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Simulation on the dynamics of forest area changes in Northeast China

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Abstract: There is plenty of forests in Northeast China which contributes a lot to the conservation of water and land resources, produces timber products, and provides habitats for a huge number of wild animals and plants. With changes of socio-economic factors as well as the geophysical conditions, there are dramatic changes on the spatial patterns of forest area. In this sense, it is of great significance to shed light on the dynamics of forest area changes to find the underlining reasons for shaping the changing patterns of forest area in Northeast China. To explore the dynamics of forest area change in Northeast China, an econometric model is developed which is composed of three equations identifying forestry production, conversion from open forest to closed forest and conversion from other land uses to closed forest so as to explore the impacts on the forest area changes from demographic, social, economic, location and geophysical factors. On this basis, we employ the Dynamics of Land System (DLS) model to simulate land-use conversions between forest area and non-forest cover and the land-use conversions within the sub-classes of forest area for the period 2000–2020 under business as usual scenario, environmental protection scenario and economic growth scenario. The simulation results show that forest area will expand continuously and there exist various kinds of changing patterns for the sub-classes of forest area, for example, closed forest will expand continuously and open forest and shrub will decrease a little bit, while area of other forest will keep intact. The research results provide meaningful decision-making information for conserving and exploiting the forest resources and making out the planning for forestry production in the Northeast China region.

Keywords: forest area; forestry production; econometric model; dynamics of land system; Northeast China

1 Introduction

With the economic development and population growth, quantities of forest area have been

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converted to cultivated land or other land covers (Chen, 1995; Ge *et al*., 2005; Wang *et al*., 2004). Forest area changes have most significant impact on ecosystem and climates. Therefore, monitoring the changes of the forest area and canopy structure through time is necessary, and it is important for many applications, such as decision-making (Zimble *et al*., 2003), forest planning and management (Sironen *et al*., 2001), climate change studies (Nuutinen and Kellomäki, 2001; Justice *et al*., 2001; Matala, 2005), and wildlife habitat (Coops and Catling, 1997). There are plenty of methodologies to monitor the change rate, conversion direction and intensity of forest area, and the most common one is using the remote sensing images. A large number of experts and scholars have used the remote sensing images interpretation to monitor the regional land changes (Ge *et al*., 2005; Liu *et al*., 2003). However, these studies can only get the land changes in history, but cannot obtain the land uses in future (Deng, 2008a). So we need to develop a model to simulate the forest area spatial distribution in any time based on the land use information in the past period.

Northeast China, an important production base for timber and forestry by-products in China, is also the water conservation area for essential rivers—Heilong River and Songhua River—as well as the ecological barrier of Sanjiang Plain, Songnen Plain and Hulun Buir Grassland, and bears the important significance to the maintenance of the regional ecological safety and socio-economic development (Dai *et al.*, 2006; Yuan, 2007; Chen, 2006; Deng *et al.*, 2006). After half a century of exploitation, forest area in Northeast China region has shrunk dramatically, the age structure of forests has tended to be monotonous and juvenile, and the forest resources suitable for exploitation decrease gradually. According to the national survey of forest resources, mature forest area reduced by 49.0% in the period 1981–1988, then in the next 10 years, 0.61 million ha of forest area will further disappear, accounting for about 60.0% of the total mature forest area of the whole country (Xiao *et al.*, 2002). Therefore, protection of forest quality has been the significant challenge for the environmental conservation and ecological engineering construction, which would restrict the development of local forestry production seriously (Ge *et al.*, 2000).

As is known, forest area changes are closely related to many factors such as economic growth, social development and the changes of geophysical conditions (Zhu *et al.*, 2007; Zhang *et al.*, 2006; Wang *et al.*, 2007). Logging out of plan, forest fire, extreme weather events and deforestation all promote the shrinkage of forest area to some extent. Although Northeast China is the pilot region for the Grain for Green Project, Logging Ban Project, and other ecological restoration projects have achieved success to some extent, the shrinking trends of forest area and forest degradation still exist (Wang *et al.*, 2004; Zhao *et al.*, 2006; Shen *et al.*, 2006; Peng *et al.*, 2007). In addition, forest area changes in Northeast China refer to not only conversions between forest area and other land uses, but also the conversions among the sub-classes of forests consisting of closed forest, shrub, open forest and other forest (Zhang *et al.*, 2003; Chen, 1993; Ge and Dai, 2005), which have drawn more and more attentions from the scholars as well as the decision-makers. Therefore, it is of significance to explore the dynamics and spatial patterns of forest area changes in the future for improving the management of the forest area and understanding the causes and possible effects of deforestation at the regional level and even for the entire China.

2 Data processing

Before building the econometric model to explore the dynamics of forest area changes in the

Northeast China region, detailed information needs to be gathered and integrated. The first step is to build a database which includes relevant data related to the influencing forces and data to describe the changes of land uses from 1988 to 2005 to provide parameters for the econometric model. Parameters for the econometric model can be generically categorized into three categories: land use information, geophysical variables and socio-economic variables (Table 1).

2.1 Land-use data

Land-use data is derived from the Data Center of the Chinese Academy of Sciences, which is composed of six kinds of land-use categories: cultivated land, forest area, grassland, water area, built-up area and unused land. In this study, the Landsat Thematic Mapper (TM) and/or

Table 1 Variables for exploring the dynamics of forest area changes in Northeast China

Definition of variables	Variables
Population density	*popden*
Agricultural population proportion, one-period lagged term	*ap*
GDP	*gdp*
Average elevation	*dem*
Quadratic term of average elevation	*dem2*
Average terrain slope	*slope*
Quadratic term of average terrain slope	*slope2*
Soil organic matter	*organic*
Annual precipitation	*pa*
Quadratic term of annual precipitation	*pa2*
Annual temperature	*ta*
Distance to the provincial capital	*d2pvcp*
Distance to the nearest port city	*d2port*
Distance to the nearest road	*d2road*
Distance to the nearest water area	*d2water*
Gross output value of forestry industry	*y*
Forestry production	*prod*
Forestry product price index	*value*
Whether the county with the natural reserve area? 1=yes, otherwise 0	*fpark*
Whether the county with major grain production? 1=yes, otherwise 0	*grain*
Whether the county involved in the state-owned forest protection plan and nursery financial system regulation? 1=yes, otherwise 0	*mng*
Area of other land-use categories converted into closed forest	*cvother21*
Area of open forest	*ld22*
Whether the county has implemented the Logging Ban Project? 1=yes, otherwise 0	*tbp*
Whether the county has implemented the Grain for Green Project? 1=yes, otherwise 0	*tghl*
Forestry coverage rate	*forcover*

†The land-use data in 1988, 1995, 2000 and 2005 are derived from Data Center of the Chinese Academy of Sciences; The one-period lagged terms are the average values of the chosen variables for the last three years.

