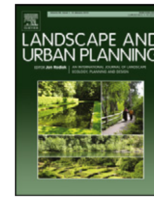
Landscape and Urban Planning 104 (2012) 34–46

Contents lists available at SciVerse ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan



The potential impacts of sprawl on farmland in Northeast China—Evaluating a new strategy for rural development

Fengming Xi[a], Hong S. He[a,b,*], Keith C. Clarke[c], Yuanman Hu[a], Xiaoqing Wu[d], Miao Liu[a], Tiemao Shi[e], Yong Geng[a], Chang Gao[e]

[a] *Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China*
[b] *School of Natural Resources at the University of Missouri-Columbia, Columbia, MO 65211, USA*
[c] *Department of Geography, University of California-Santa Barbara, Santa Barbara, CA 93106, USA*
[d] *Institute of Coastal Zone Research for Sustainable Development, Chinese Academy of Sciences, Yantai 264003, China*
[e] *School of Architecture and Urban Planning, Shenyang Jianzhu University, Shenyang 110168, China*

A R T I C L E I N F O

Article history:
Received 23 October 2010
Received in revised form 9 September 2011
Accepted 24 September 2011
Available online 21 October 2011

Keywords:
Farmland
Urban and rural sprawl
Rural residential land
SLEUTH
Building a new countryside
Landscape metrics

A B S T R A C T

China's "building a new countryside" strategy for coordinating urban and rural development and gearing up national economic growth brings challenges to the country's farmland protection. The objective of this study is to evaluate potential impacts of implementing the strategy on farmland and to provide scientific guidelines and decision support for decision makers in northeast China. We analyzed three "building a new countryside" implementation scenarios (Historical Trend, Intensive Development, and Extensive Development) using the SLEUTH urban growth and land cover change model in combination with remote sensing and GIS analysis. The results indicated that farmland loss was inevitable, but revealed large differences in landscape patterns and the amount of farmland loss among the three BNC implementation scenarios. The Extensive Development scenario showed the largest increase in urban and rural residential land, the highest level of landscape fragmentation, and the largest loss of farmland. Farmland loss under the Intensive Development scenario is higher than that under the Historical Trend scenario; however, urban and rural sprawl and the fragmentation of landscape under the Intensive Development scenario were lower than those under the Historical Trend scenario. Consequently, the Intensive Development scenario was recommended for actual "building a new countryside" implementation in the study area. Potential rural sprawl under the Intensive Development scenario was also discussed, which provided useful information for guiding scientific-based decision support and policy making. While most studies of sprawl prediction involve urban centers only, our study presents a case of predicting urban and rural sprawl simultaneously.

1. Introduction

Sprawl of human settlements, both around existing cities and within rural areas, is a major driving force of land use and land cover change worldwide (Batisani & Yarnal, 2009; Gonzalez-Abraham et al., 2007; Hawbaker, Radeloff, Clayton, Hammer, & Gonzalez-Abraham, 2006; Liu, Daily, Ehrlich, & Luck, 2003). During sprawl, urban and rural development moves out to occupy other land resources such as farmland, forest, and wetland (Liu, Zhan, & Deng, 2005; Su, Jiang, Zhang, & Zhang, 2011a). Farmland loss resulting from urban and rural sprawl occurs both in developed countries and developing countries (Brown, Johnson, Loveland, & Theobald, 2005; del Mar López, Aide, & Thomlinson, 2001; Hart, 2001; Seto, Kaufmann, & Woodcock, 2000; Tan, Li, Xie, & Lu, 2005; Theobald, 2001, 2004). Farmland is very important for China because it still supports a vast population even at a low proportion of farmland per capita (Yang & Li, 2000). The Brown debate about who will feed China emphasized the scarcity of farmland (Brown, 1995). Urban sprawl is often considered an important driver of farmland loss (Han & He, 1999; Lichtenberg & Ding, 2008; Lin & Ho, 2003; LRDC, 2004), whereas rural residential land growth (rural sprawl) has often been neglected in China (Long, Heilig, Li, & Zhang, 2007; Tian, Yang, & Zhang, 2007). Rural residential land refers to the built-up area of rural settlements, which includes buildings, roads, huts, vegetable gardens, thickets, livestock enclosures, and the bare lands associated with villages and small rural market towns (Petit, Scudder, & Lambin, 2001; Tian et al., 2007). Rural settlements in

* Corresponding author at: Institute of Applied Ecology, Chinese Academy of Sciences. No.72 Wenhua Road Shenyang 110016, China. Tel.: +86 24 83970352; fax: +86 24 83970352.

E-mail addresses: xifengming@iae.ac.cn (F. Xi), HeH@iae.ac.cn (H.S. He), kclarke@geog.ucsb.edu (K.C. Clarke), huym@iae.ac.cn (Y. Hu), xqwu@yic.ac.cn (X. Wu), lium79@163.com (M. Liu), Tiemaos@sjzu.edu.cn (T. Shi), gengyong@iae.ac.cn (Y. Geng), gaochang717@163.com (C. Gao).

0169-2046/$ – see front matter
doi:10.1016/j.landurbplan.2011.09.003

China are small in typical size but numerous and scattered. A rural population of nearly 810 million people was distributed among 730 thousand Chinese administrative villages in 2000 (NSBC, 2001). The total area of rural residential land is much greater than that of urban land. Rural residential land was 16.5 million ha, 5.61 times the urban land in 1999 (LRDC, 2000). About 60% of the rural residential land was converted from farmland in China (Tian et al., 2007), and more than 92% of the increased rural residential land was from farmland in economic developed region of coastal China (Long, Liu, Wu, & Dong, 2009). Rural housing and buildings are mainly single-story in most of the countryside of northeastern China. In the countryside around Shenyang City, the total rural residential land was 658 481.44 ha, 3.6 times the size of the city (Xu & Wang, 2008). The growth percentage of rural sprawl is lower, but the amount of farmland involved is larger than in the better studied urban sprawl (Hodge, 1996; Sargeson, 2002; Theobald, 2001, 2004). Thus, rural residential land growth management is crucial for farmland protection in China, perhaps more so that for the zones surrounding major cities.

Building a New Countryside was put forward as China's long-term rural development strategy in 2003, and aims to coordinate urban and rural development and to gear up national economic growth. The strategy sets ambitious goals of advanced production, improved livelihood, clean and tidy villages, a civilized social atmosphere and efficient management (Long et al., 2009; Long, Liu, Li, & Chen, 2010). Regional economic discrepancies, rural poverty, rural land-use issues and the present international environment are four factors that are influencing the strategy (Long et al., 2009). The strategy represents a new form of central planning that focuses on rural areas and has the potential to restructure both China's rural economy and rural landscape, especially rural sprawl induced farmland loss. The ultimate goal of the rural development enacted in the strategy is to reconstruct the countryside, such that farmers have similar living standard to city dwellers, especially in their housing and living environments (SCPRC, 2006; Xinhuanet, 2006, 2008). The strategy is very important to rural land use change in China because of the dominance of rural settlements, which carry the potential for reconstructing both China's rural economy and rural landscape. At the time the strategy was enacted, there was a serious loss of farmland to rural residential land in China, and Chinese central and local governments have introduced multiple protective measures for farmland in recent years (Ding, 2007; Lichtenberg & Ding, 2008; Long et al., 2009; Tan et al., 2005; Tian et al., 2007). The strategy implementations will have a large impact on growth patterns and areas of rural residential land because the ongoing rural industrialization and urbanization are directly related to the amount and pattern of farmland loss caused by rural infrastructure construction, rural housing improvement, rural industrialization development, and the corresponding construction of rural service establishments (Long et al., 2009, 2010). The strategy poses an opportunity for more sustainable rural development, but a challenge for further farmland protection (Long et al., 2009; Xi et al., 2008). Meanwhile, however, there has been very little research about the impacts of urban and rural sprawl on farmland because of the strategy implementation.

Chinese local decision-makers and land managers need to carefully consider farmland loss and landscape change that will result from urban and rural sprawl under different Building a New Countryside strategy scenarios. Land use and land cover change models are useful tools not only to analyze and predict the changes and their impacts, but also to understand their causes and consequences (Clarke, Hoppen, & Gaydos, 1997; Xi et al., 2009; Yang & Lo, 2003). Using these models, decision-makers can visualize and analyze alternative land use and land cover change scenarios and evaluate their impacts (Veldkamp & Lambin, 2001; Zhang, Ban, Liu, & Hu, 2011). Recent research suggests that cities are complex systems that mainly grow from the bottom up. Their size, scale and shape result from intense competition for land (Batty, 2008). Urban growth and land use change models based on the bottom up Cellular Automata (CA) methods probably have been used extensively in modeling and predicting land use changes when urban growth is the main driving force (Wang, Li, Long, Qiao, & Li, 2011; Yang & Lo, 2003; Zhang et al., 2011). CA-based land use change models can easily integrate remote sensing, GIS, and spatial pattern analysis technologies (Herold, Goldstein, & Clarke, 2003; Xi et al., 2009). Researchers can use the integrated methods to objectively quantify and predict farmland loss and rural landscape changes caused by future strategy implementation.

In order to explore the potential impacts of implementing the strategy on farmland and to provide guidelines and decision support to local decision-makers and land managers, the SLEUTH urban growth and land use change model was used to conduct simulation experiments with a goal of revealing the potential impacts of strategy implementation scenarios on farmland. SLEUTH is a policy driven, transparent, and spatial model, which is often chosen for the quantitative simulation of urban growth and land use change (Clarke et al., 1997; Dietzel & Clarke, 2006; Jantz, Goetz, & Shelley, 2003; Wu et al., 2009; Yang & Lo, 2003). It has been used in many major cities in the U.S., Europe, and around the world (Clarke et al., 2007; Rafiee, Mahiny, Khorasani, Darvishsefat, & Danekar, 2009; Silva & Clarke, 2002; USGS, 2003; Xi et al., 2008, 2009). Specifically, we intend to explore: (1) the impacts of Building a New Countryside strategy implementations on urban and rural sprawl; (2) the impacts of urban and rural sprawl on farmland and other landscape types; and (3) an optimal Building a New Countryside strategy implementation pathway that could benefit both farmland protection and rural residential land improvement through alternative scenario design.

