Use of multi-temporal Landsat images for analyzing forest transition in relation to socioeconomic factors and the environment

Zhi-Hua Shi a,b,c, Lu Li b, Wei Yin c, Lei Ai b, Nu-Fang Fang b, Yan-Tun Song b

Abstract

Recently there have been reports of forest regrowth occurring in different regions across the world. There is also a growing recognition of the potential beneficial impact that secondary forests may have on the global environment: providing crucial ecosystem services such as soil conservation, stabilization of hydrological cycles, carbon sequestration, and support for forest dependent communities. Consequently, there is a growing awareness of the need to recognize that landscapes are complex shifting mosaics wherein forest clearing and reforestation take place. In this study, the rates of reforestation, deforestation, forest regrowth and degradation were measured using multi-temporal Landsat images of Danjiangkou, China. Landsat data from 1990, 1999 and 2007 were (1) classified as dense forest, open forest and non-forest areas and (2) compared between years to identify forest cutting, regeneration and degradation. The results showed that there was a net gain of 29,315 ha of forest area (including dense and open forest) from 1990 to 2007, showing a clear trend of reforestation in the study area. Forest modification (degradation and regrowth) and change categories (deforestation and reforestation) occurred simultaneously during the observation time period. Socioeconomic data from public statistics and environmental attributes allowed the assessment of the socioeconomic factors and the environmental conditions that caused these changes using non-metric multidimensional scaling (NMDS). The research showed that the socioeconomic factors due to different policies were major driving forces of forest transition, whereas environmental attributes of the underlying landscape constrained forest cover changes. These findings have led to a better understanding of forest transition at a local scale in our study region. Comprehensive knowledge of these relationships may be useful to reconstruct past forest transitions and predict future changes, and may help to enhance sustainable management practices aimed at preserving essential ecological functions.

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1. Introduction

Forests provide a range of ecosystem services essential to human survival, such as maintenance of biological diversity, regulation of climate and purification of air and water. Forests are however, primary target areas in many countries for agricultural and urban expansion. Worldwide deforestation continues at an alarmingly high rate: 13 million hectares per year (FAO, 2006). However, a growing body of recent literature suggests that there has been a reversal in this trend in multiple regions across the world (Lamb et al., 2005). Due to tree planting, landscape restoration and natural expansion of forests, the net loss of global forest area during the periods of 1990–2000 and 2000–2005 are estimated at 8.9 million and 7.3 million hectares per year, respectively. In Asia there was a net loss of about 800,000 ha per year in the 1990s, however from 2000 to 2005 a net gain of 1 million hectares per year was reported, primarily as a result of large-scale afforestation efforts, particularly in China (FAO, 2006). Secondary forests often do not contain the same range of species diversity or supply the same ecosystem services when compared with less-disturbed forests. However, it has multiple beneficial impacts on the global environment, providing crucial environmental or ecosystem services such as soil conservation, stabilization of hydrological cycles, carbon sequestration, and support for forest dependent communities (Lugo and Helmer, 2004; Rudel et al., 2005). Consequently, there is a growing aware-
The need to recognize that landscapes are complex shifting mosaics wherein forest clearing and reforestation take place, often simultaneously (Nagendra, 2007).

The Danjiangkou Reservoir Area (DRA) in central China represents a useful and crucial setting for conducting a study of forest landscapes. In response to the water deficiency in northern part of the country, in 2002 China implemented the three-route (East, Middle and West) South to North Water Transfer Project. This has a capacity of transferring a total of 44.8 billion m$^3$ of water annually from the Yangtze River and its tributaries to the drought bound region of north China. The Danjiangkou reservoir on the Han River, the largest tributary of the Yangtze River, is the water source of the Middle Route supplying 13.8 billion m$^3$ of water annually to North China including Tianjin and Beijing (Fig. 1). The forests of DRA support millions of residents in the region as well as many people residing in the water-receiving area through water cycle regulation. Agriculture is the principle activity in the region, and depends on the natural forest vegetation cover for sustainability. The local residents prioritize their subsistence requirements and thus the expansion of agriculture. However, the government and others residing in the water receiving area argue for greater forest cover to ensure an environmental balance at the macro level. In order to guarantee the quantity and quality of the transferred water, the central and local governments have worked very hard on reforestation since the late 1990s. This region provides an excellent context in which to examine trajectories of forest change, with extensive evidence of deforestation in some regions and large-scale reforestation in others.