Enhanced Thematic Mapper (ETM) remote sensing data of the late 1980s and late 1990s are chosen and used as the basic information given that the application of satellite remote sensing proves to be a good choice for detecting and monitoring forest area changes. Landsat TM/ETM images in 1988, 1995, 2000 and 2005 were interpreted at a scale of 1:100,000 and the overall interpretation accuracy of the land-use categories reached 92.7% by field survey and random sampling check conducted by the Data Center of the Chinese Academy of Sciences (CAS) (Liu *et al.*, 2003; Deng *et al.*, 2008a, 2008b). In order to identify the spatial variability of forest quality, forest area is further declassified into four kinds: closed forest, open forest, shrub and other forest. Closed forest is defined as natural or man-made forest with a canopy cover of over 30%. Open forest refers to land covered by trees with a canopy cover of 10%–30%. Shrub is land covered by trees less than 2 m high and with a canopy cover of over 40%. Other forest refers to land covered by tea-garden, orchid, and/or non-grownup forest (Xu *et al.*, 2004).

2.2 Geophysical data

Geophysical data include measurements on climatic change, information on terrain slope, information on soil property variability, and so on. The meteorological data, consisting of annual temperature and annual precipitation, are acquired from China Meteorological Bureau, and are interpolated into the 1km×1km grid pixel data according to the Kriging algorithm (Eric *et al*., 2001). Information on the terrain slope and the plain area proportion are derived from DEM data at a scale of 1:250,000 covering the entire Northeast China. Information on the soil property comes from the national soil survey of China, and is finally interpreted into 1 km×1 km grid pixel data using the Kriging method.

Location data are to measure the distance to the nearest expressway, the nearest provincial capital, the nearest water area and the nearest port city, and these measurements are calculated by using measuring tools based on the road network, provincial capital map, water area map and the port city maps, which are derived from the topographic map at a scale of 1:250,000 for the Northeast China region.

2.3 Socio-economic data

Socio-economic dataset consists of variables such as population density, agricultural production, agricultural population proportion, GDP, timber production, forest product price index, gross output value of forestry production, and those binary values, e.g., if it is a major grain production area, if it is a natural reserve, and so on. Those continuous data, including population density, agricultural population proportion and GDP, are derived from provincial statistics. Forestry production data are derived from the forestry products yearbook of China.

The policy variables involved in this study include the involvement of Grain for Green Project and Logging Ban Project which have been released at the national level. Logging Ban Project is put forward after the devastating flood in the summer of 1998, and is designed to achieve the restorative development of forest, control water and soil loss and preserve ecological environment (State Natural Protection Project, 1998). Grain for Green Project is implemented in 1999 which protects the ecological environment in Northeast China to some extent (Uchida *et al.*, 2005).

3 Scenario design and policy variables

3.1 Scenario design

Scenario analysis is of necessity for predicting the forest area changes in the future, which is done based on the explored dynamics for forest area changes. For the geophysical conditions, unless some geological events occur, e.g. landforms, elevation, and terrain slope will be kept stable for a relative short time. Although temperature and precipitation always change among various years, the extent of their changes is limited at a marginal level for a relative short time, e.g., less than 30 years in this study. Therefore, this study assumes that the geophysical conditions of the Northeast China region will keep intact, or just change to a small extent which is not enough to affect dramatically forest area changes in the period of 2000–2020. Geophysical data in the historical period will then be included in the process of prediction of the dynamics of forest area changes in Northeast China.

According to the characteristics of land uses and regional socio-economic developments, three kinds of scenarios – baseline as usual (BU) scenario, economic growth (EG) scenario and environmental protection (EP) scenario – are designed. BU scenario is a reference case depicting a future state of society and/or environment in which no new environmental protection policies or economic policies are implemented, and population growth and economic expansion will continue in the same trend. Under EP scenario, a number of effective measurements would be taken to protect local environment, and the growth of population and GDP would be maintained at a lower rate. Under EG scenario, local economic growth is above the average level of the nation, and industrial structure adjustment, policies, and technology revolution would be taken to promote the expansions of population and economy.

Based on the above three kinds of scenarios, this study predicts the population growth and GDP expansion in the period 2008–2020 in Northeast China (Figure 1). Under BU scenario, the annual population birth rate, mortality rate and GDP expansion are set as the average value of the first five years. Under EP scenario, the annual population growth and GDP expansion are lower than that under BU scenario by an amount of a standard deviation, and mortality rate is consistent with that under BU scenario. Under EG scenario, the population birth rate and GDP expansion are higher than those of BU scenario by an amount of a standard deviation, and mortality rate is also consistent with that of BU scenario.