2. Materials and methods

2.1. Study area

The study area, the Shenyang metropolitan area, covers approximately 3400 km^2. Shenyang is the capital of Liaoning province and the communication, commercial, scientific, and cultural center of Northeastern China. The Hun River runs through the center of the Shenyang city (Fig. 1). The industrial and agricultural production of the area is about 287.53 billion RMB in 2007. The average disposable annual income of urban dwellers was 14 607 RMB (about 2000 dollars), and the average annual disposable income of rural dwellers was 6806 RMB (about 932 dollars) in 2007. The population was 5 048 558 in the study area in 2007 (Shenyang Statistics Bureau, 2008). The history of human settlement goes back more than 7200 years in the area (SCHRC, 1999). Urban and rural residential land continuously expanded with the growth of population and industry in Shenyang, especially after 2000 (Wu et al., 2009). Rural residential land grew rapidly in the past two decades (Zhao, Zhu, Shao, & Ness, 2008). The resulting urban and rural sprawl has occupied much of the surrounding farmland and created substantial change to the region's landscape and ecosystems (Xi et al., 2009).

2.2. SLEUTH urban growth and land cover change model

SLEUTH is a self-modifying probabilistic cellular automata (CA) model (Clarke et al., 1997; USGS, 2003). The model's acronym is an abbreviation for the initials of input data layers: Slope, Land Use, Exclusion, Urban, Transportation, and Hill Shade. Version 3.0Beta used in this study consisting of an urban growth model (UGM) and a Land Cover Deltatron Model (LCDM). The UGM simulates urban growth, in which non-urban cells are converted to urban cells. The

Table 1
Summary of growth types simulated by the SLEUTH model (based on Jantz et al., 2003).

Growth cycle order	Growth type	Controlling coefficient	Summary description
1	Spontaneous	Diffusion, slope resistance	Randomly selects potential new urban and rural growth cells
2	New spreading center	Breed, slope resistance	Growing urban and rural centers from spontaneous growth
3	Edge	Spread, slope resistance	Old or new urban and rural centers spawn additional growth
4	Road-influenced	Road-gravity, Dispersion, Breed, Slope resistance	Newly urbanized cell spawns urban and rural growth along transportation network
Throughout	Excluded layer	User-defined	User specifies areas resistant or excluded to development
Throughout	Self-modification	Critical high or low boom or bust	Self-regulate growth race to simulate nonlinear urban and rural growth process

LCDM driven by the UGM simulates land use and land cover change. The LCDM can specify the nature of the non-urban to urban changes and the transactions among different land covers (Candau & Clarke, 2000; Dietzel & Clarke, 2004, 2006). The UGM can run independently, but the LCDM must run with the UGM. SLEUTH simulates four types of urban growth (Spontaneous growth, New spreading center growth, Edge growth, and Road-influenced growth) controlled through the interactions of five growth coefficients (ranging in value from 0 to 100): Dispersion, Breed, Spread, Road gravity, and Slope (Table 1). The meanings of the five growth coefficients have been discussed in many publications (e.g. Clarke et al., 1997; Dietzel & Clarke, 2006; USGS, 2003). The four urban development types in UGM are described briefly below (Jantz et al., 2003; USGS, 2003).

Spontaneous growth simulates the chaotic or uncontrolled urbanization of land in undeveloped areas, and has the potential to capture low-density development patterns. The stochastic urban and rural growth was controlled by the rule. The rural residential lands under Building a New Countryside strategy implementation were given high growth rate. The overall probability that a non-urbanized cell in the study area will become urbanized is determined by the Dispersion and Slope coefficients. An increase in the Dispersion coefficient results in a more diffused pattern of urban growth.

New spreading center growth models the emergence of new urbanizing centers by generating up to two neighboring urbanized cells from the previous step in selected areas. The rural and urban sprawl around newly growth rural residential land under the strategy implementations were simulated by the rule. The development of new urban and rural residential areas is controlled by the Breed and Slope coefficients. An increase in the Breed coefficient will result in more spreading centers, while an increase in the Slope coefficient will result in higher resistance to growth on steeper slopes. The Moore neighborhood of new urbanized cells and rural residential land cells under the strategy implementation were given higher growth probability.

Edge growth simulates the expansion of established urban and rural residential cells into their surroundings, and is controlled by the Spread and Slope coefficients. Only undeveloped cells that have at least two urban or rural neighbors and pass the Spread coefficient and Slope resistance tests can become new urban or rural cells. The Spread coefficient controls the probability that nonurban or non-rural land will become urban or rural residential land by outward growth or infill. The rural residential land under the strategy implementation showed similar growth rate with urban land in this growth rule.

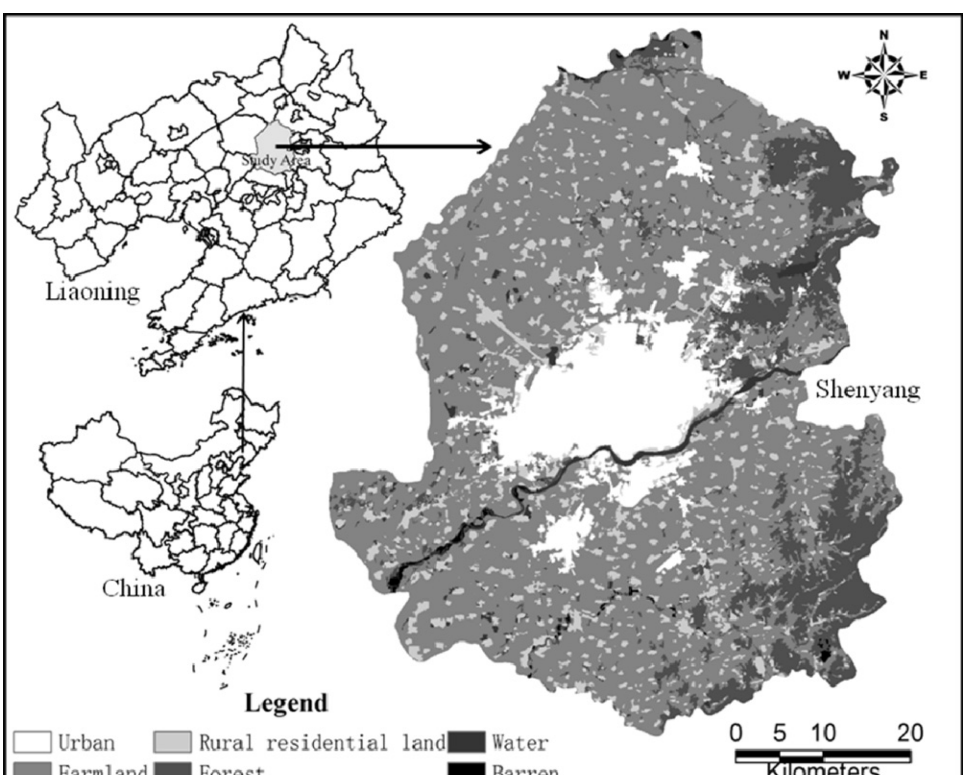


Fig. 1. Location of Shenyang metropolitan area and land use in 2004 in China.

Road-influenced growth simulates the influence of the transportation network on growth patterns by generating spreading centers adjacent to roads, and is controlled by the Dispersion, Breed, Slope and Road gravity coefficients. For a selected urbanized or rural residential cell, the existed roads are sought within a defined search radius. If roads are found near the selected cell, a temporary urban cell is placed at the closest location adjacent to the road. This temporary urban cell then searches along the road for a final location. The direction of the search along the road is random and the search distance is determined by the Dispersion coefficient. The final location becomes a new spreading center, and up to two neighbors are urbanized. The implementation rural residential lands along with main road under the strategy were given high growth probability.

Each of the growth rules is affected by the coefficient values set at the beginning of a growth cycle, as well as the slope, urban extent, land cover (if LCDM is used), and excluded layers (e.g. land such as water area and national parks that cannot be urbanized). Combinations of the five parameters are tested for their ability to replicate historic growth patterns and landscape changes and the best are selected to predict future urban growth patterns and landscape changes.

The LCDM simulates land use/cover changes via a transition matrix. The LCDM uses an updatable "Deltatron" layer to simulate land use and land cover change. Deltatrons, which are agents of change, track the spatial and temporal effects of land transitions. They do not contain land class values, but act as a reference to where and when a change has occurred. Depending upon the age (in time steps) of the Deltatron, its locally associated land class may be available for propagating change, or holding it in its current state. The initial conditions of LCDM are definitions of cluster size and minimal years between transitions. The LCDM operates as follows (Candau & Clarke, 2000; Solecki & Oliveri, 2004):

Initiate change. Newly urbanized cells created in the UGM are assumed to induce potential changes in land cover and, as a result, produce deltatrons in selected cells (non-urban, non-water, non-deltatron) at random. A probability of transition is then computed based on the weighted average slopes for each land class type, the historical land class changes, and the slope of the current cell. If a transition does occur, a new deltatron is created.

Create change cluster. This is an aggregation process (growth) of the newly created deltatrons and their associated land cover transition. Neighboring cells of the new deltatrons are randomly selected and tested by the weighted slope and historic transition probabilities for potential transition. The cells can only change to the same land class that the associated deltatron has, or remain unchanged. The newly transitioned cell now acts as the land cover change aggregation center again. The *cluster_size*, an initial condition, controls the extents to which each new deltatron cluster can grow.

Propagate change. All non-deltatron cells which are neighbors to at least two deltatron cells that were created in the previous year are tested against the same weighted probability of transition to either remain unchanged or change to the same land cover types as a neighboring deltatron's land cover type.

Age the deltatrons. All deltatrons are aged to the next time step. The number or cycles a deltatron may live is defined by the constant *min_years_between_transitions*. If they exceed a user set age, they 'die' and can potentially again become new deltatrons in the next growth cycle.

SLEUTH also maintains an optional self-modification rule. Self-modification alters the diffusion, breed, and spread coefficient values to simulate accelerated growth (boom condition) or depressed growth (bust condition). At the end of a year, the amount of growth is compared to a set of limits (*critical_high*, *critical_low*). If the amount of growth exceeds the *critical_high* limit, the three coefficients are multiplied by a value greater than one, increasing growth. If the amount of growth is less than the *critical_low* limit, the three coefficients are multiplied by a value less than one, depressing growth. The coefficient changes take effect during the next year of growth. The *critical_high*, *critical_low*, and multiplier values for boom and bust are defined as constants in a scenario input control file that initiates model calibration and forecasting. The road gravity factor is increased as the road network enlarges, promoting a wider band of urbanization around the roads. The critical slope value is increased, allowing expansion onto steeper slopes. When new growth in a time cycle takes place on steeper slopes, the spread factor is increased which accelerates urban expansion on flat land. The self-modification rule makes the urban growth a nonlinear process (Candau, Rasmussen, & Clarke, 2000; Clarke et al., 1997; Dietzel & Clarke, 2004; USGS, 2003).