Forest transition results from complex interactions of environmental and socioeconomic factors and in many situations it is not possible to isolate a single cause. Comprehensive studies are urgently needed to establish a knowledge base for future sustainable management practices aimed at preserving essential forest ecosystem functions. Understanding the relationships between the forest transitions and socioeconomic and environmental factors will be an important part of such a knowledge base. Therefore, the Danjiangkou was chosen as a case study area, and the objectives of this study are: (1) to assess spatial and temporal characteristics of reforestation, deforestation and forest regrowth from 1990 to 2007 using multi-temporal Landsat images; (2) to analyze possible factors influencing forest transition.

2. Materials and methods

2.1. Description of the study area

The study was conducted in Danjiangkou, which stretches across 3123 km$^2$ of DRA in China (Fig. 1). The area, bounded geographically by 32°14′19″ to 32°58′09″ N latitude and 110°48′06″ to 111°34′39″ E longitude, is quite typical of the agricultural landscapes of central China. The area has a subtropical with monsoon climate and an average annual precipitation of 870 mm with the highest intensity of rainfall from June to September. Due to the monsoon, the total amount of rainfall in these 4 months account for more than half of the total amount of the yearly rainfall in this area. The topography of the area represents elevations ranging from 87 to 1612 m, and 67.58% of the total area falls within an altitude of 151–500 m. Approximately 60.04% of the total area consists of moderate to moderately steep slope (11–30°). Vegetation has typical subtropical characteristics. Evergreen forests are distributed below an elevation of 1500 m, and conifer and broad-leaf mixed forests occur above an elevation of 1500 m. Residual forests are located only in the mountainous areas of the region. In 2007 the city’s population reached 495,100 of which more than 69% were farmers.

2.2. Processing of remote sensing data

Phenological variation could complicate consistency in image classification between scenes. In early autumn the vegetation is vigorous and it is most likely to distinguish between different land cover type. We therefore selected images of 1990 (TM), 1999 (ETM+), and 2007 (TM) from approximately September to analyze forest change in the study area. A brief description of the
The visual interpretation of Landsat image can be used as a useful tool in light red, inhomogenous colors and dark color, relatively rough sites were chosen from the images. The image signs of dense forest image signs in different land cover were established and training results of the unsupervised classification, then different types of algorithm to identify spectral clusters in the images. Based on the out using the Interactive Self-Organizing Data Analysis (ISODATA) non-forest. In this study, unsupervised classification was carried area. The land cover was classified as dense forest, open forest, or satellite images was used in Table 1. We chose the three Landsat scenes that corresponded with significant policy change. China adopted a market-directed economy system in the early 1990s, and the Chinese government took various measures to protect forest after massive floods in 1998. Images were subjected to atmospheric correction, radiometric calibration and radiometric rectification procedures to facilitate comparability between dates (Jensen, 2000). The 1990 image was geometrically registered to 1:50,000 scale topographic maps; the 1999 and 2007 images were geometrically registered to the 1990 base image. Root mean square errors of registration were maintained at levels below 0.5 pixels (<15 m) and registration was verified visually by overlaying and swiping registered images. Finally, the remote sensing images were masked using the boundary of Danjiangkou. Before interpretation of the remote sensing imageries into land cover maps, a land cover reconnaissance survey was carried out to obtain a general understanding of the land cover of the study area. The land cover was classified as dense forest, open forest, or non-forest. In this study, unsupervised classification was carried out using the Interactive Self-Organizing Data Analysis (ISODATA) algorithm to identify spectral clusters in the images. Based on the results of the unsupervised classification, then different types of image signs in different land cover were established and training sites were chosen from the images. The image signs of dense forest was sheet or band shape, rich red (broad leafed forest or dark red (coniferous forest) in color, uniform colors and bright color, uniform texture. While the image signs of open forest was bright red patch in light red, inhomogenous colors and dark color, relatively rough texture. For each image, spectral signatures for the training sites were carefully chosen and examined. A maximum likelihood classifier was then employed for image classification. Our preliminary classification indicated that misclassification errors include boundary and spectral confusion. As demonstrated in previous studies, visual interpretation of Landsat image can be used as a useful tool in land cover mapping (Liu et al., 2005). In this study, the preliminary classification results were therefore revised according to visual interpretation and ground survey.