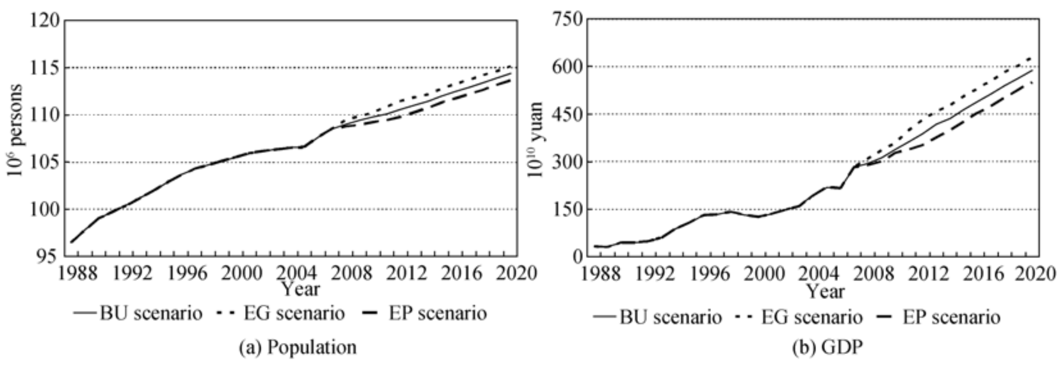

Figure 1 Population growth and GDP expansion for the period between 1988 and 2020 in Northeast China
Note: GDP at constant prices (the year 2000)

3.2 Ecological projects

The ecological projects including Grain for Green Project and Logging Ban Project are of importance for reducing the logging of the local forests as well as spurring the expansion of forest area in Northeast China. This study assumes that both of the ecological projects continue to be implemented in Northeast China in the period 2000–2020, adding subsidies of 70 yuan per *mu* for the efforts of converting cultivated land back to forest area from the current subsidy standard of 20 yuan per *mu* annually, extending the compensation to eight years for the efforts to convert the cultivated land to ecological forest, to five years for converting to economic forest, and to two years for converting to grassland. At the same time, this study assumes that Logging Ban Project will be implemented through 2020 and continue to play an important role for the conservation of forest cover.

4 Methodology

4.1 Exploration of the dynamics of forest area changes

We develop an econometric model to explore the dynamics of forest area changes. In the econometric model, the forest area changes are as explained variables and the driving factors set as explanatory variables. The econometric model for the dynamics of forest area changes in Northeast China are composed of three regression equations, the process of forestry production (1), the conversion of open forest to closed forest (2) and the conversion of other land uses to closed forest (3). This model takes into account the causality among various variables, that is, some explained variables in the left side of the equation can be regarded as explanatory variables to present in the right side of another equation. In this way, the dynamics of forest area changes can be estimated and described quantitively. The main variables included in the econometric model are presented in Table 1.

When establishing the econometric model, we diagnose the collinearity between every two variables to offset the influences of collinearity among variables on the estimation results. The natural logarithm for each variable in 1988, 1995, 2000 and 2005 is employed to preclude the effects of dimension differences on the bias of the estimation results. The econometric model used to explore the dynamics of forest area changes in Northeast China is in the following form, which involves three explained variables including forestry production (y_{it}), conversion of open forest to closed forest (sy_{it}) and the conversion of other land uses to closed forest (oy_{it}):

$$\begin{aligned} y_{it} = {} & \alpha_0 + \alpha_1 popden_{it-1} + \alpha_2 \ln(gdp_{it-1}) + \alpha_3 \ln(dem_i) + \alpha_4 \ln(dem2_i) + \alpha_5 \ln(slope_i) + \alpha_6 \ln(slope2_i)) + \alpha_7 splain_i \\ & + \alpha_8 \ln(organic_{it}) + \alpha_9 \ln(pa_{it}) + \alpha_{10} \ln(ta_{it}) + \alpha_{11} \ln(d2pvcp_i) + \alpha_{12} \ln(d2port_i) + \alpha_{13} \ln(d2road_i) \\ & + \alpha_{14} \ln(d2water_i) + \alpha_{15} \ln(prod_{it}) + \alpha_{16} \ln(value_{it}) + \alpha_{17} fpark_{it-1} + \alpha_{18} tbp_{it-1} + \alpha_{19} grain_{it} + \alpha_{20} mng_{it-1} \end{aligned} \tag{1}$$

$$\begin{aligned} sy_{it} = {} & \beta_0 + \beta_1 \ln(y_{it-1}) + \beta_2 popden_{it-1} + \beta_3 ap_{it-1} + \beta_4 \ln(gdp_{it-1}) + \beta_5 \ln(dem_i) + \beta_6 \ln(dem2_i) + \beta_7 \ln(slope_i) + \beta_8 \ln(slope2_i) \\ & + \beta_9 \ln(organic_i) + \beta_{10} \ln(pa_{it}) + \beta_{11} \ln(pa2_{it}) + \beta_{12} \ln(ta_{it}) + \beta_{13} \ln(d2pvcp_i) + \beta_{14} \ln(d2port_i) + \beta_{15} \ln(d2road_i) \\ & + \beta_{16} \ln(d2water_i) + \beta_{17} \ln(prod_{it-1}) + \beta_{18} tbp_{it-1} + \beta_{19} \ln(cvother21_{it-1}) + \beta_{20} foreserve_{it-1} + \beta_{21} \ln(ld22_{it-1}) \end{aligned} \tag{2}$$

$$\begin{aligned} oy_{it} = {} & \rho_0 + \rho_1 \ln(y_{it-1}) + \rho_2 popden_{it-1} + \rho_3 ap_{it-1} + \rho_4 \ln(gdp_{it-1}) + \rho_5 \ln(dem_i) + \rho_6 \ln(dem2_i) + \rho_7 \ln(slope_i) + \rho_8 \ln(slope2_i) \\ & + \rho_9 \ln(organic_i) + \rho_{10} \ln(pa_{it}) + \rho_{11} \ln(ta_{it}) + \rho_{12} \ln(d2pvcp_i) + \rho_{13} \ln(d2port_i) + \rho_{14} \ln(d2road_i) + \rho_{15} \ln(d2water_i) \\ & + \rho_{16} \ln(prod_{it-1}) + \rho_{17} \ln(value_{it-1}) + \rho_{18} fpark_{it-1} + \rho_{19} tbp_{it-1} + \rho_{20} grain_{it-1} + \rho_{21} tghl_{it-1} + \rho_{22} forcover_{it-1} \end{aligned} \tag{3}$$

where i identifies the basic analysis unit, county or municipality; t is to refer to one of a certain year, 1988, 1995, 2000 or 2005; and *t*-1 refers to the one-period lagged terms of the chosen variables.