SLEUTH enables its users to define future urban growth and landscape changes as a projection of the past, then to design future alternative urban growth and land management scenarios (Clarke et al., 1997; Jantz et al., 2003; Silva & Clarke, 2002; Yang & Lo, 2003), as well as to estimate the effects of increased urbanization on a local environment (Civerolo et al., 2007; Solecki & Oliveri, 2004; Xi et al., 2008).

2.3. Scenarios design and assumptions

Three scenarios were created to represent different implementations of the strategy to explore the impacts of urban and rural sprawl on farmland: (1) a Historical Trend scenario that allows historical trend rural residential land growth, which is the business as usual scenario, the urban lands were simulated as types of urban growth while residential lands were simulated as types of residential land growth; (2) an Intensive Development scenario that selects rural residential lands (e.g., areas with good economic conditions and large population) on which to implement the strategy, the selected rural residential lands were simulated as types of urban growth while the other residential lands were simulated as types of rural residential land growth; and (3) an Extensive Development scenario that implements the strategy on any available rural residential land, all the human settlement areas (including urban lands and rural residential lands) were simulated as types of urban growth. If a rural settlement is selected to implement the strategy, national and regional investment and a series of favorable policies were placed into the area to promote rural development (Fan & Zhang, 2004; Long et al., 2009). The policies of improved livelihood, clean and tidy villages, and rural areas development are direct driving forces of urban and rural sprawl (Xi et al., 2008). The selected residential land that implemented the policies will be given higher growth probability. The selected residential land that implemented indirect policies of efficient agriculture, taxes decrease on agricultural products, low-cost loans subsidization for new farm equipment, rural electrification, 9-year education program for rural children, etc. will be given lower growth probability (Xi et al., 2008). The areas and pattern of the human settlements and their impacts on farmland under different scenarios were compared. The human settlement area is composed of both urban land and rural residential land. The differences among the scenarios are simulated through different types of rural residential land sprawl, whether it is selected for implementing the strategy or not. The selected rural residential lands showed the same sprawl types as urban sprawl, while the other rural residential lands showed the same sprawl types as that of the Historical Trend scenario.

The SLEUTH growth protocol has some limitations on conversion of urban to other land use types (Jantz et al., 2003). Thus, there are two assumptions in our study: (1) urban land cannot convert to other land types once it become urban land; (2) once rural residential land of a particular administrative town or village is chosen to implement the strategy, it is taken as urban land because it has

Table 2
Six themes of layer and input data in the SLEUTH model.

Theme (number of layers)	Year	Sources
Urban extent and rural residential land extent (5)	1988 1992 1997 2000 2004	Classified from Landsat5 TM satellite images (1988, 1992, 1997[a], 2000, and 2004). The ancillary data: the Topographical map (1:100 000) of 1981; the Shenyang central city maps derived from air photos (1:10 000) of and 2001 (1:15 000); the map of Shenyang city (1:10 000) of 2000 and the ground survey information (GPS points). Classification overall accuracy (OA) of each classified image is more than 88.5%; Kappa index (KI) of each classified image is more than 0.847
Land use/cover (3)	1988 1997 2004	Classified from Landsat5 TM satellite images (1988, 1997[a] and 2004). Classification overall accuracy (OA) of each classified image is more than 85.5%; Kappa index (KI) of each classified image is more than 0.807. Land use data in 1997 and 2004 were used for calibration and prediction, while land use data in 1988 is used for validation
Roads (5)	1988 1992 1997 2000 2004	Digitalized from Transportation Maps of Liaoning Province, and modified with Landsat5 TM satellite images (1988, 1992, 1997[a], 2000, and 2004) and transportation construction data and the historical maps
Slope (1)	1980	Topographical map
Exclusion (1)	1980 2004	Classified from Landsat5 TM satellite image of 1988 Conserves in China
Hill shade (1)	1980	Topographical map

[a]The urban extent, rural residential land, land cover, and road in 1997 obtained from Institute of Applied Ecology, Chinese Academy of Sciences. The data sources and classification methods are same as to the other years.

same development opportunity as city and a series of additional favorable policies.

2.4. Data preparation

Data sources for historical urban and rural extents and other input layers are listed in Table 2. Urban extents and rural residential land data for the Shenyang metropolitan area for the years 1988, 1992, 1997, 2000, and 2004 were derived from Landsat TM images and based on corresponding urban administrative maps (1:100 000), supplemental ground survey information, and municipal infrastructure distribution maps. The urban spectrum characteristic of Landsat TM images, distribution of municipal infrastructure, administrative level, urban development zones, and urban land classification standards were considered in extracting the urban extent and rural residential land (MHURDPRC, 1994, 2008). The three scenarios of implementing the strategy mean three different types of urban and rural sprawl, so also in the calibration and prediction phases of the SLEUTH application. The slope and hill shade layers were derived from the topographical map of 1980 (1:100 000). The transportation networks were derived from Transportation Maps of Liaoning province (1:550 000) for their corresponding years. The excluded layer is typically defined as large areas of water, existing parks and conservation lands, which are excluded from future development. The excluded layer is from the topographical map in 1980 (1:100 000) and the Natural Reserves of China (Xie, Wang, & Schei, 2004). The land use layer for 1988, 1997 and 2004 were derived from Landsat TM images.

The three scenarios of the strategy have the same excluded layer, slope, transportation network, non-residential land use, and hill shade layers in the calibration and prediction stages. The urban land and rural residential land were analyzed by one human settlement land type in output analysis of each scenario. The parameter sets for the three scenarios derived from calibrations were used to predict urban and rural sprawl, farmland loss, and changes of forest, water, and barren from 2005 to 2045, with a 70% and above urbanization threshold probability and 100 Monte Carlo simulations for each year in both graphical and tabular forms. The graphical outputs from the year 2005 to 2045 were analyzed using ArcGIS.

2.5. SLEUTH model calibration and validation

The calibration of SLEUTH is the most important phase for the capture of urban growth characteristics and for success in model forecasting. The calibration approach explores parameters sets for each scenario by synthesizing physical, economic, political, policy, planning, and the management factors that influence the spatiotemporal dynamics of urban and rural sprawl, farmland loss, and landscape changes. Using the "brute force calibration" method (Silva, 2004; Silva & Clarke, 2002), the three different urban and rural sprawl scenarios were tested to determine differences in the model parameter set, and future urban and rural sprawl and farmland loss. The SLEUTH model performed well in this area (Wu et al., 2009). The three different scenarios of implementing the strategy resulted in three different parameters sets from calibrations. The calibration phases and best fit metrics are shown in Table 3. The best fit metrics are high in each of the calibration processes (Dietzel & Clarke, 2006; Silva & Clarke, 2002; USGS, 2003). Parameters sets for the different scenarios were shown in Table 4.

The Kappa index is an effective tool for map comparison and consists of the standard Kappa, location Kappa, and quantity Kappa (Pontius, 2002; Stehman, 1999). It can reveal the accuracy of the simulated map with respect to the observed map, from the quantity and location (of urban grid) when used in model validation (Oguz, Klein, & Srinivasan, 2007; Xi et al., 2009). The urban extent in 1988 and the land use map of each scenario in 1988 were used as input seed layers. Then, the SLEUTH model was run to predict urban growth and land use pattern in 2004. The simulated urban extent and land use maps of each scenario in 2004 were obtained from running the SLEUTH model using growth coefficients derived from calibration. A Kappa index was calculated using the simulated maps and the observed maps of 2004. All the Kappa indices in the three scenarios were more than 0.75 (Table 5), which revealed that the simulated map had high coherence to the observed map of 2004. The SLEUTH model had higher quantity simulation accuracy than location simulation accuracy (Wu et al., 2009). It had high simulation accuracy in both the class level and the landscape level in the study area.

2.6. Landscape metrics

In order to compare the impacts of urban and rural sprawl on farmland under the three scenarios of the strategy in Shenyang, four landscape metrics (Annex 1), Class Area (CA), Number of Patches (NP), Mean Patch Size (MPS), and Aggregation Index (AI) were used in farmland and urban and rural residential at the class level, and in the whole landscape at the landscape level (He, DeZonia, &

Mladenoff, 2000; Kong & Nakagoshi, 2006; Li et al., 2005; Lin, Hong, Wu, Wu, & Verburg, 2007; Long et al., 2009; Sui & Zeng, 2001; Xie, Mei, Guangjin, & Xuerong, 2005). The landscape metrics were calculated using the Fragstats software (McGarigal, Ene, & Holmes, 2002).

3. Results

3.1. Landscape changes at the landscape level

Urban land and rural residential land were combined as one human settlements land landscape type in outcomes analysis. There were five landscape types in the simulation result under each scenario, urban and rural residential land (human settlements land), farmland, forest, water, and barren. The trajectories of the different landscape types are shown in Fig. 2. The areas of farmland, forest, water, and barren decreased in each scenario, while urban and rural residential land type increased. The urban and rural residential land is the most significant change landscape type in each scenario. The Extensive Development scenario showed the largest urban and rural residential land growth area, largest farmland loss, and largest loss of forest, water and barren land. Farmland was the dominant landscape type in both the Historical Trend scenario and the Intensive Development scenario from 2005 to 2045. In the Extensive Development scenario farmland was the dominant landscape type from 2005 to 2039, after which urban and rural residential land landscape type is larger than farmland and is dominant from 2040 to 2045. The landscape matrix remains farmland in each scenario from 2005 to 2045 except for the Extensive Development scenario which changed to the urban and rural residential landscape type from 2040 to 2045. The areas of landscape types in 2045 were different. The areas of farmland were 174 211.2 ha in 2045 in the Historical Trend scenario, 173 224.08 ha in 2045 in the Intensive Development scenario, and 141 959.52 ha in 2045 in the Extensive Development scenario, respectively. The areas of urban and rural residential land were 135 331.20 ha in 2045 in the Historical Trend scenario, 137 673.00 ha in 2045 in the Intensive Development scenario, and 174 418.20 ha in 2045 in the Extensive Development scenario, also respectively.