In order to evaluate the accuracy of the land use maps derived from remote sensing images, we conducted a field surveys in June 2008, covering a total survey length of 105 km across the study area, 398 patches and more than 300 photos located with GPS facilities. The overall accuracy of the land cover classification was found to be 92.8 and 92.9% respectively, based on the evaluation of 166 and 98 patches, respectively. For non-forest areas, the accuracy was 90.3% based on an evaluation of 134 patches. We collected 217 slices to evaluate the accuracy of location during mapping process. The results indicated that 99% of the polygon boundaries show less than 1.5 pixels (45 m) shift from the real boundary. We chose 415 and 435 land use patches in 1990 and 1999, respectively, to make an accuracy evaluation by interviewing local people. We also referred to aerial photos and historical land use maps obtained from the local authorities. The results showed that the overall identification accuracies were 90.6% in 1990 and 92.4% in 1999 (Table 2).

2.3. Socioeconomic and environmental data

The socioeconomic data came from statistical yearbooks (Danjiangkou City Statistical Bureau, 1991, 2000, 2008). The selection of data items was made with consideration of the literature of Chinese scholars (Xu et al., 2004; Zhang et al., 2006; Zou et al., 2006) and the factors are listed in Table 3. Data were compiled for townships and villages (143 in total). The rates of yearly increase were computed from the observed values of the selected factors between 1990–1999 and 1999–2007, based on the equation,

\[ R_i = \left( \frac{V_2}{V_1} \right)^{1/n} - 1 \]

where \( R_i \) is the increase rate of the observed value of a socioeconomic indicator; \( V_1 \) the value of an indicator i at the date \( t_1 \); \( V_2 \) the value of the indicator i at the date \( t_2 \); and n is the difference in years between the two dates.

In addition to socioeconomic factors, there are environmental conditions that potentially influence forest changes. In an earlier study, we focused on environmental impacts, analyzing the correlation between environmental factors and forest changes in DRA (Li et al., 2009). The results showed that forest changes are constrained by the environmental attributes of elevation, slope, soil quality, distance to road and distance to the nearest town. Local climatic conditions are represented by the topographic data. Therefore, we included elevation, slope, soil quality, distance to road and the nearest town as environmental factors in our model (Table 3). These factors were applied as stable discriminant factors without variation in time. Elevation data were taken from a digital elevation model (DEM) provided by State Bureau of Surveying and Cartography. Slope was calculated from the DEM with the surface analysis function in IDRISI (GIS software package). The soil map was digitized from the 1:50,000 exploratory soil map of Danjiangkou, compiled by the Danjiangkou Soil Survey Office in 1987. The exploratory soil map was remapped into five suitability classes. These classes (from “1”: most suitable, to “5”: least suitable) were based on the intrinsic soil characteristics of the soil types. Two vector layers of roads and towns were digitized from 1:50,000 scale.
maps of the study region. Most of the roads in the study area are paved roads. Each road segment was therefore treated as being equally suitable for transport of goods and people.