4.2 Simulation approach of the spatial pattern of the forest area changes

We simulate the spatial pattern of forest area changes using the Dynamics of Land System (DLS) model. According to the causality analysis of forest area change, land demands at regional level for the prediction period, land allocation under the requirement of supply and demand, and spatial allocation, DLS simulates the changes of forest area at two scales, the regional scale and the grid pixel scale. The model improves the robustness of the simulation results through carrying out scenario analysis under the hypothesis for key explanatory variables. It predicts the spatial pattern of the forest area changes on the basis of the land allocation among various sectors and spatial allocation for land-use changes by regions (Figure 2).

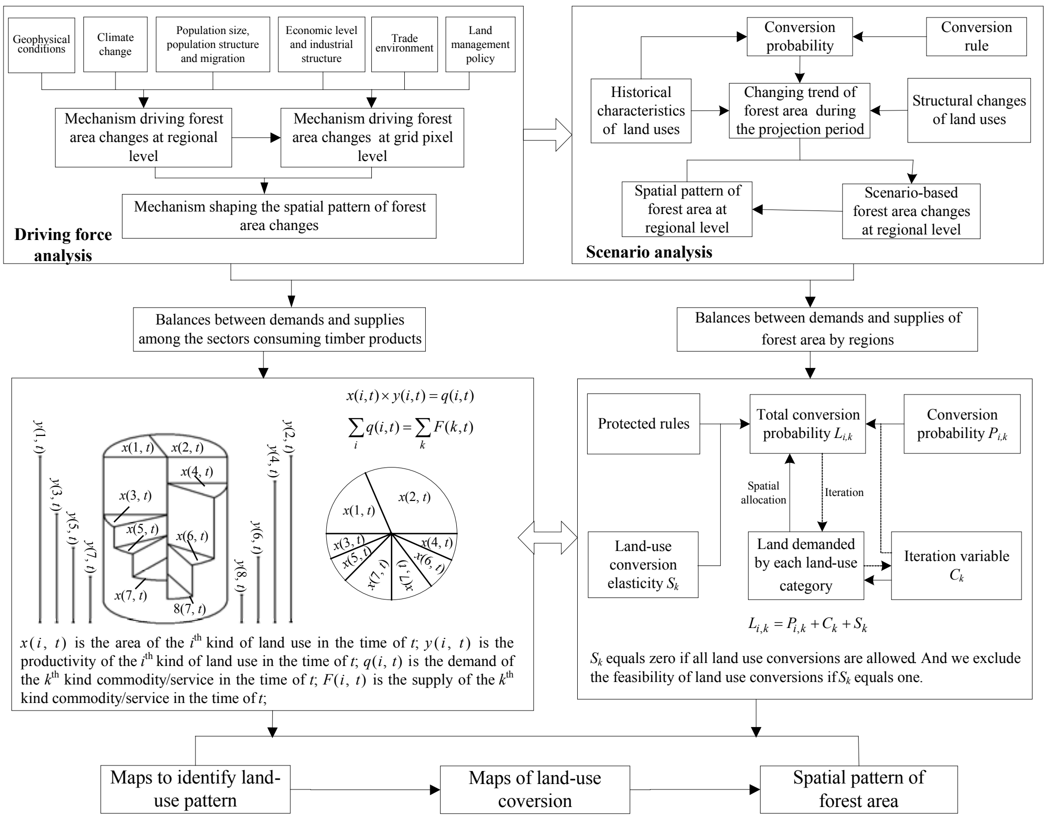

Figure 2 Flow chart for simulating the spatial pattern of forest area changes by using DLS model

The simulation of the spatial pattern of forest area changes using DLS model includes four steps (Figure 2). Firstly, it analyzes the relationship between the spatial patterns of sub-classes of forest area and the driving factors at both the regional and grid pixel scales. The effects of geophysical conditions and socio-economic environment on the spatial patterns of forest area are explored, and the predominant driving factors on the spatial pattern of forest area changes are extracted. Secondly, we predict the changing trend of the predominant factors influencing spatial patterns of forest area by considering the historical characteristics and current status of forest area at the regional level. Thirdly, a proper scenario is chosen to predict the balances between the land supply and land demand in terms of the industrialization. The net changes of forest area, which are constrained by the supply and demand of land among various land-consuming sectors, are allocated into each of the pixels according to balances between demands and supplies of forest area changes by counties. Finally, the spatial allocation of forest area at 1km×1km grid pixel level is identified, the patterns of the sub-classes of forest area are produced, and then the spatial pattern map of forest area is finally generated (Deng, 2008a, 2008b).

5 Results

It is of importance to understand the dynamics of forest area changes in Northeast China from 1988 to 2005 for the best management of forest resources, because it can not only help us recognize and represent the spatial pattern of forest area changes but also deepen our understanding for the dynamics of forest area changes in Northeast China. Table 2 displays the quantitative relationship between endogenous variables and exogenous variables in the process of forestry production, open forest conversion to closed forest, and other land uses conversion to closed forest. In order to explain the dynamics of forest area changes, we will elaborate the driving factors by dividing them into geophysical conditions and socio-economic variables.

5.1 Impacts of geophysical conditions

Geophysical conditions are the controlling factors for forestry production and forest area changes. The estimation illustrates that average terrain slope and elevation exert an obvious influence on the forestry production and the conversion of forest cover. The steeper the terrain slope is and/or the higher the elevation is and the larger the forest area is, the higher the forestry production is. Those areas with poor condition for residence and unsuitable for cultivation are with low levels of the urbanization and industrialization, while they provide the advantageous conditions to spur the conversion of open forest and other land uses to closed forest. Similarly, when the altitude surpasses a certain height, the further development of forestry sector would get limited, and the possibility of the conversion of other land uses to forest area would be somewhat held back. Variables such as annual temperature and annual precipitation are chosen to analyze and illustrate the influence of climate changes on forest area changes. Estimation results show that annual temperature and annual precipitation might exert somewhat effects on the forestry production although both of them bear no apparent influences on the conversion of forest area. The coefficients of annual precipitation on the forestry production is around 0.686 and its significance is at 1% level, which indicates that forestry production would increase by 68.6% while annual precipitation increase by 10%. However, temperature has somewhat held back the expansion of the forestry production as can be seen apparently that happened in the northern part of Northeast China.