The increased areas of urban and rural sprawl by 2045 were 547 26.84 ha, 57 068.64 ha, and 93 813.84 ha in the Historical Trend, Intensive Development, and Extensive Development scenarios respectively. The increased areas of urban and rural sprawl were converted from farmland, forest, and other landscape types. The urban and rural sprawl occupied mainly farmland. The areas of corresponding farmland loss were 40 061.52 ha, 41 048.64 ha, and 72 313.20 ha in the Historical Trend, Intensive Development, and Extensive Development scenarios (Fig. 3).

The number of patches increased at the landscape level under each scenario from 2005 to 2045 (Fig. 4a). The Extensive Development scenario had the largest increase of the number of patches. The Historical Trend and Intensive Development scenarios showed similar increased rates of number of patches, whereas the Intensive Development scenario showed the least increase. The value of mean patch size decreased under each scenario (Fig. 4b), whereas the Extensive Development scenario had the lowest mean patch size value at each simulation year, the Historical Trend and Intensive Development scenarios show similar mean patch size value, and the Intensive Development scenario had the lowest value. The aggregation index shows similar tendency to the mean patch size (Fig. 4c). In general, the Extensive Development scenario showed the most fragmented landscape pattern, the Historical Trend scenario showed a medium fragmented landscape pattern, and the Intensive Development scenario showed the least fragmented landscape pattern (Fig. 5).

Table 3
Calibration process, best fit metrics, and results for SLEUTH model of Shenyang under three scenarios (based on Dietzel & Clarke, 2006).

Scenario types	Growth parameters	Coarse			Coarse			Coarse			Driving parameters value
		Monte Carlo iterations = 5			Monte Carlo iterations = 7			Monte Carlo iterations = 9			
		Total # of simulation = 3125			Total # of simulation = 3600			Total # of simulation = 7776			
		Range	Step	Best fit metrics	Range	Step	Best fit metrics	Range	Step	Best fit metrics	
Historical Trend scenario	Diffusion	1–100	25	Compare = 0.95751	1–25	5	Compare = 0.99867	6–11	1	Compare = 0.91670	13
	Breed	1–100	25	Population = 0.96953	1–25	5	Population = 0.96889	21–26	1	Population = 0.97794	30
	Spread	1–100	25	Lee–Sallee = 0.77395	25–50	5	Lee–Sallee = 0.78280	30–40	2	Lee–Sallee = 0.80224	41
	Slope resistance	1–100	25	*F*-match = 0.93173	50–100	10	*F*-match = 0.93820	60–80	4	*F*-match = 0.94275	60
	Road gravity	1–100	25	Composite = 0.66943	1–100	25	Composite = 0.71063	1–76	15	Composite = 0.67802	63
				Metric mean = 0.90818			Metric mean = 0.92214			Metric mean = 0.90991	
Intensive Development scenario	Diffusion	1–100	25	Compare = 0.97736	1–25	5	Compare = 0.98998	1–5	1	Compare = 0.95126	6
	Breed	1–100	25	Population = 0.95536	75–100	5	Population = 0.95745	90–95	1	Population = 0.96618	92
	Spread	1–100	25	Lee–Sallee = 0.75265	25–50	5	Lee–Sallee = 0.76581	25–30	1	Lee–Sallee = 0.78617	30
	Slope resistance	1–100	25	*F*-match = 0.92341	1–25	5	*F*-match = 0.92852	1–5	1	*F*-match = 0.93712	3
	Road gravity	1–100	25	Composite = 0.64895	75–100	5	Composite = 0.67399	75–80	1	Composite = 0.67713	78
				Metric mean = 0.90220			Metric mean = 0.91044			Metric mean = 0.91018	
Extensive Development scenario	Diffusion	1–100	25	Compare = 0.99610	75–100	5	Compare = 0.99998	75–80	1	Compare = 0.94527	87
	Breed	1–100	25	Population = 0.94213	25–50	5	Population = 0.94711	45–50	1	Population = 0.95725	52
	Spread	1–100	25	Lee–Sallee = 0.73146	1–25	5	Lee–Sallee = 0.73981	10–15	1	Lee–Sallee = 0.76484	13
	Slope resistance	1–100	25	*F*-match = 0.91502	1–25	5	*F*-match = 0.91745	10–15	1	*F*-match = 0.92620	14
	Road gravity	1–100	25	Composite = 0.62811	50–75	5	Composite = 0.64283	40–50	2	Composite = 0.64100	50
				Metric mean = 0.89618			Metric mean = 0.90109			Metric mean = 0.89839	

Composite = Compare * Population * Lee–Sallee * *F*-match; Metric mean = (Compare + Population + Lee–Sallee + *F*-match)/4.

Table 4
Calibration parameter sets in three implementation scenarios of "building a new countryside" strategy.

Scenarios of "building a new countryside" strategy implementations	Parameter sets				
	Diffusion	Breed	Spread	Slope resistance	Road gravity
Historical Trend scenario	13	30	41	60	63
Intensive Development scenario	6	92	30	3	78
Extensive Development scenario	87	52	13	14	50

Table 5
The Kappa index of the simulated map to the observed map in 2004.

Scenario types	Kappa index	Agricultural	Urban	Rural	Forest	Other land	Landscape
Historical Trends scenario	Standard Kappa	0.900	0.775	0.835	0.821	0.827	0.929
	Kappa location	0.901	0.885	0.923	0.847	0.964	0.958
	Kappa quantity	0.996	0.900	0.904	0.980	0.859	0.970
Intensive Development scenario	Standard Kappa	0.912	0.798	0.853	0.831	0.817	0.938
	Kappa location	0.903	0.880	0.903	0.852	0.954	0.961
	Kappa quantity	0.998	0.914	0.884	0.986	0.879	0.983
Extensive Development scenario	Standard Kappa	0.856	0.755	0.821	0.801	0.803	0.914
	Kappa location	0.879	0.849	0.899	0.889	0.935	0.937
	Kappa quantity	0.900	0.889	0.900	0.923	0.898	0.916

3.2. Landscape changes at the class level

Human settlements land (including urban land and rural residential land) and farmland were two dominant landscape types from 2005 to 2045. The total percentage of the two landscape types was more than 84.8% in each scenario in 2005 and more than 89.0% in each scenario in 2045. The proportion of the other landscape types is relatively small. Urban and rural sprawl and farmland loss were key issues. The urban and rural residential land and farmland were two landscape types were subjected, and the other landscape types not further considered.

3.2.1. Urban and rural sprawl at class level

The urban and rural land sprawl patterns of the three different scenarios showed large differences in 2045 (Fig. 5). The area of urban and rural residential land increased under each scenario from 2005 to 2045, the Extensive Development scenario showed the highest sprawl rate both urban and rural, the Intensive Development and Historical Trend scenarios show similar growth rates (Fig. 6a).

The number of urban and rural residential patches increased under each scenario from 2005 to 2045. The Extensive Development scenario showed the largest number of urban and rural residential patches, the Intensive Development scenario shows the lowest number, and the Historical Trend scenario was in the middle at each year from 2005 to 2045. The number of urban and rural residential patches increased dramatically from 2005 to 2030, but decreased from 2031 to 2045 under the Extensive Development scenario. The number of urban and rural residential patches increased slowly from year 2005 to 2030 and decreased slowly from

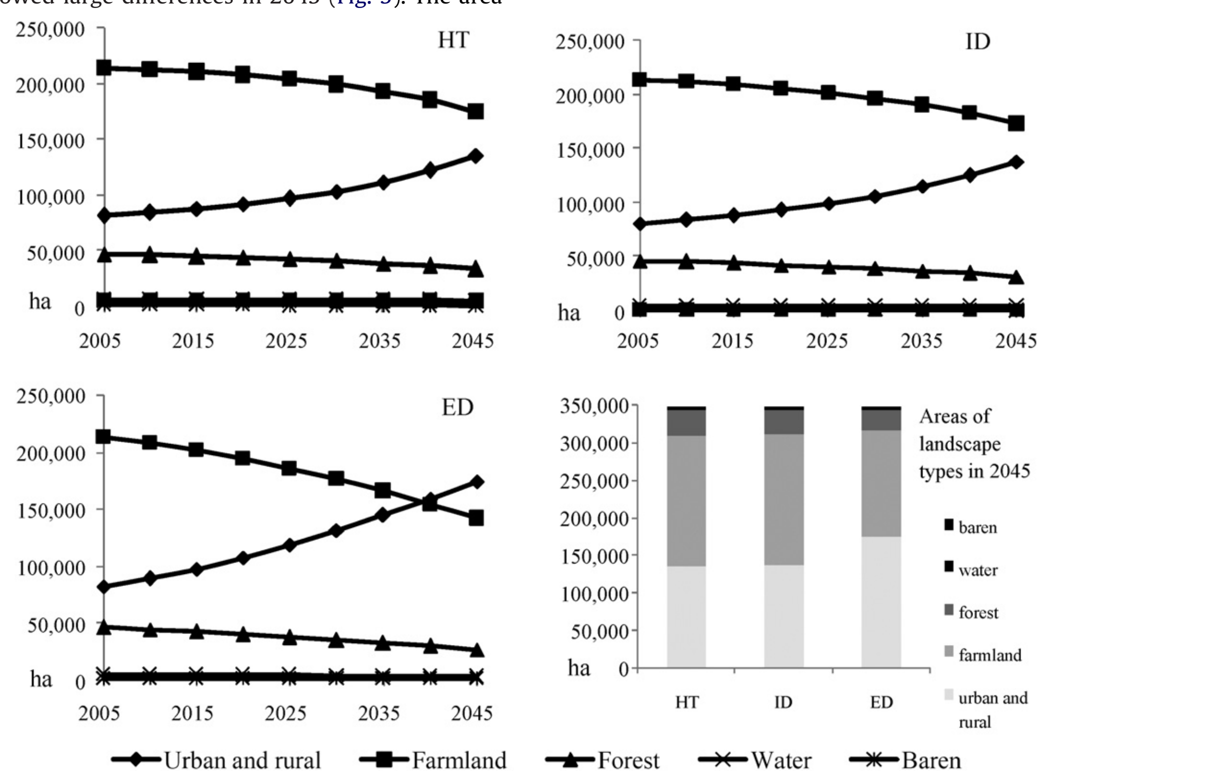


Fig. 2. The areas changes of landscape types from 2005 to 2045 and areas of landscape types in 2045 (HT: Historical Trend scenario; ID: Intensive Development scenario; ED: Extensive Development scenario).

