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RESEARCH ARTICLE

Land cover dynamics of different topographic conditions in Beijing, China

WU Xiaopu (✉)[1,2], TANG Zhiyao[1], CUI Haiting[1], FANG Jingyun[1]

1 Department of Ecology, Key Laboratory for Earth Surface Processes of the Ministry of Education, Peking University, Beijing 100871, China
2 Chinese Research Academy of Environmental Sciences, Beijing 100012, China

Abstract Topographic conditions play an important role in controlling land cover dynamic processes. In this study, remotely sensed data and the geographic information system were applied to analyze the changes in land cover along topographic gradients from 1978 to 2001 in Beijing, a rapidly urbanized mega city in China. The study was based on five periods of land cover maps derived from remotely sensed data: Landsat MSS for 1978, Landsat TM for 1984, 1992, 1996 and 2001, and the digital elevation model (DEM) derived from 1:250,000 topographic map. The whole area was divided into ten land cover types: conifer forest, broadleaf forest, mixed forest, shrub, brushwood, meadow, farmland, built-up, water body and bare land. The results are summarized as follows. (1) Shrub, forest, farmland and built-up consist of the main land cover types of the Beijing area. The most significant land cover change from 1978 to 2001 was the decrease of the farmland and expansion of the built-up area. Farmland decreased from 6354 to 3813 km^2 in the 23 years, while the built-up area increased from 421 to 2642 km^2. Meanwhile, the coverage of forest increased from 17.2% to 24.7% of the total area. The conversion matrix analysis indicated that the transformation of farmland to the built-up area was the most significant process and afforestation was the primary cause of the replacement of shrub to forest. (2) Topographic conditions are of great importance to the distribution of land cover types and the process of land cover changes. Elevation has an intensive impact on the distribution of land cover types. The area below 100 m mostly consists of farmland and built-up areas, while the area above 100 m is mainly covered by shrub and forest. Shrub has the maximum frequency in areas between 100 and 1000 m, while forest has dominance in areas above 800 m. According to the analysis of land cover changes in different ranges of elevation, the greatest change below 100 m was the process of urbanization. The process of the main land cover change occurred above 100 m was the transformation from shrub to forest. This result was consistent with the vertical change of natural vegetation distribution in Beijing. (3) Slope has a great influence on the distribution of land cover. Farmland and built-up areas are mostly distributed in flat areas, while shrub and forest occupy steeper areas compared with other land cover types. Forest frequency increased with the increasing slope. Land cover changes differed from the slope gradients. In the plain area, the land cover change occurred as the result of urbanization. With the increasing of the slope gradient, afforestation, which converts shrub to forest, was the process of the primary land cover change.

Keywords land use/land cover, topographical factors, conversion matrix, remote sensing, DEM, vegetation

1 Introduction

Land use/ land cover (LUCC) is one of the key issues in the research on global environmental changes nowadays (Turner and Meyer, 1991; Turner et al., 1995). The land use process of human beings greatly changes the original natural landscape, which alters regional and global biodiversity even more, and also has a deep impact on regional and global climate changes (Turner et al., 1993, 1995; Li, 1996; Imbernon, 1999; Reid et al., 2000). The hotspots of LUCC mostly lie in the temporal and spatial patterns of land cover type change and driving factors that cause the changes (Ramankutty and Foley, 1999).

This research focuses on the land cover and vegetation changes in the Beijing area in the last 20 years. Research work on the vegetation distribution pattern in the Beijing area began early. Since the 1950s, many systematic investigations have been carried out regarding the vegetation in the Beijing area by ecologists (Department of Biology, Beijing Normal

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E-mail: wuxiaopu163@163.com

University, 1958; Li et al., 1959; Chen et al., 1963). In recent years, studies on LUCC in the area through remote sensing and the geographic information system (GIS) have gradually attracted more and more interest (Gu, 1999; He et al., 2001; Tian et al., 2003; Qi et al., 2004). Due to the complex geographic environment in the Beijing area, the vegetation and land cover types differ a lot under different terrain conditions, and analyses are uncommon on the regional land cover change under the impact of natural conditions. This study combined DEM/DTM data with remote sensing analysis, and researched the relationship between land cover changes and topographic factors from 1978 to 2001 in Beijing City.

