing-GIS approach in accurate quantification of deforestation in Heilongjiang Province of Northeast China. Specifically, this research aims (1) to ascertain the level and extent of deforestation in this subarctic region of China over the last century; (2) to detect structural changes of primary (e.g., non-plantation) and secondary (e.g., planted and regenerated) forest resources and their spatiotemporal patterns; (3) to establish the association between the observed pattern and physiographic features; and (4) to explore the causes of deforestation.

Study area

Heilongjiang is located in Northeast China between 121°13′–135°05′E and 43°22′–53°24′N. This Province has a territory of 452,000 km^2 and a population of 38.17 million (2010 census data). It has a continental monsoon climate with an annual temperature of −4 to 4 °C. Winters are long and frigid (temperature averages −31 to −15 °C), and summers are short and cool with an average temperature of 18–23 °C. Annual rainfall averages 500–600 mm, concentrated mostly in the summer months. The terrain is dominated by a few mountain ranges, two most important ones being the Greater Khingan and Lesser Khingan (Fig. 1). This Province has relatively plentiful water resources with several major rivers, of which the Amor (black dragon) in the north-east bordering Russian, and the Songhua River that flows across it are the most important ones. Wetlands are distributed in low lying plains of 50–250 m above sea level. The Province has the country's largest natural forests that constitute the principal component of the forest resources. They are also one of the most distinctive temperate forests in the world. Forestry covers 19.19 million ha of the Province's total land area (41.9%), with a total reserve of 1.5 billion m^3 of timber.

The Province has a long history of deforestation. Large-scale logging started in the early 1920's with the construction of the "mid-eastern" railway. During 1929–1944 forest area in Northeast China decreased by 18%, with the timber reserve decreased by 14.3%. Deforestation has caused grave environmental degradation, such as soil erosion and flooding.

Methodology

Remotely sensed data and land use map

Two historical forest cover maps produced by the forest resources investigation and management unit of the Headquarters of Forestry and Industry Bureau in Heilongjiang Province were collected. They showed the distribution of forest (including Korean pine) in 1896 and 1949 at a scale of 1:2.5 million. These maps were produced by the Forestry Resource Investigation and Management Office of (then) Heilongjiang Forest Chief Bureau to the highest accuracy possible (Wang et al., 2003). A land use map of Northeast China was collected from the Institute of Geographical Science and Natural Resources, Chinese Academy of Science. It was produced at a scale of 1:3 million from visual interpretation of aerial photographs taken in 1958. Displayed in this map were ten categories of general land covers, such as primary and secondary forest. In addition, Landsat TM/Enhanced TM Plus (ETM+) images recorded in 1980 and 2000 were collected from the ground receiving station in Beijing. About 58 images were acquired to cover the entire Province in each time. These images were recorded during the June–September period when forest has a maximum spectral disparity from other covers.

GIS data

These data include a digital elevation model (DEM), roads, rails and stream data. The DEM was downloaded from the NASA's EOS data archive (http://asterweb.jpl.nasa.gov/gdem.asp). These archived global DEM data are publicly available free of charge. They cover the Earth's land surface between 83°N and 83°S. Global DEM is produced at 30 m from stereoscopic ASTER VNIR bands. These data are available in 1 by 1° tiles in the GeoTIFF format. Roads, rails and stream data were extracted from the Digital Charts of the