2.4. Assessment of forest status: land cover transition

To assess land cover change the three temporal land cover layers (1990, 1999, 2007) were intersected in turn, and two land cover transition layers (1990–1999 and 1999–2007) were extracted. The CROSSTAB module of the IDRISI software was used for performing this analysis (Clark Labs, 2001). The CROSSTAB offers cross-classification, which can be described as a multiple overlay showing all combinations of the logical AND operation. The result is a new image that shows the locations of all combinations of the categories in the original images. A legend is automatically produced showing these combinations. Cross-classification thus produces a map with representation of all non-zero entries in the cross-tabulation table. Because there were three land cover classes for each date, recoding resulted in a total of nine change classes for each pair of dates. These were grouped into stable forest, stable non-forest, deforestation, reforestation, regrowth, and degradation categories depending on the nature of change in forest cover that they represented (Nagendra et al., 2008).

Stable forest was forested in both dates (forest-forest). Stable non-forest was not forested in either date. Deforestation comprised of grid cells that changed from open forest or dense forest to non-forest. Reforestation comprised of grid cells that changed from non-forest to either open or dense forest. The remaining categories represent land cover modification changes that affect the quality or density of forest cover without changing the nature of the land cover class. Grid cells that changed from open forest to dense forest were categorized as regrowth. Grid cells that changed from dense forest to open forest were categorized as degradation.

2.5. Multivariate analysis

For statistical analysis, the study area is divided into quadrats. Analyses were conducted at two spatial scales, using quadrats of 9 km² (3 km x 3 km) and 25 km² (5 km x 5 km). Because the patterns were similar, however, only results for the 25 km² quadrats are presented here. There were 159 quadrats of 25 km² in the Danjiangkou (Fig. 2). The quadrats in our analysis do not include those along the margins of the Danjiangkou that had <70% of their area within the region’s boundaries, which were excluded from analyses. Therefore, a subset of 122 quadrats was selected for statistical analysis. For each quadrat, the ratio of different forest transition categories and the socioeconomic or environmental variables were extracted into data tables to permit statistical analysis for both periods 1990–1999 and 1999–2007, respectively. Because many of the socioeconomic and environmental variables were strongly intercorrelated, a robust ordination method, non-metric multidimensional scaling (NMDS), was used to identify key orthogonal (statistically independent) gradients in the data set. We performed 500 runs using random starting configurations stepping down in dimensionality from 6 to 1. The final configuration was chosen by comparing the final stress values for each dimensionality. An increase in dimensions was considered only if the final stress was reduced by 5 units or more. A Monte Carlo test with 50 randomized runs was used to determine the statistical significance of the final ordination configuration (PC-ORD v5 software used) (McCune and Mefford, 1999). We used Pearson Product Moment correlations to examine the associations between axis scores and the socioeconomic or environmental variables. All variables were standardized before analysis with the relativization by maximum method. The Danjiangkou reservoir, which was digitized from 1:50,000 scale maps of the study region, was excluded from analysis as this area was almost constant over time and our focus was on the change of forest cover.

3. Results

3.1. Dynamics in forest areas

The temporal changes in the forest area in Danjiangkou City are illustrated in Fig. 3. The process of spatial change in forest cover in the study area is shown in Fig. 4. The estimated area of dense forest increased from 138,966 ha in 1990 to 155,941 ha in 2007, at an average rate of 998.5 ha/year. In 2007, dense forest covered 49.9% of the total area of the region. As seen in Fig. 2, the rate of increase during 1990–2007 was very high. From 1990 to 1999, the area of dense forest showed a small decrease of approximately 2.3%
Fig. 4. Temporal and spatial variation of land cover types in Danjiangkou for the years: (a) 1990, (b) 1999, and (c) 2007.