2 Studied site

Beijing City is located in the northeast of the North China Plain, with the geographic range of 39°38′–41°05′ N, 115°24′–117°30′ E. The west and north parts are mostly mountainous areas, belonging to the Taihang Mountain and the Yanshan Mountain, respectively; the southeast part belongs to the North China Plain. The total area is 16 807.8 KM^2, with 6 390 km^2 of plain areas, accounting for about 38%, and 10 418 km^2 of mountainous areas, accounting for about 62%. The elevation differs largely in Beijing and the highest site is the Donglin Mountain with an altitude of 2 303 m, while much of the plain area only has an average altitude of 15–50 m.

The Beijing area is a continental monsoon type of the temperate zone. It is cold and dry in winter, but warm and wet in summer. The temperate and spatial distribution of heat and water is quite unbalanced. The mean annual temperature is about 11.8°C and the highest average temperature could reach 31.0°C. The mean annual precipitation is about 565 mm, most of which is concentrated in July and August. Because of the effect of the landform, the precipitation in mountainous and plain areas differ much (Land and Environmental Protection Division, Beijing Planning Commission, 1988).

Beijing has a long history of development, which brought serious destruction to the natural vegetation. Furthermore, as the capital of China and an international mega city, great changes of landscape have been taking place in Beijing with the process of rapid urbanization, accelerated increase in population and development of the suburban counties in mountain areas. In 2000, Beijing had a population of 140 000 000 and administered 16 districts and 2 counties (National Bureau of Statistics of P. R. China, 2001).

3 Methods

3.1 Data processing

Using GIS software, Erdas Imagine 8.5 and ArcGIS 9.0, the research analyzed the land cover changes in Beijing from 1978 to 2001 through five periods of Landsat satellite images. The information of the RS image data is listed in Table 1.

Table 1 Remote sensing data used in this study

Time	Path code
1978-6-12	MSS132-32, MSS131-32
1984-10-2	TM123-32
1992-5-18	TM123-32
1996-5-29	TM123-32, TM124-32
2001-5-19	ETM123-32

In order to reduce the disturbance of homologous spectrum from different objectives, the images of the studied areas are divided into different altitude segments according to the regulations of vegetation distribution and the impacts of human activities.

There are clear vertical regulations of vegetation distribution in the mountainous areas in Beijing. The lower altitude limit of birch forests at the shady aspect and *Corylus mandshurica* shrub is about 800 to 1000 m. In addition, *Quercus liaotungensis* forest distribution extends from the shady aspect to the sunny aspect at this range. This range is also the higher limit of *Vitex negundo* var. *heterophylla* at the sunny aspect and *Myripnois dioica* at the shady aspect. The lower altitude limit of *Quercus liaotungensis* is about 500 to 600 m, and it is also the inflexion of *Quercus dentata* forest distribution between the sunny to the shady aspect. Sub-alpine meadow and *Larix principis- rupprechtii* forests mostly exist above the level of 1600 m. Furthermore, the altitude of plain areas is mostly lower than 100 m (Huo et al., 1989; Chen et al., 1990). Therefore, the altitude points of 100, 500, 800, 1000 and 1600 m can be regarded as the key borderlines of the vegetation distribution in the Beijing area. When being processed, the images were divided into six range altitude sections through DEM according to the vegetation distribution rules: lower than 100, 500–800, 800–1000, 1000–1600 and higher than 1600 m.