Variables to measure the effects of distances to the nearest port city, the nearest water area and nearest main road cannot be ignored. The estimated coefficients from these variables of

Table 2 Estimation of the dynamics of forest area changes in Northeast China

Variables	Equation(1)	Equation(2)	Equation(3)
popden	–0.009(1.88)*	–0.025(0.89)	–0.010(1.69)*
ap	—	0.383(0.47)	0.294(1.85)*
ln(*gdp*)	0.034(1.34)	0.247(1.19)	–0.043(0.92)
ln(*dem*)	0.379(2.45)**	0.945(1.52)**	0.564(2.05)**
ln(*dem2*)	–0.095(5.56)***	–0.725(3.16)***	–0.063(2.07)**
ln(*slope*)	0.522(10.25)***	1.188(2.57)**	0.397(3.58)***
ln(*slope2*)	0.059(3.90)***	0.407(3.09)***	0.097(2.99)***
ln(*organic*)	–0.551(11.61)***	0.051(0.11)	–0.148(1.74)*
ln(*pa*)	0.686(4.52)***	1.787(1.49)	0.323(1.21)
ln(*pa2*)	—	–2.223(0.81)	—
ln(*ta*)	–30.42(6.54)***	–43.693(0.95)	–26.519(0.86)
ln(*d2pvcp*)	–0.025(0.76)	–0.055(0.2)	0.083(1.46)
ln(*d2port*)	–0.737(10.44)***	0.589(0.93)	0.100(0.97)
ln(*d2road*)	–0.340(5.90)***	0.660(1.39)	0.142(1.44)
ln(*d2water*)	–0.066(1.73)*	0.426(1.19)	–0.022(0.35)
ln(*y*)	—	0.776(2.16)**	0.412(6.18)***
ln(*prod*)	0.162(1.89)*	–0.528(1.56)	–0.330(4.59)***
value	0.003(2.48)**	—	0.001(0.92)
fpark	–0.004(0.05)	—	0.156(0.99)
grain	–0.010(0.21)	—	0.167(1.96)*
mng	1.300(20.12)***	—	—
ln(*cvother21*)	—	0.218(2.09)**	—
ln(*ld22*)	—	0.932(7.05)***	—
tbp	0.282(4.64)***	1.142(2.67)***	0.362(2.49)**
tghl	—	—	0.207(2.56)**
forcover	—	—	–0.018(3.67)***
Constant	4.848(8.53)***	–3.576(3.88)***	5.117(7.02)***
Observations	645	365	398

†Absolute value of t statistics in parentheses; ††***, **, * is the significant level of 1%, 5% and 10%, respectively; †††(t-1) identifies the one-period lagged terms of the chosen variables.

distances to the nearest port city and nearest main road are 0.278 and 0.340, respectively. The variable on the distance to the nearest water area is also the important factor to promote forestry production, because a close distance to the water resource can not only provide conditions for the conversions of forest area, but also provide the possibility for the timber shipping. Although the location conditions have dramatic influence on the forestry production, however, they have only marginal influence on the conversion of other land uses to closed forest.

5.2 Impacts of socio-economic variables

Socio-economic variables are the major factors affecting forestry production and the spatial pattern of forest area. Population density, agricultural population proportion (one-period lagged term) and GDP are taken to identify and characterize the relationship between economic or population growth and forest area changes. In populated area, the damage to forest is usually more dramatic, so gross output value of forestry production is relatively lower, and the conversion of other land uses to closed forest is impeded. However, the increase of agricultural population could promote the conversion from other land-use categories to the closed forest. The expansion of gross output value of forestry production stimulates the development of forestry sectors, promotes the closed forest expansion, and the coefficients of the conversion of open forest to closed forest and the conversion of other land uses to closed forest are up to 0.776 and 0.412, respectively. Although in natural reserve area and main grain production counties the forestry production will be influenced, the magnitude is marginal. In the main grain production area, the conversion of forest area is dramatic, the coefficient is 0.167, and its significance is at 10%. Open forest provides the resources for the conversion of open forest to the closed forest, the larger the area of the open forest is, the more the conversion of open forest to closed forest is.

By analyzing policies of Grain for Green Project and Logging Ban Project, the influences of forestry management policies and the coefficients are measured. Research results show that the implementation of Grain for Green project and Logging Ban Project have obvious influences on forestry production and the conversions from open forest to closed forest, and the estimated coefficients of the Logging Ban Project are 0.282 and1.142, respectively. The effect of Grain for Green Project is to promote the conversion of other land uses to closed forest, and its coefficient is up to 0.207.

All in all, the dynamics of forest area changes in Northeast China are affected by both geographical conditions and socio-economic environment. Geographical conditions of forest area constitute the basis of spatial pattern of forest area changes, and determine its changing trend at large scale. Socio-economic environment would influence the direction and intensity of forest area changes. Therefore, forest area change is the result of interaction of a variety of factors.

6 Forest area changes in Northeast China

6.1 Conversions of forest area

On the basis of analysis for dynamics of forest area changes in Northeast China in the period 1988–2000, this study simulates the changing pattern of forest area in Northeast China for the period 2000–2020 under three kinds of scenarios using DLS model (Figure 3). The simulation results show that under BU scenario forest area of Northeast China will experience a decreasing trend and then an increasing trend as time goes on. The most apparent pattern of forest area change is that closed forest will expand mainly around the original closed forest, which is converted mainly from cultivated land and grassland and partly from open forest, shrub and other forest. On the contrary, open forest and shrub will both show the shrinking trend, a great proportion of which is converted to other land uses besides the closed forest. Other forest does not change apparently. Under EP scenario, the forest area will experience an increasing trend in Northeast China, with the converting trends varying among different forest sub-classes. Compared to BU scenario, there is an increase in the expansion amplitude for the closed forest under EP scenario, with an accumulative increase of 2.08×10^4 km^2 from 2000 to 2020, while the decrease amplitude of the open forest and shrub also increases further under EP scenario. Under EG scenario, the