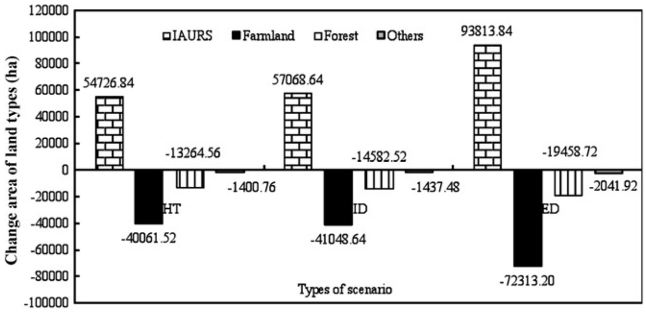


Fig. 3. The increased area of urban and rural sprawl (IAURS) and the decreased area of farmland and other landscape types in 2045 (HT: Historical Trends scenario; ID: Intensive Development scenario; ED: Extensive Development scenario).

year 2031 to 2045 under the Intensive Development scenario, and the number of urban and rural residential patches increased equally from 2005 to 2045 under the Historical Trend scenario. The number of urban and rural residential patches was 1353 in 2004, increasing to 4167, 3046, and 5315 under the Historical Trend, Intensive Development, and Extensive Development scenarios respectively in 2045. The highest value of the number of urban and rural residential patches (maximum sprawl) was 5999 that appeared in 2030 under the Historical Trend scenario (Fig. 6b). The changes in the number of urban and rural residential patches under the Extensive Development and Intensive Development scenarios exhibit the pattern of diffusion and coalescence of the urban and rural residential patches observed by Dietzel, Herold, Hemphill, and Clarke (2005a, 2005b).

The value of mean patch size (urban aggregation) under the Intensive Development scenario was the highest in each forecast year, the value of mean patch size under the Extensive Development scenario was the lowest, and the value of mean patch size under the Historical Trend scenario was in the middle (Fig. 6c).

Fig. 6d shows that the values of the aggregation index under the Historical Trend and the Intensive Development scenarios were similar, ranging from 90.21 to 91.91. The values of the aggregation index under the Extensive Development scenario decreased dramatically from 91.55 to 85.89 and then increase slowly to 86.91. The highest values of the number of urban and rural residential patches, the lowest values of the mean patch size, and the lowest aggregation index under the Extensive Development scenario showed its most diffused urban and rural sprawl pattern, and vice versa, the Intensive Development scenario shows the least diffused urban and rural sprawl pattern and the Historical Trend scenario shows a moderate diffused urban and rural sprawl pattern (Fig. 5).

3.2.2. Farmland loss and fragmentation at class level

The predicted results show that the areas of farmland decreased in each scenario from 2005 to 2045. The areas of other non-settlement land types also decreased accordingly (Fig. 7a). The Extensive Development scenario showed the largest decrease in farmland, while the Intensive Development and Historical Trend scenarios show similar lower rates of farmland loss. The number of farmland patches was the highest, and increased dramatically under the Extensive Development scenario; but increased only slowly under the Historical Trend and Intensive Development scenarios from 2005 to 2045. The number of farmland patches under the Intensive Development scenario was lower than that under the Historical Trend scenario at each year (Fig. 7b). The mean patch size for farmland decreased under each scenario from 2004 to 2045, implying greater fragmentation. The Historical Trend scenario showed the largest value, the Extensive Development scenario shows the lowest, and the Intensive Development scenario was in the middle (Fig. 7c). The aggregation index decreased under each scenario from 2005 to 2045. The Historical Trend and Intensive Development scenarios showed a similar lower aggregation index ranging from 95.47 to 91.66 and the Extensive Development scenario showed the lowest value ranging from 95.31 to 84.19 (Fig. 7d).

The Extensive Development scenario had the largest loss and fragmentation of farmland in each year from 2005 to 2045. The Historical Trend and Intensive Development scenarios showed similar loss and fragmentation of farmland. Farmland loss under the Intensive Development scenario was slightly higher than under the Historical Trend scenario from 2005 to 2045 at the class level, but the sprawl of urban and rural residential and the fragmentation of the landscape under the Intensive Development scenario were lower than those under the Historical Trend scenario.

4. Discussion

4.1. Building a New Countryside strategy implementation and farmland protection

The farmland loss and fragmentation is dire when considering the implications for the strategy, although it has been observed due

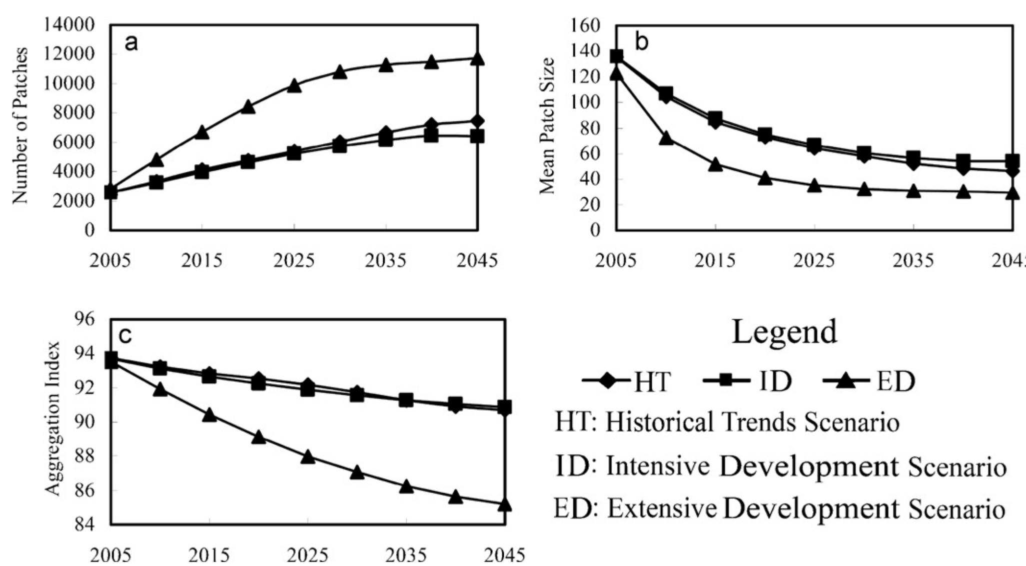


Fig. 4. Landscape metrics of three scenarios at landscape level (a) number of patches, (b) mean patch size, (c) aggregation index.

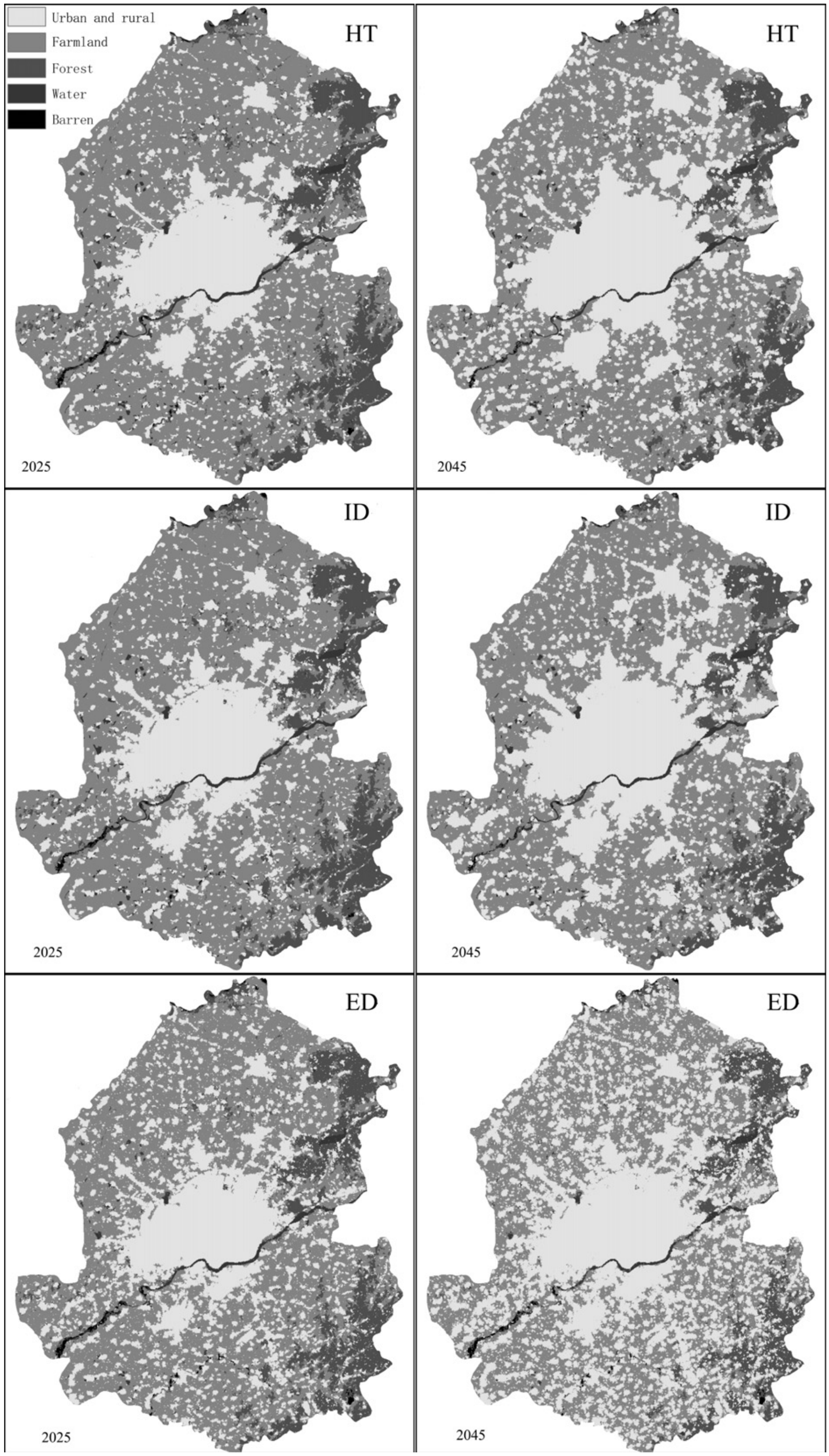


Fig. 5. The landscape pattern under each scenario in year 2025 and 2045 (HT: Historical Trend scenario; ID: Intensive Development scenario; ED: Extensive Development scenario).