Table 4

<table>
<thead>
<tr>
<th>Forest change categories</th>
<th>Total area (ha)</th>
<th>Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable forest</td>
<td>120,795</td>
<td>146,117</td>
</tr>
<tr>
<td>Regrowth</td>
<td>18,963</td>
<td>25,355</td>
</tr>
<tr>
<td>Reforestation</td>
<td>21,995</td>
<td>27,296</td>
</tr>
<tr>
<td>Deforestation</td>
<td>23,697</td>
<td>9,769</td>
</tr>
<tr>
<td>Degradation</td>
<td>20,268</td>
<td>12,211</td>
</tr>
<tr>
<td>Stable non-forest</td>
<td>106,572</td>
<td>91,542</td>
</tr>
</tbody>
</table>

The results indicate that stable forest was the largest area of cover type and covered 38.7% and 46.8% of the study area during the periods 1990–1999 and 1999–2007, respectively. Stable non-forest was ranked as the second largest area of cover type. However, the area of stable non-forest shrank from 34.1% of the total land area during the first time period to 29.3% during the second period of time.

3.2. Forest transition

The forest transition maps for both periods (1990–1999 and 1999–2007) are shown in Fig. 5. Table 4 summarizes the distribution of forest transition categories for both time periods shown in Fig. 5. The results indicate that stable forest was the largest area of cover type; and covered 38.7% and 46.8% of the study area during the periods 1990–1999 and 1999–2007, respectively. Stable non-forest was ranked as the second largest area of cover type. However, the area of stable non-forest shrank from 34.1% of the total land area during the first time period to 29.3% during the second period of time.

Forest modification categories (degradation and regrowth) and change categories (deforestation and reforestation) occurred simultaneously during the observation time period. Clear differences in the proportional distribution of the modification and change categories were observed (Table 4). Reforestation represented 7.0% of land area between 1990 and 1999; between 1999 and 2007, reforestation represented approximately 8.7% of the study area. Regrowth increased from 18,963 ha (6.1%) during 1990–1999, to 25,355 ha (8.1%) during 1999–2007. Deforestation and degradation categories showed the most extensive changes. During the study period, 20,268 ha and 9,769 ha of dense or open forest were converted into non-forest during the first and second time periods, respectively, representing an approximate 50% decrease in the area experiencing deforestation during the second time period. From 1990 to 1999, 23,697 ha of dense forest was degraded into open forest in the study area, and the annual rate of degradation was 2370 ha/year. During the next 8 years up to 2007, the annual rate of degradation decreased significantly to nearly 1/3rd of that of the previous 9 years.
3.3. Forest transition in relation to socioeconomic factors and the environment

Fig. 6 shows the ordination of forest transition related to the socioeconomic and environmental variables using the 120 selected quadrats in the two observed time periods. During the period of 1990–1999, the final configuration for the NMDS ordination had two dimensions (Fig. 6). A Monte Carlo test of 500 runs with randomized data indicated the minimum stress of the 2D solution was 16.67 and 0.00115, respectively. Axis 1 captured 35.7% of the variability in the dataset and the first ordination axes were 14.32 and 0.00079, respectively. The first ordination axis explained (Fig. 6). Results from correlation analyses between ordination scores and various socioeconomic/environmental factors (Table 5) indicate that NMDS axis 1 had significant negative correlation with income in agriculture, forestry, animal husbandry and fishery (IAFHA, \( r = -0.369, p < 0.01 \)), agricultural population density (A-POP, \( r = -0.336, p < 0.01 \)), population density (T-POP, \( r = -0.232, p < 0.05 \)), grain yield (Y-GRAIN, \( r = -0.373, p < 0.01 \)), and distance to the nearest town (D-TOWN, \( r = -0.239, p < 0.05 \)). In addition, NMDS axis 1 had significant positive correlations with slope (SLOPE, \( r = 0.350, p < 0.01 \)). The significant correlation between NMS axis 2 and the socioeconomic and environmental variables was IAFHA (\( r = -0.366, p < 0.01 \)), A-POP (\( r = -0.571, p < 0.01 \)), Y-GRAIN (\( r = -0.313, p < 0.01 \)), D-ROAD (\( r = 0.190, p < 0.05 \)), SLOPE (\( r = 0.376, p < 0.01 \)), and SOIL (\( r = 0.375, p < 0.01 \)).