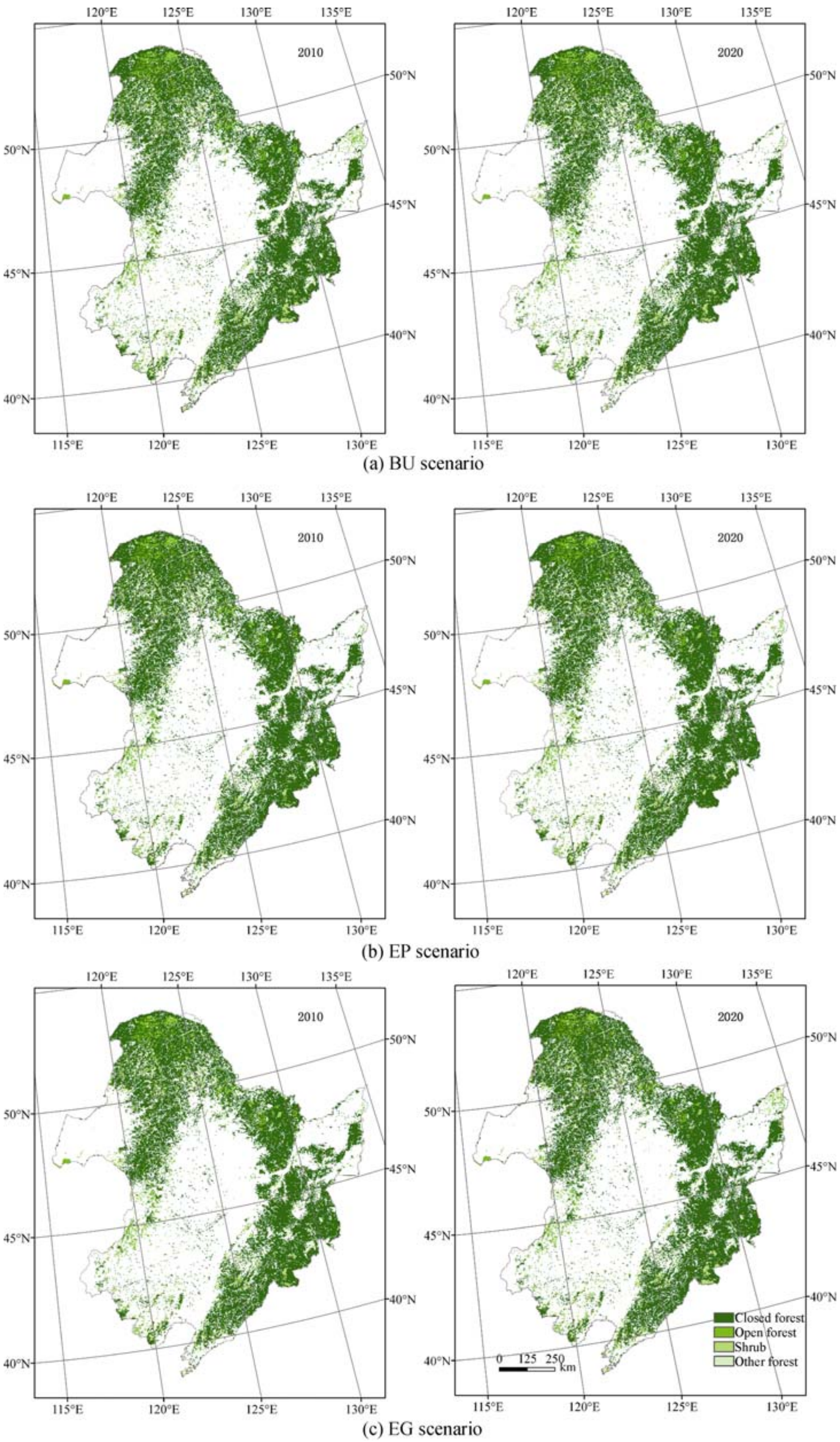

Figure 3 Spatial patterns of forest area changes in Northeast China in the period of 2010–2020

Table 3 Directions and magnitudes of the conversions among the sub-classes of forest area in Northeast China during the periods of 2000–2010 and 2010–2020 (km^2)

Scenario		2000–2010					2010–2020				
		CF	OF	Shr	OF	OLU	CF	OF	Shr	OF	OLU
BU	CF	—	0	0	0	63	—	0	0	0	342
	OF	2889	—	0	0	891	945	—	0	0	783
	Shr	3114	0	—	0	2007	1827	0	—	0	378
	OF	135	0	0	—	36	45	0	0	—	18
	OLU	4446	0	0	0	—	2403	414	558	27	—
EP	CF	—	0	0	0	45	—	0	0	0	243
	OF	4608	—	0	0	1764	1350	—	0	0	621
	Shr	4563	0	—	0	3546	2619	0	—	0	279
	OF	81	0	0	—	54	27	0	0	—	0
	OLU	5292	0	0	0	—	2565	0	1602	621	—
EG	CF	—	0	0	0	90	—	0	0	0	567
	OF	1674	—	0	0	414	369	—	0	0	1008
	Shr	909	0	—	0	558	1386	0	—	0	675
	OF	18	0	0	—	0	63	0	0	—	45
	OLU	3348	0	0	0	—	603	315	477	90	—

Note: Self-conversions of sub-classes of forest area is marked with "—"; CF, OF, Shr, OrF and OLU refer to "Closed forest", "Open forest", "Shrub", "Other forest" and "Other land use".

expansion of closed forest will be slower than it is under BU scenario, with an accumulative increase rate of 4.0%, and the decrease of the open forest and shrub will also correspondingly slow down, with an accumulative decrease of 3.15×10^3 km^2 and 3.08×10^3 km^2, respectively by the end of 2020 (Table 3).

6.2 Changes of spatial pattern

Under all of the three kinds of scenarios, there is a large amount of open forest and shrub converted into closed forest, which means the local forest canopy is gradually improved (Figure 4). Analysis results show that internal conversions of sub-classes of forest area are characterized by a remarkable spatial heterogeneity. Compared with that of the period 2000–2010, conversions among the four sub-classes of forest area decreased dramatically in the period 2010–2020, which is mainly due to the implementation of Grain for Green Project and Logging Ban Project, there are not much cultivated land or other land uses converted to forest area.