to the construction of residential settlements in the countryside (Lin & Ho, 2003; Tian et al., 2007; Xu, 2004). Different scenarios for implementing the strategy show only different degrees of additional loss and fragmentation of farmland in Shenyang. The Extensive Development scenario will lead to more rural sprawl, more rural construction, and more rural residential land increases (Fan & Zhang, 2004; Shen & Ma, 2005). The Extensive Development scenario showed the largest urban and rural sprawl and the largest landscape fragmentation, which will result in the largest loss and fragmentation of farmland. The rural residential land growth and

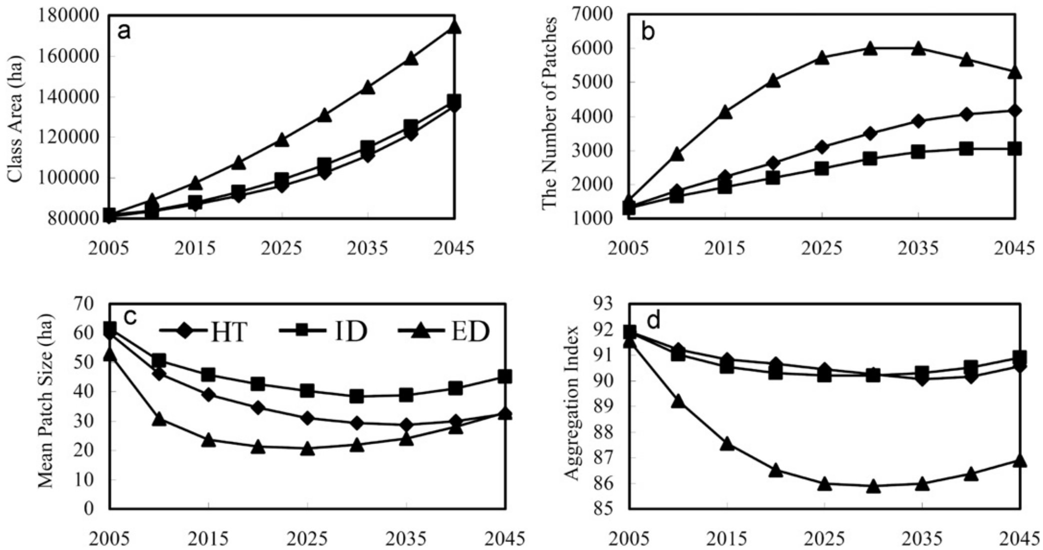


Fig. 6. Landscape metrics of three scenarios at urban land and rural residential land class level (a) class area (b) number of patches, (c) mean patch size, (d) aggregation index (HT: Historical Trend scenario; ID: Intensive Development scenario; ED: Extensive Development scenario).

farmland loss seem inevitable in implementing this strategy for rural residential infrastructure and housing improvement and in implementing the related development policies. The farmland loss in the Intensive Development scenario was a little higher than that in the Historical Trend scenario. The Historical Trend scenario also does not prevent urban and rural sprawl, farmland loss and landscape fragmentation. The lower urban and rural sprawl and landscape fragmentation in the Intensive Development scenario compared to Historical Trend scenario benefited from selectively intensive development policy and control of some rural sprawl in the scenario designs. The diffused urban and rural sprawl pattern will result in fragmentation of farmland and accelerated farmland loss (Xie, Yu, Bai, & Xing, 2006), biodiversity decrease (Liu et al., 2003), water quality decline (Wang, Da, Song, & Li, 2008; Zhang et al., 2007), and other ecological impacts (Goetz, Wright, Smith, Zinecker, & Schaub, 2003; Zhao et al., 2008). The reduced rural investment, less rural construction, and lack of favorable policies in the Historical Trend scenario can only lead to a slowing down of the rural settlement development and improvement of housing conditions (Zhang & Fan, 2004), not their reversal. Thus, even the Historical Trend scenario cannot achieve the target of Building a New Countryside strategy. The Intensive Development scenario is good for farmland and landscape protection if urban and rural sprawl could be further controlled considering the strategy. The environmental impacts of the Intensive Development scenario are comparatively smaller. While most studies of sprawl prediction involve urban centers only, the study presents a case of predicting urban and rural sprawl simultaneously.

The centralized settle-down practice is another Building a New Countryside tactic commonly used in the coastal regions in China. Implementing this tactic requires farmland expropriation–compensation balance that may result in quality decrease of newly increased farmland, that is, some farmlands with good quality were expropriated for urban and rural construction while newly increased farmlands with poor quality were used for the occupied farmlands compensation (Yu et al., 2010; Zheng & Shen, 2007). In addition, northeast China is the most important grain production base and implementing such a tactic may lead

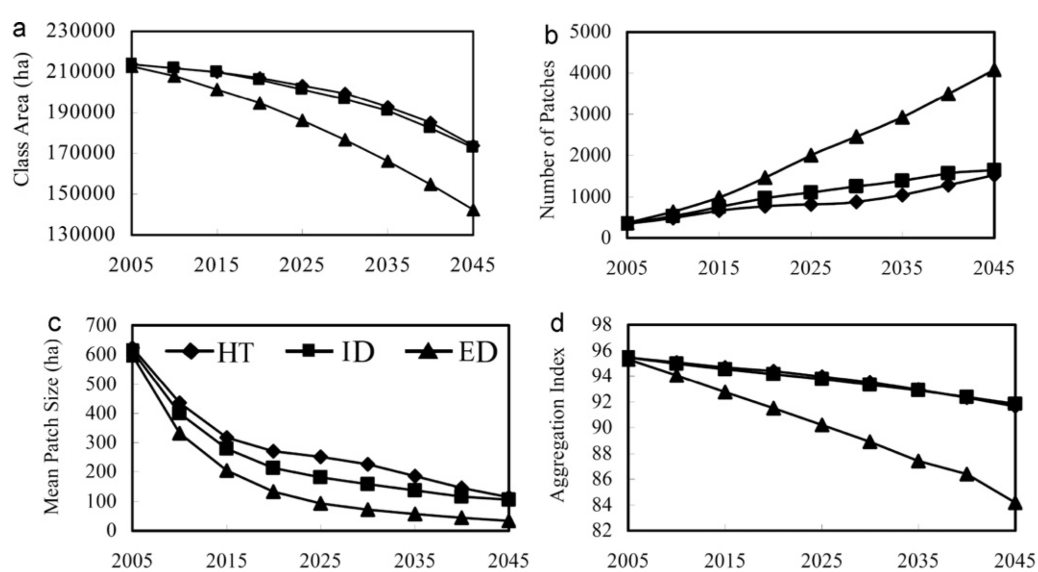


Fig. 7. Landscape metrics of three scenarios at farmland class level (a) class area (b) number of patches, (c) mean patch size, (d) aggregation index (HT: Historical Trend scenario; ID: Intensive Development scenario; ED: Extensive Development scenario).

to decrease in both farmland quantity and quality, which endangers national food security. Thus, the tactic was not simulated in this study.

4.2. Policy implication

Building a New Countryside is a Chinese national strategy for solving the three issues related to farmers, agriculture, and rural area in China. Further, and even greater, rural residential land growth and farmland loss seem inevitable in implementing the strategy. China's rural development should consider further how to deal with rural land-use issues, especially the conflict between rural residential land and farmland.

Building a new countryside in an intensive, compact and proven way is a recommended policy in northeastern China. The Extensive Development scenario projected the possible large amount of farmland loss. Spontaneous urban and rural spatial growth should be prohibited in future land management. So, building a new countryside in an intensive, compact and proven way can contribute to reducing farmland loss and the related rural environmental impacts. Su, Zhang, Zhang, Zhi, and Wu (2011b) study that rural residential land sprawl typically occurs on farmland within 5 km of build-up rural settlements supported our policy implication, which support our policy implication. Compact rural development and smart-growth type rural residential land growth are important visions for local planners and decision makers. Demonstration projects for implementing the strategy in rural settlement with large population are recommended to test these concepts. Through field survey, we found that the use efficiency of rural public services is very low in most existing Building a New Countryside implementation rural settlements with small populations, which result in not only further loss of farmland, but also a waste of investment in the public service infrastructure.

Rural land management legislation and regulations related to the strategy implementation should be adopted. Although the Chinese central government has adopted a "basic farmland protection areas regulation" policy to protect farmland from being converted to developed land (Pan & Zhao, 2007), relative legislation and regulations in implementing the strategy are few. For example, excessive scattering of rural landholdings is also commonly regarded as a major obstacle to farmland protection in China (Tan et al., 2005; Wu, Liu, & Davis, 2005), yet there are few regulations aimed at intensive rural land management.

A land law enforcement system should be established in China. It is urgent to strictly enforce farmland protection laws and to control rural and urban sprawl in implementing the strategy in China. Farmland loss in the Su-Xi-Chang region coastal China while implementing the strategy through rural construction land consolidation witnesses weak land law enforcement (Long et al., 2009). A national land law enforcement system would be helpful to prevent farmland from converting to developed land under local protectionism. Converting farmland to other build-up land is prohibited when implementing the strategy.

Scientifically-based rural planning policies and management programs for implementing the strategy should be critical from the perspective of land management. There is a lack of planning in rural China, which has led to diffused rural residential land growth, farmland loss, insufficient utilization and management of land resources, and related environmental problems (Su et al., 2011b). Local governors, managers, rural planners, and land resource managers should put forward adaptive scientific village plans to management old and new houses alike in developing the strategy in rural China. Plans should coordinate among local landscape planning, local land-use planning, and industrial planning.

4.3. Limitations and future research directions

There were some limitations in the simulation assumptions and SLEUTH model. The centralized settle-down practice in the Chinese Building a New Countryside strategy is scarce in other countries. There is no focused urban and rural growth model that can simulate it. Although SLEUTH model can simulate all the implementation scenarios in Northeast China and west China, it cannot simulate displacement, shrinkage and disappearance of urban and rural construction land in only one type of Building a New Countryside implementation practice in the Su-Xi-Chang region of coastal China. Developing a model to simulate urban and rural land shrinkage and disappearance is a future research direction. In addition, how to protect farmland through improving land use efficiency and enhancing labor productivity is good topic for future research when implementing the strategy.