<table>
<thead>
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<tbody>
<tr>
<td></td>
<td>Axis 1</td>
<td>Axis 2</td>
</tr>
<tr>
<td>IAFHA</td>
<td>-0.118</td>
<td>-0.168</td>
</tr>
<tr>
<td>A-POP</td>
<td>0.177</td>
<td>0.138</td>
</tr>
<tr>
<td>Y-CASH</td>
<td>-0.088</td>
<td>0.411**</td>
</tr>
<tr>
<td>N-IAFHF</td>
<td>-0.024</td>
<td>-0.001</td>
</tr>
<tr>
<td>T-POP</td>
<td>-0.165</td>
<td>0.068</td>
</tr>
<tr>
<td>Y-GRAIN</td>
<td>0.022</td>
<td>0.208</td>
</tr>
<tr>
<td>ELEV</td>
<td>0.019</td>
<td>-0.630**</td>
</tr>
<tr>
<td>D-ROAD</td>
<td>0.192</td>
<td>-0.437**</td>
</tr>
<tr>
<td>D-TOWN</td>
<td>-0.250**</td>
<td>-0.273**</td>
</tr>
<tr>
<td>SLOPE</td>
<td>-0.095</td>
<td>-0.682**</td>
</tr>
<tr>
<td>SOIL</td>
<td>-0.111</td>
<td>-0.598**</td>
</tr>
<tr>
<td>Variation explained</td>
<td>35.7%</td>
<td>45.2%</td>
</tr>
</tbody>
</table>

Legend

- Stable forest
- Degradation
- Regrowth
- Deforestation
- Reforestation
- Stable non-forest

Fig. 5. Spatial distribution of forest change categories in Danjiangkou: (a) 1990–1999 and (b) 1999–2007.
4. Discussion

4.1. Forest transition and their driving forces

Some studies of land cover changes have revealed close relationships with environmental conditions (del Barrio et al., 1997; Chen et al., 2001), whereas other studies have found that land cover changes are controlled by socioeconomic factors (Iverson, 1988; Schneider and Pontius, 2001). The ordination analyses reported here clarify a number of important questions about the drivers of forest transition in the study area. First, Danjiangkou is typically very irregular and about 73% of the area has an incline of more than 10° (Fig. 7a), with 22.3% of the area having grades of >25°. The altitude modal values in the region vary from 150 to 750 m (Figs. 1 and 7b), with a maximum amplitude of 1525 m (87–1612 m). The rugged topography of the study area clearly determines the distribution of forest and non-forest. Forest cover was particularly high in steeper areas and/or at higher altitudes. The use of land for economic purposes is preferentially done in less steep areas and at a lower altitude, leading to a greater reduction in forest cover in these areas. To characterize the districts relative to the most important environment for forest transitions, we quantified elevation, slope, and soil quality. These physical factors were identified in several previous studies as being related to land cover change (Poudevigne et al., 1997; Chen et al., 2001; Bürgi and Turner, 2002; Hietel et al., 2004; Fu et al., 2006).

Although our results imply that there are physical constraints on forest transition, the basic driving force behind forest transition can be assumed to be socioeconomic factors resulting from different policies (Li et al., 2009). In Danjiangkou two distinct periods of forest transition can be seen during 1990–2007. The first period is from 1990 to 1999. Policies that influenced this period included the “Household Responsibility System” in 1978 as well as the market-directed economy system which China adopted in 1992. As a result the collectives that owned approximately 60% of China’s forests handed most of them over to individual families to manage. Government allowed farmers to make all decisions about production, and a diversified economy has been encouraged. Once the demands of contracted quota and family subsistence have been met, the household has the freedom to allocate land resources. Shift of policy and new socioeconomic formation have also brought short-term patterns in forest management, because farmers have only the right to use, but not own forest. In order to obtain the maximum immediate benefit from the land, many farmers that received forests overexploited or deforested them. A high demand for wood for economic development and the subsistence needs of the rural
population were also important causes for the increase in forest degradation. During this period, a series of policies were implemented to develop and protect forest resources in China. In the 1980s, a national compulsory tree-planting campaign was initiated requiring all citizens (women aged 11–55 and men aged 11–60) to plant 3–5 trees every year. In 1985 a revised forest law was introduced, which in theory provided protection for natural forests. In practice this law provided very limited protection due to problems of implementation and enforcement (Yang, 2001). The government also partially liberalized forest product markets, which enabled households to receive degraded land to establish fast-growing and high-yielding forest plantations. The trends in forest transition in Danjiangkou as identified by this study mirrored the changes in policy and socioeconomic factors. The total area of forest grew by 3780 ha between 1990 and 1999. Yet, while the area of open forest increased by 7020 ha, the area of dense forest declined by 3240 ha.