Forest area will change dramatically in the northwestern, northeastern and western parts of Northeast China during the period 2000–2010 although it will take place apparently in the northeastern part of Northeast China in the period 2010–2020. Under BU and EP scenarios, the changes of forest area are characterized by conversions of non-forest to shrub and open forest, while under EG scenario, the predominant changes of forest area would be identified as conversions of shrub and open forest to non-forest. Area of open forest and shrub

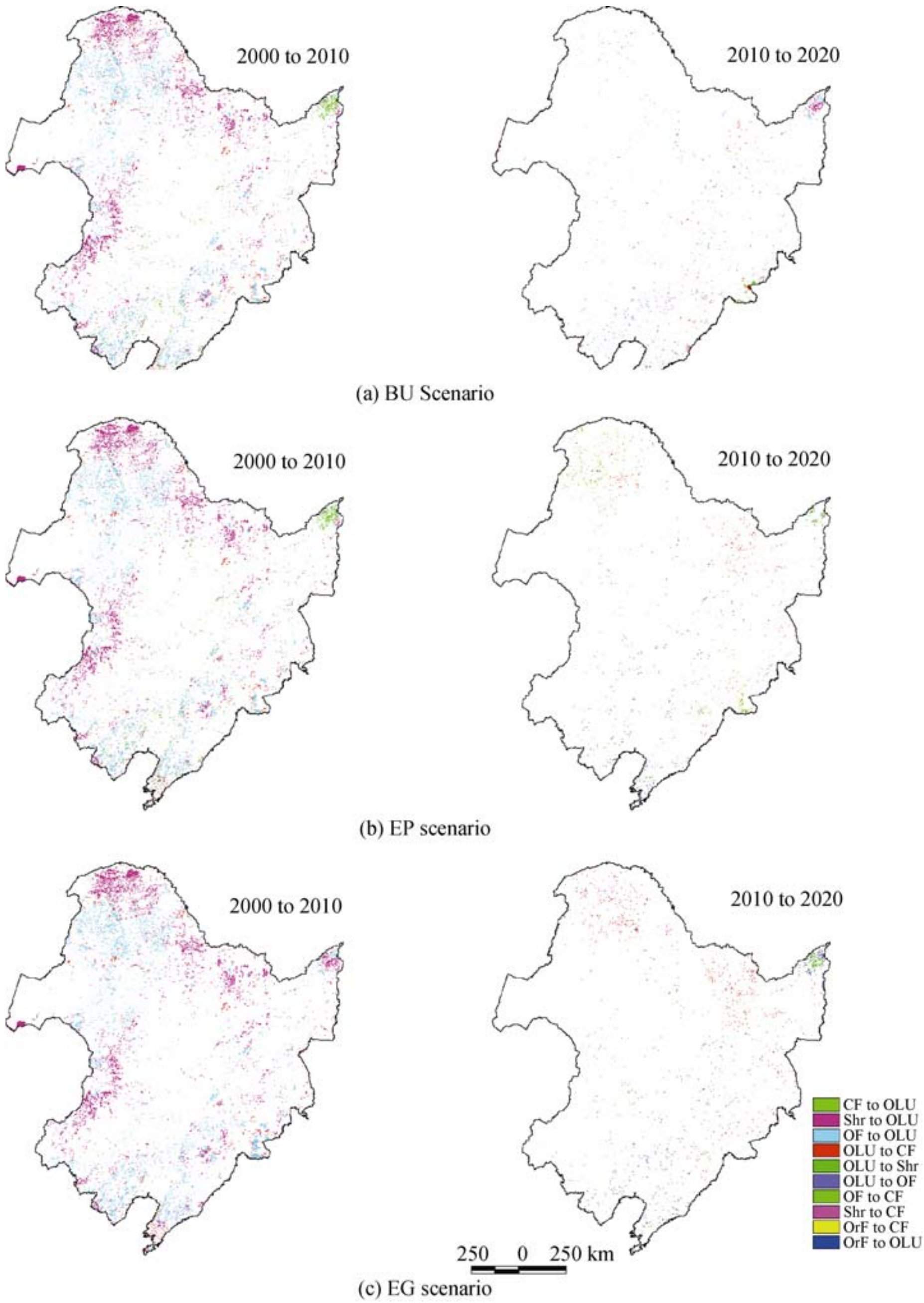

Figure 4 Spatial patterns of forest area changes in Northeast China during the periods of 2000–2010 and 2010–2020

Note: CF, Shr, OF, OrF and OLU refer to closed forest, shrub, open forest, other forest and other land uses, respectively.

converted to closed forest under BU scenario will decrease sharply compared with that occurred under EP scenario, but will keep an expanding trend compared with that under EG scenario.

7 Conclusions

It is of great significance to explore the dynamics and spatial pattern of forest area changes to reveal the macro-structure and spatial heterogeneity of land system at regional level. In this paper, we develop a model to analyze the dynamics of forest area changes in the Northeast China region. In this model, we build three equations, set explanatory variables associated with forest area changes, and then estimate the relationship between forest area changes and factors including geophysical conditions, socio-economic environment and forest management policies in Northeast China from 1988 to 2005. The research results show that terrain slope, elevation and climate conditions are important factors affecting the forestry production and conversions of forest area. Location conditions, as the socio-economic factors, have dramatic influence on forestry production. At the same time, population density, gross output value of forestry production, policies of Grain for Green Project and Logging Ban Project will have varying degrees of influence on the forest area changes. In general, it can be concluded that the socio-economic factors play a decisive role in the changes of forest area in the short term, while the geophysical conditions factors play an important role in the long term.

According to the socio-economic development, this study designs three kinds of scenarios, BU scenario, EP scenario and EG scenario, and simulates the changes of forest area in the period 2000–2020. Under BU scenario, the simulation results show that forest area will experience a decreasing trend and then an increasing trend as time goes on during the period 1988–2020. However, it will continue expanding under EP scenario, and will continue shrinking under EG scenario. As for the internal conversions of sub-classes of forest area, under all of the scenarios, there will experience the conversion from open forest and shrub to closed forest, leading to the increase of closed forest and decrease of open forest and shrub. Research results provide meaningful decision-making information for conserving and exploiting the forest resources and for making out the planning for forestry production in the Northeast China region.