5. Conclusion

China's Building a New Countryside strategy is helpful for rural development, but represents a challenge to farmland protection. To scientifically implement the strategy is critical for farmland protection. The farmland loss was inevitable in implementing the strategy. The combined methods of remote sensing, geographical information system, landscape metrics, and the SLEUTH urban growth and land cover change model are effective decision-support tools to analyze and compare the impacts of classical urban and rural sprawl patterns on farmland in China. SLEUTH model can simulate most Building a New Countryside implementation scenarios in Northeast China and West China, except for the displacement, shrinkage and disappearance of urban and rural construction land. The Intensive Development scenario, which selects rural residential land with good economic conditions and large populations to implement the strategy, is recommended if spontaneous urban and rural sprawl can be further decreased. Possible policies include (1) to build a new countryside in an intensive, compact and smart way, (2) to establish rural land management legislation and regulations and land law enforcement system related to the strategy implementation, (3) to implement scientific planning of a new countryside. Local governors, managers, rural planners, and land resources managers should put forward adaptive village plans and schemes that are informed by scientific forms of inquiry to improve old housing while also building new houses under the strategy in rural China, coordinating with local landscape planning, local land-use planning, urban planning and industrial planning. Our findings and suggestions will give not only decision-support for implementation of the Building a New Countryside strategy in northeast China and west China, but also new perspectives for rural urbanization in other developing countries.

Acknowledgements

This research was supported by the National Natural Science Foundation of China (31100346), the National Science and Technology Supporting Programme of China (2011BAJ06B01; 2008BAJ10B01-01), the Natural Science Foundation of China (71033004), the Chinese Academy of Sciences (08YBR111SS), Shenyang Bureau of Science and Technology (1091147-9-00).

References

Batisani, N. & Yarnal, B. (2009). Urban expansion in Centre County, Pennsylvania: Spatial dynamics and landscape transformations. *Applied Geography*, *29*(2), 235–249.
Batty, M. (2008). The size, scale, and shape of cities. *Science*, *319*(5864), 769.
Brown, L. R. (1995). *Who will feed China? Wake-up call for a small planet*. New York: W.W. Norton & Co.

Brown, D. G., Johnson, K. M., Loveland, T. R. & Theobald, D. M. (2005). Rural land-use trends in the conterminous United States, 1950–2000. *Ecological Applications*, *15*(6), 1851–1863.
Candau, J. C. & Clarke, K. C. (2000). Probabilistic land cover modeling using deltatrons. In *Proceedings of the 38th annual conference of the Urban Regional Information Systems Association* Orlando, FL,. Available from: http://www.ncgia.ucsb.edu/projects/gig/v2/About/references/Santa_Barbara_CA/candau_clarke_2000.pdf
Candau, J. C., Rasmussen, S. & Clarke, K. C. (2000). A coupled cellular automaton model for land use/land cover dynamics. In *4th International conference on integrating GIS and environmental modeling (GIS/EM4): Problems, prospects and research needs* Banff, Alberta, Canada, September 2–8,. Available from: http://www.colorado.edu/research/cires/banff/pubpapers/94/
Civerolo, K., Hogrefe, C., Lynn, B., Rosenthal, J., Ku, J. Y., Solecki, W., et al. (2007). Estimating the effects of increased urbanization on surface meteorology and ozone concentrations in the New York City metropolitan region. *Atmospheric Environment*, *41*, 1803–1818.
Clarke, K. C., Hoppen, S. & Gaydos, L. (1997). A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area. *Environment and Planning B: Planning and Design*, *24*, 247–261.
Clarke, K. C., Gazulis, N., Dietzel, C., & Goldstein, N. C. (2007). A decade of SLEUTHing: Lessons learned from applications of a cellular automaton land use change model. Classics in IJGIS: Twenty Years of the International Journal of Geographical Information Science and Systems, 413–427.
del Mar López, T., Aide, T. M. & Thomlinson, J. R. (2001). Urban expansion and the loss of prime agricultural lands in Puerto Rico. *Ambio*, *30*(1), 49–54.
Dietzel, C. & Clarke, K. C. (2004). Spatial differences in multi-resolution urban automata modeling. *Transactions in GIS*, *8*(4), 479–492.
Dietzel, C. & Clarke, K. C. (2006). The effect of disaggregating land use categories in cellular automata during model calibration and forecasting. *Computers, Environment and Urban Systems*, *30*, 78–101.
Dietzel, C., Herold, M., Hemphill, J. J. & Clarke, K. C. (2005). Spatio-temporal dynamics in California's Central Valley: Empirical links to urban theory. *International Journal of Geographical Information Science*, *19*, 175–195.
Dietzel, C., Oguz, H., Hemphill, J. J., Clarke, K. C. & Gazulis, N. (2005). Diffusion and coalescence of the Houston Metropolitan Area: Evidence supporting a new urban theory. *Environment and Planning B: Planning and Design*, *32*, 231–246.
Ding, C. R. (2007). Policy and praxis of land acquisition in China. *Land Use Policy*, *24*, 1–13.
Fan, S. & Zhang, X. (2004). Infrastructure and regional economic development in rural China. *China Economic Review*, *15*, 203–214.
Goetz, S. J., Wright, R., Smith, A. J., Zinecker, E. & Schaub, E. (2003). Ikonos imagery for resource management: Tree cover, impervious surfaces and riparian buffer analyses in the Mid-Atlantic Region. *Remote Sensing of Environment*, *88*, 195–208.
Gonzalez-Abraham, C. E., Radeloff, V. C., Hammer, R. B., Hawbaker, T. J., Stewart, S. I. & Clayton, M. K. (2007). Building patterns and landscape fragmentation in northern Wisconsin, USA. *Landscape Ecology*, *22*, 217–230.
Han, S. S. & He, C. X. (1999). Diminishing farmland and urban development in China: 1993–1996. *GeoJournal*, *49*, 257–267.
Hart, J. F. (2001). Half a century of cropland change. *Geographical Review*, *91*(3), 525–543.
Hawbaker, T. J., Radeloff, V. C., Clayton, M. K., Hammer, R. B. & Gonzalez-Abraham, C. E. (2006). Road development, housing growth, and landscape fragmentation in northern Wisconsin: 1937–1999. *Ecological Applications*, *16*, 1222–1237.
He, H. S., DeZonia, B. & Mladenoff, D. J. (2000). An aggregation index (AI) to quantify spatial patterns of landscapes. *Landscape Ecology*, *15*, 591–601.
Herold, M., Goldstein, N. C. & Clarke, K. C. (2003). The spatiotemporal form of urban growth: Measurement, analysis and modeling. *Remote Sensing of Environment*, *86*(3), 286–302.
Hodge, I. (1996). Onpenguins on icebergs: The Rural White Paper and the assumptions of rural policy. *Journal of Rural Studies*, *12*, 331–337.
Jantz, C. A., Goetz, S. J. & Shelley, M. K. (2003). Using the SLEUTH urban growth model to simulate the impacts of future policy scenarios on urban land use in the Baltimore–Washington metropolitan area. *Environment and Planning B: Planning and Design*, *30*, 1–15.
Kong, F. & Nakagoshi, N. (2006). Spatial–temporal gradient analysis of urban green spaces in Jinan, China. *Landscape and Urban Planning*, *78*, 147–164.
Li, X., He, H. S., Bu, R., Wen, Q., Chang, Yu., Hu, Y., et al. (2005). The adequacy of different landscape metrics for various landscape patterns. *Pattern Recognition*, *38*, 2626–2638.
Lichtenberg, E. & Ding, C. R. (2008). Assessing farmland protection policy in China. *Land Use Policy*, *25*, 59–68.
Lin, G. C. S. & Ho, S. P. S. (2003). China's land resources and land-use change: Insights from the 1996 land survey. *Land Use Policy*, *20*, 87–107.
Lin, Y., Hong, N., Wu, P., Wu, C. & Verburg, P. H. (2007). Impacts of land use change scenarios on hydrology and land use patterns in the Wu–Tu watershed in Northern Taiwan. *Landscape and Urban Planning*, *80*, 111–126.
Liu, J., Daily, G. C., Ehrlich, P. R. & Luck, G. W. (2003). Effects of household dynamics on resource consumption and biodiversity. *Nature*, *421*, 530–533.
Liu, J., Zhan, J. & Deng, X. (2005). Spatio-temporal patterns and driving forces of urban land expansion in China during the economic reform era. *Ambio*, *34*(6), 450–455.
Long, H., Heilig, G. K., Li, X. & Zhang, M. (2007). Socio-economic development and land-use change: Analysis of rural housing land transition in the Transect of the Yangtse River, China. *Land Use Policy*, *24*, 141–153.
Long, H., Liu, Y., Wu, X. & Dong, G. (2009). Spatio-temporal dynamic patterns of farmland and rural settlements in Su-Xi-Chang region: Implications for building a new countryside in coastal China. *Land Use Policy*, *26*, 322–333.
Long, H., Liu, Y., Li, X. & Chen, Y. (2010). Building new countryside in China: A geographical perspective. *Land Use Policy*, *27*, 457–470.
LRDC (Land Resource Department of China). (2000). *The land resource report of 1999*. Beijing: Ocean Press. (in Chinese).
LRDC (Land Resource Department of China). (2004). *The land resource report of 2003*. Beijing: Ocean Press. (in Chinese).
McGarigal, K., Ene, E. & Holmes, C. (2002). *FRAGSTATS (Version 3): FRAGSTATS metrics*. University of Massachusetts-Produced Program. Available from: http://www.umass.edu/landeco/research/fragstats/documents/fragstats documents.html
MHURDPRC. (1994). *The criterion of urban land classification and planning and construction*. Ministry of Housing and Urban-Rural Development of the People's Republic of China). Available from: http://www.lvhua.com/chinese/fagui/faguidetail.asp?articleno=A00000005262 (in Chinese)
MHURDPRC. (2008). *Urban-Rural Planning law of People's Republic of China*. Ministry of Housing and Urban–Rural Development of the People's Republic of China. Available from: http://www.mohurd.gov.cn/zcfg/fl/200710/t20071029_159509.htm (in Chinese)
NSBC National Statistics Bureau of China. (2001). *Chinese statistical yearbook in 2001*. Beijing: China Statistics Press. (in Chinese).
Oguz, H., Klein, A. & Srinivasan, R. (2007). Using the sleuth urban growth model to simulate the impacts of future policy scenarios on urban land use in the Houston–Galveston–Brazoria CMSA. *Research Journal of Social Sciences*, *2*, 72–82.
Pan, X. & Zhao, Q. (2007). Measurement of urbanization process and the paddy soil loss in Yixing city, China between 1949 and 2000. *Catena*, *69*, 65–73.
Petit, C., Scudder, T. & Lambin, E. (2001). Quantifying processes of land-cover change by remote sensing: Resettlement and rapid land-cover changes in south-eastern Zambia. *International Journal of Geographical Information Science*, *22*(17), 3435–3456.
Pontius, R. O., Jr. (2002). Statistical methods to partition effects of quantity and location during comparison of categorical maps at multiple resolutions. *Photogrammetric Engineering & Remote Sensing*, *68*(10), 1041–1049.
Rafiee, R., Mahiny, A. S., Khorasani, N., Darvishsefat, A. A. & Danekar, A. (2009). Simulating urban growth in Mashad City, Iran through the SLEUTH model (UGM). *Cities*, *26*(1), 19–26.
Sargeson, S. (2002). Subduing "the rural house-building craze": Attitudes towards housing construction and land-use controls in four Zhejiang villages. *The China Quarterly*, *172*, 927–955.
SCHRC (Shenyang Culture History Research Center). (1999). *The first city of Northeast China: The past events of Shenyang. Shenyang Culture and History Research Center*. Shenyang, China: Shenyang Press. (in Chinese).
SCPRC The State Council of the People's Republic of China. (2006). *Guidelines of PRC's 11th Five-year plan for national economic and social development*. Beijing: People's Press. (in Chinese).
Seto, K. C., Kaufmann, R. K. & Woodcock, C. E. (2000). Landsat reveals China's farmland reserves, but they're vanishing fast. *Nature*, *406*(13), 121.
Shen, X. P & Ma, L. J. C. (2005). Privatization of rural industry and de facto urbanization from below in southern Jiangsu, China. *Geoforum*, *36*, 761–777.
Shenyang Statistics Bureau. (2008). *Shenyang statistical yearbook 2008*. Beijing: National Bureau of Statistics of China.
Silva, E. A. & Clarke, K. C. (2002). Calibration of the SLEUTH urban growth model for Lisbon and Porto, Portugal. *Computers, Environment and Urban Systems*, *26*, 525–552.
Silva, E. A. (2004). The DNA of our regions: Artificial intelligence in regional planning. *Futures*, *36*, 1077–1094.
Solecki, W. D. & Oliveri, C. (2004). Downscaling climate change scenarios in an urban land use change model. *Journal of Environment Management*, *72*, 105–115.
Su, S., Jiang, Z., Zhang, Q. & Zhang, Y. (2011). Transformation of agricultural landscapes under rapid urbanization: A threat to sustainability in Hang-Jia-Hu region, China. *Applied Geography*, *31*(2), 439–449.
Su, S., Zhang, Q., Zhang, Z., Zhi, J. & Wu, J. (2011). Rural settlement expansion and paddy soil loss across an ex-urbanizing watershed in eastern coastal China during market transition. *Regional Environmental Change*, *11*(3), 651–662.
Sui, D. Z. & Zeng, H. (2001). Modeling the dynamics of landscape structure in Asia's emerging desakota regions: A case study of Shenzen. *Landscape and Urban Planning*, *53*(1–4), 37–52.
Stehman, S. V. (1999). Basic probability sampling designs for thematic map accuracy assessment. *International Journal of Remote Sensing*, *20*(12), 2423–2441.
Tan, M., Li, X., Xie, H. & Lu, C. (2005). Urban land expansion and arable land loss in China—a case study of Beijing–Tianjin–Hebei region. *Land Use Policy*, *22*, 187–196.
Theobald, D. M. (2001). Land-use dynamics beyond the American urban fringe. *Geographical Review*, *91*(3), 544–564.
Theobald, D. M. (2004). Placing exurban land-use change in a human modification framework. *Frontiers in Ecology and the Environment*, *2*(3), 139–144.
Tian, G., Yang, Z. & Zhang, Y. (2007). The spatio-temporal dynamic pattern of rural residential land in China in the 1990s using Landsat TM images and GIS. *Environmental Management*, *40*, 803–813.