The second period (1999–2007) can be considered a period of the introduction of strengthened controls on deforestation and of vigorous attempts at reforestation. The massive floods in 1998 prompted China to take two other unprecedented conservation actions: the development and implementation of the Natural Forest Conservation Program (NFCP), and the Grain to Green Program (GTGP). The NFCP conserves natural forests through logging bans and afforestation with incentives to forest enterprises. The commercial cutting of natural forest in the upper reaches of the Yangtze River is forbidden, and many forest employees changed their work from cutting to planting and tending. In 2000, 296,300 employees changed from work involving logging and transportation of logs to other jobs. These included a shift of 147,100 people to forest planting and tending, 76,500 people to work concerning to ecological and public benefit forestry, 10,700 people to seeds and seedlings work and 62,000 people to others (Zhang et al., 2006). To complement the effort of the NFCP, China initiated the GTGP in 1999. The GTGP conserves arable areas where the slope is more than 25° to forest and grassland by providing farmers with grain and cash subsidies. This program aims to convert an additional 5.33 million ha of marginal farmland to forestland for soil erosion control and to regenerate an additional 39 million ha of forest plantation and natural forest in degraded areas. As expected, with implementation of large-scale forest conservation programs, an increasing amount of farmland on sloped ground has been returned to woodland, and woodland quality has been substantially improved. The area of dense forest increased between 1999 and 2007 with protection of existing natural forest areas and work on natural regeneration in Danjiangkou.

4.2. Methodological issues

In explaining forest transition, remote sensing techniques using satellite imagery are an effective approach to analyze the rates and patterns of change in forest ecosystems. Repeated satellite images are useful for both visual assessment of natural resource dynamics occurring at a particular time and space (Tekle and Hedlund, 2000). Analysis and presentation of such data can be greatly facilitated through the use of GIS technology (Gautam et al., 2003). Use of GIS was essential for our overlay processing and multivariate analyses. GIS helped to effectively evaluate the general characteristics of the spatial distribution of forest and clearly revealed interesting dynamic events. The combined use of RS and GIS technology can be invaluable to address a wide variety of resource management problems including forest transition. By using NMDS, it is possible to assess the relationship between the forest spatial distribution or temporal transformation and important socioeconomic factors and the environment. NMDS proved to be a useful tool to detect relationships present. The results of this study may be extrapolated to other similar regions.

In our study, we analyzed the relationship between forest transition, socioeconomic factors and the environment. To combine forest transition types, socioeconomic and environmental variables, we first had to consider that they were based on different spatial scales. Forest transition types and environmental variables referred to grid cells, whilst socioeconomic variables referred to the district level. Considering the small–scale relationship between forest transition and socioeconomic factors, socioeconomic data were compiled for townships and villages, which are the smallest statistical unit in China and are easily available from public statistics. More detailed socioeconomic data (e.g. at farm level) cannot be obtained from public statistics because of data privacy protection legislation. Data at farm level can be obtained only by directly questioning farmers. However, such surveys can only provide data in relation to relatively short periods of time. They always include personal opinion and experiences of those interviewed, and are therefore likely to be more subjective than standardized statistical data (Hietel et al., 2005). When modeling the relationships between forest transition and socioeconomic and environmental variables, it is not possible to include all socioeconomic and environmental aspects that influence forest changes, due to unavailable data, unknown influencing factors and factors which are not possible to quantify. Therefore, only a relatively small part of the variance in forest transition data is unexplained by socioeconomic and environmental variables.