References

Chen Lingzhi, 1993. Biodiversity in China. Beijing: Science Press. (in Chinese)

Chen Lingzhi, 1995. The China Council for International Cooperation on Environment and Development. BWC: Forest Restoration in North China. (in Chinese)

Chen Xiongwen, 2006. Tree diversity, carbon storage, and soil nutrient in an old-growth forest at Changbai Mountain, Northeast China. *Communications in Soil Science and Plant Analysis*, 37(3/4): 363–375.

Coops N C, Waring R H, 2001. The use of multiscale remote sensing imagery to derive regional estimates of forest growth capacity using 3-PGS. *Remote Sensing of Environmen*t, 75: 324–334.

Dai Limin, Zheng Bofu, Guo Fanhao, 2006. The roles of a decision support system in applying forest ecosystem management in Northeast China. *Science in China* (Series E), 49: 9–18.

Deng X, Huang J, Rozelle S *et al.*, 2006. Cultivated land conversion and potential agricultural productivity in China. *Land Use Policy*, 23: 372–384

Deng Xiangzheng, 2008a. Analysis of Land Use Conversions. Beijing: China Land Press. (in Chinese)

Deng Xiangzheng, 2008b. Simulation of Land System Dynamics. Beijing: China Land Press. (in Chinese)

Deng X, Huang J, Rozelle S *et al.*, 2008a. Growth, population and industrialization and urban land expansion of China. *Journal of Urban Economics*, 63: 96–115.

Deng X, Su H, Zhan J, 2008b. Integration of multiple data sources to simulate the dynamics of land systems. *Sensors*, 8: 620–634.

Eric P J Boer, Kirsten M de Beurs, 2001. A Dewi Hartkamp, Kriging and thin plate splines for mapping climate variables. *International Journal of Applied Earth Observation and Geoinformation*, 3(2): 146–154.

Ge Quansheng, Dai Junhu, 2005. Farming and forestry land use changes in China and their driving forces from 1900 to 1980. *Science in China* (Series D), 48(10): 1747–1757.

Ge Quansheng, Zhao Mingcha, Zheng Jingyun, 2000. Land use change of China during the 20th century. *Acta Geographica Sinica*, 55(6): 698–706. (in Chinese)

Justice C, Wilkie D, Zhang Q *et al.*, 2001. Central African forests, carbon and climate change. *Climate Research*, 17: 229–246.

Liu Jiyuan, Zhang Zengxiang, Zhuang Dafang *et al.*, 2003. A study on the spatial-temporal dynamic changes of land-useand driving forces analyses of China in the 1990s. *Geographical Research*, 22(1): 1–12. (in Chinese)

Matala J, 2005. Impacts of climate change on forest growth: A modelling approach with application to management [D]. Faculty of Forestry, University of Joensuu, Finland.

Nuutinen T, Kellomäki S, 2001. A comparison of three modelling approaches for large-scale forest scenario analysis in Finland. *Silva Fennica*, 35(3):299-308.

Peng H, Cheng G, Xu Z *et al.*, 2007. Social, economic, and ecological impacts of the "Grain for Green" project in China: A preliminary case in Zhangye, Northwest China. *Journal of Environmental Management*, 85(5): 774–784.

Shen Yueqin, Liao Xianchun, Yin Runsheng, 2006. Measuring the socioeconomic impacts of China's Natural Forest Protection Program. *Environment and Development Economics*, 11: 769–788.

Sironen S, Kangas A, Maltoma M *et al.*, 2001. Estimating individual tree growth with the k-nearest neighbour and k-most similar neighbour methods. *Silva Fennica*, 35(4): 453-467.

State Natural Protection Project, 1998.

Uchida E, Xu Jintao, Rozelle Scott, 2005. Grain for green: Cost-effectiveness and sustainability of China's consevation set-aside program. *Land Economics*, 81(18): 247–264.

Wang Tianming, Wang Xiaochun, Guo Qingxi *et al.*, 2004. Forest landscape diversity changes in Heilongjiang Province. *Biodiversity Science*, 12(4): 396–402.

Wang Xugao; He H S; Li Xiuzhen, 2007. The long-term effects of fire suppression and reforestation on a forest landscape in northeastern China after a catastrophic wildfire. *Landscape and Urban Planning*, 79(1): 84–95.

Xiao Xiangming, Boles S, Liu Jiyuan *et al.*, 2002. Characterization of forest types in Northeastern China, using multi-temporal SPOT-4 VEGETATION sensor data. *Remote Sensing of Environment*, 82(2/3): 335–348.

Xu Xinliang, Liu Jiyuan, Zhuang Dafang *et al.*, 2004. Spatial-temporal characteristics and driving forces of woodland resources changes in China. *Journal of Beijing Forestry University*, 26(1): 41–46. (in Chinese)

Yuan Changyan, 2007. Superiority of forest resources in Northeast China. *Journal of Northeast Forestry University*, 35(12): 65–67. (in Chinese)

Zhang Guoping, Liu Jiyuan, Zhang Zengxiang, 2003. Analysis of deforested land reclamation during the late 20th century in China based on remote sensing and GIS. *Geographical Research*, 22(2): 221–228. (in Chinese)

Zhang Yufu, Tachibana S, Nagata S, 2006. Impact of socio-economic factors on the changes in forest areas in China. *Forest Policy and Economics*, 9(1): 63–76.

Zhao Bingzhu, Jia Weiwei, Li Fengri, 2006. Effect evaluation of Natural Forest Protection Project for forestry enterprises in Daxing'anling of Inner Mongolia. *Journal of Northeast Forestry University*, 34(2): 84–86. (in Chinese)

Zhu Jiaojun, Mao Zhihong, Hu Lile *et al.*, 2007. Plant diversity of secondary forests in response to anthropogenic disturbance levels in mountainous regions of northeastern China. *Journal of Forest Research*, 12(6): 403–416.

Zimble D A, Evans D L, Carlson G C *et al.*, 2003. Characterizing vertical forest structure using small-footprint airborne LiDAR. *Remote Sensing of Environment*, 87(2/3): 171−182.