USGS. (2003). *Project gigalopolis: Urban and land cover modeling*. US Geological Survey. Available from: http://www.ncgia.ucsb.edu/projects/gig/
Veldkamp, A. & Lambin, E. (2001). Predicting land-use change. *Agriculture, Ecosystems & Environment*, *85*(1–3), 1–6.
Wang, H., Li, X., Long, H., Qiao, Y. & Li, Y. (2011). Development and application of a simulation model for changes in land use patterns under drought scenarios. *Computational Geosciences*, *37*(7), 831–843.
Wang, J., Da, L., Song, K. & Li, B. L. (2008). Temporal variations of surface water quality in urban, suburban and rural areas during rapid urbanization in Shanghai, China. *Environmental Pollution*, *152*, 387–393.
Wu, X., Hu, Y., He, H. S., Bu, R., Onsted, J. & Xi, F. (2009). Performance evaluation of the SLEUTH model in the Shenyang metropolitan area of northeastern China. *Environmental Modeling & Assessment*, *14*, 221–230.
Wu, Z. P., Liu, M. Q. & Davis, J. (2005). Land consolidation and productivity in Chinese household crop production. *China Economic Review*, *16*, 28–49.
Xi, F., He, H. S., Hu, Y., Wu, X., Bao, L., Tian, Y., et al. (2008). Simulation and prediction of urban and rural settlements growth and land use change in Yingkou city. *Chinese Journal of Applied Ecology*, *19*, 1529–1536 (in Chinese).
Xi, F., He, H. S., Hu, Y., Bu, R., Chang, Y., Wu, X., et al. (2009). Simulating the impacts of ecological protection policies on urban land use sustainability in Shenyang-Fushun, China. *International Journal of Urban Sustainable Development*, *1*, 111–127.
Xie, Y., Wang, S. & Schei, P. (2004). *Conserves in China*. Beijing: Tinghua University Press.
Xie, Y., Mei, Y., Guangjin, T. & Xuerong, X. (2005). Socio-economic driving forces of arable land conversion: A case study of Wuxian City, China. *Global Environmental Change*, *15*, 238–252.
Xie, Y., Yu, M., Bai, Y. & Xing, X. (2006). Ecological analysis of an emerging urban landscape pattern-desakota: A case study in Suzhou, China. *Landscape Ecology*, *21*, 1297–1309.
Xinhuanet. (2006). *Building a new socialist countryside*. Available from: http://news.xinhuanet.com/ziliao/2006-02/07/content_4146460.htm (in Chinese)
Xinhuanet. (2008). *China confirm explicitly five key areas for expanding consumption in 2009*. Available from: http://news.xinhuanet.com/newscenter/2008-12/12/content_10494069_1.htm (in Chinese)
Xu, W. (2004). The changing dynamics of land-use change in rural China: A case study of Yuhang, Zhejiang Province. *Environment & Planning A*, *36*, 1595–1615.
Xu, H. & Wang, J. (2008). Primary research on control standard of intensive land use in new rural construction of Liaoning. *Territory & Natural Resources Study*, *30*(2), 44–45 (in Chinese).
Yang, H. & Li, X. B. (2000). Cultivated land and food supply in China. *Land Use Policy*, *17*, 73–88.
Yang, X. & Lo, C. P. (2003). Modelling urban growth and landscape changes in the Atlanta metropolitan area. *International Journal of Geographical Information Science*, *17*, 463–488.
Yu, G., Feng, J., Che, Y., Lin, X., Hu, L. & Yang, S. (2010). The identification and assessment of ecological risks for land consolidation based on the anticipation of ecosystem stabilization: A case study in Hubei Province, China. *Land Use Policy*, *27*(2), 293–303.
Zhang, Q., Ban, Y., Liu, J. & Hu, Y. (2011). Simulation and analysis of urban growth scenarios for the Greater Shanghai Area, China. *Computers, Environment and Urban Systems*, *35*(2), 126–139.
Zhang, Q. L., Shi, X. Z., Huang, B., Yu, D., Öborn, I., Blombäck, K., et al. (2007). Surface water quality of factory-based and vegetable-based peri-urban areas in the Yangtze River Delta region, China. *Catena*, *69*, 57–64.
Zhang, X. & Fan, S. (2004). Public investment and regional inequality in rural China. *Journal of Agricultural Economics*, *30*, 89–100.
Zhao, J., Zhu, Y. G., Shao, G. & Ness, D. (2008). Coping with an urbanising world: Interdisciplinary research towards sustainability. *International Journal of Sustainable Development and World Ecology*, *15*, 584–589.
Zheng, H. & Shen, L. (2007). Grading assessment of cultivated land for the balance of arable land: A case study in Lianzhou county, Guangdong province. *Resources Science*, *29*(4), 152–157 (in Chinese).

Fengming Xi is an assistant professor at the Institute of Applied Ecology, Chinese Academy of Sciences. Dr. Xi's research interests include urban landscape modeling, urban sustainable development, landscape ecology, industrial ecology, circular economy simulation system, and low carbon city.

Hong S. He is a landscape ecologist and a professor at the University of Missouri and a research professor at the Institute of Applied Ecology, Chinese Academy of Sciences. Dr. He's research interests include effects of climate warming, natural and anthropogenic disturbances on forest landscapes, forest landscape modeling, quantifying and predicting urban and rural sprawl.

Keith C. Clarke is a professor of Geography, University of California, Santa Barbara. His research interests include land use modeling, automated data processing, and cellular automaton.

Yuanman Hu is a landscape ecologist and research professor at the Institute of Applied Ecology, Chinese Academy of Sciences. His research interests focus on landscape ecology, urban landscape modeling, and forest landscape dynamics.

Xiaoqing Wu is an assistant professor at the Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences. Dr. Wu's research interests include simulating and assessing urban growth and its environmental impacts, and integrated coastal zone management.

Miao Liu is an associate professor at the Institute of Applied Ecology, Chinese Academy of Sciences. Dr. Liu's research interests focus on landscape ecology, 3S applications, ecological planning and watershed ecology.

Tiemao Shi is a professor at Shenyang Jianzhu University. Dr. Shi's research interests include urban and rural planning, landscape ecology, and urban green space design.

Yong Geng is a research professor at the Institute of Applied Ecology, Chinese Academy of Sciences. His research interests focus on urban environmental management and industrial ecology.

Chang Gao is an assistant professor at Shenyang Jianzhu University. Dr. Gao's research interests include urban and rural planning, landscape ecology, and urban green space design.