5. Conclusion

The results showed that there was a net gain of 29,315 ha of forest area (including dense and open forest) from 1990 to 2007, showing a clear trend of reforestation in the study area. Reforestation, deforestation, forest degradation and regrowth occurred simultaneously during the observation time period. There was a decrease in deforestation and forest degradation. The results of our NMDS model show that in Danjiangkou City, forest transition is indicated by a combination of socioeconomic and environmental variables. The socioeconomic factors resulting from different policies were identified as major driving forces of forest transition, whilst the environmental attributes of the underlying landscape constrain forest cover changes. The model leads to a better understanding of forest transition at a local scale in our study region. With modifications, our method can be adopted for the study of forest transition in other regions. Our current research focuses on the differentiation of the types of overall forest transition at a regional scale and the correlation with socioeconomic and environmental factors. Comprehensive knowledge of these relationships may be useful to reconstruct past forest transition and predict future changes, and may help to enhance sustainable management practices aimed at preserving essential ecological functions.

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References


Tekle, M., Hedlund, H., 2000. Analysis and presentation of such data can be greatly facilitated through the use of GIS technology (Gautam et al., 2003). Use of GIS was essential for our overlay processing and multivariate analyses. GIS helped to effectively evaluate the general characteristics of the spatial distribution of forest and clearly revealed interesting dynamic events. The combined use of RS and GIS technology can be invaluable to address a wide variety of resource management problems including forest transition. By using NMDS, it is possible to assess the relationship between the forest spatial distribution or temporal transformation and important socioeconomic factors and the environment. NMDS proved to be a useful tool to detect relationships present. The results of this study may be extrapolated to other similar regions.

In our study, we analyzed the relationship between forest transition, socioeconomic factors and the environment. To combine forest transition types, socioeconomic and environmental variables, we first had to consider that they were based on different spatial scales. Forest transition types and environmental variables referred to grid cells, whilst socioeconomic variables referred to the district level. Considering the small–scale relationship between forest transition and socioeconomic factors, socioeconomic data were compiled for townships and villages, which are the smallest statistical unit in China and are easily available from public statistics. More detailed socioeconomic data (e.g. at farm level) cannot be obtained from public statistics because of data privacy protection legislation. Data at farm level can be obtained only by directly questioning farmers. However, such surveys can only provide data in relation to relatively short periods of time. They always include personal opinion and experiences of those interviewed, and are therefore likely to be more subjective than standardized statistical data (Hietel et al., 2005). When modeling the relationships between forest transition and socioeconomic and environmental variables, it is not possible to include all socioeconomic and environmental aspects that influence forest changes, due to unavailable data, unknown influencing factors and factors which are not possible to quantify. Therefore, only a relatively small part of the variance in forest transition data is unexplained by socioeconomic and environmental variables.

5. Conclusion

The results showed that there was a net gain of 29,315 ha of forest area (including dense and open forest) from 1990 to 2007, showing a clear trend of reforestation in the study area. Reforestation, deforestation, forest degradation and regrowth occurred simultaneously during the observation time period. There was a decrease in deforestation and forest degradation. The results of our NMDS model show that in Danjiangkou City, forest transition is indicated by a combination of socioeconomic and environmental variables. The socioeconomic factors resulting from different policies were identified as major driving forces of forest transition, whilst the environmental attributes of the underlying landscape constrain forest cover changes. The model leads to a better understanding of forest transition at a local scale in our study region. With modifications, our method can be adopted for the study of forest transition in other regions. Our current research focuses on the differentiation of the types of overall forest transition at a regional scale and the correlation with socioeconomic and environmental factors. Comprehensive knowledge of these relationships may be useful to reconstruct past forest transition and predict future changes, and may help to enhance sustainable management practices aimed at preserving essential ecological functions.

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