Under the supervised classification with Erdas Imagine 8.5, primary analyses on land use at different times of every altitude segment can be drawn. According to local investigations and vegetation maps (Beijing Municipal Agricultural Regionalization Committee Office, 1988), wrongly distinguished segments have been adjusted after the processing of classification such as recoding and filtering have been performed. With reference to native land use classification standard (Wu and Guo, 1994), image spectrum characteristics, and vegetation distributions, the whole studied area was classified into ten land use categories: conifer forest, broadleaf forest, mixed forest, shrub, grassland, sub-alpine meadow, farmland, built-up, water body, and bare land. The bare land represents sands, farmland and abandoned land without any plant cover. Definitions and composition of the land use classification are listed in Table 2. In order to distinctly describe and compare the distribution changes of the main land use categories, categories of conifer forest, broadleaf forest and mixed forest have combined into forests during the data analyses in this study.

Accuracy check has been taken according to local investigation through 300 checkpoints randomly selected from land use category maps of each period. To those points which could not be checked in field investigation, accuracy

Table 2 Definitions and components of the ten land cover types used in the present study (based on field investigation and vegetation map)

Land cover types	Definition and main components
Conifer forest	It includes warm-temperate conifer forests, such as *Pinus tabulaeformis* and *Platycladus orientalis*, and cold-temperate conifer forests, such as *Larix principis-rupprechtii*.
Broadleaf forest	It includes oak forests, valley shaws, *Tilia* forests, *Populus*& *Salix* forests and plantations in low elevation areas.
Mixed forest	It indicates broadleaf and conifer mixed forest, most of which consists of *Pinus*& *Quercus*.
Shrub	Secondary vegetation types with complex components, formed as human disturbance to primary forests. The main shrub types in Beijing include *Vitex negundo* var. *heterophylla*, *Spiraea*, *Corylus heterophylla*, *Prunus armeniaca* var.*ansu* and *Lespedeza*.
Grassland	An unstable vegetation type as primary vegetation was destroyed, mostly consisted with xerophilous herbages such as *Bothriochloa ischaemum* and *Themeda japonica*, some shrubs distribute in it occasionally.
Sub-alpine meadow	Distribute at top of slopes above 1800 m, mostly includes *Carex*, *Hemerocallis minor*, *Sanguisorba officinalis*, *Polygonum bistorta* and *Trollius chinensis*.
Farmland	Including large areas of cropland in the plain area and intercrop land in suburb.
Built-up	Including the built-up territory, rural residential areas and large buildings such as airports.
Water body	Including reservoirs, rivers, lakes and wetlands.
Bare land	Including light reflectivity areas such as no vegetation covered regions and wastelands.

assessment was made by composing images, local topography maps and vegetation distribution maps for reference. After the accuracy assessment using the Accuracy Assessment module of Erdas Imagine 8.5, the accuracy of the whole classification reached 76.3%.

Topography data of this study comes from 1/250000 topography maps of north China. With necessary logical operations and area statistics through the topography data (altitude, gradient and direction) and RS image processing results through ArcGIS 9.0 software, we obtained the distribution of each type of land cover at different relief conditions. The detailed data processing flow chart is shown in Fig. 1.

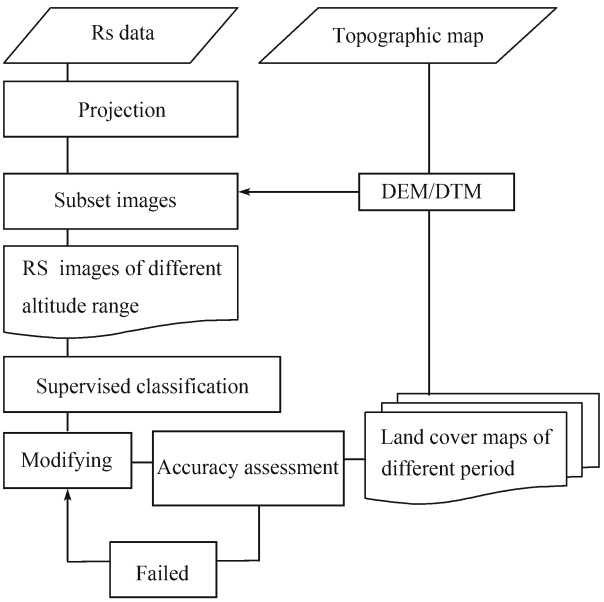

Fig. 1 Flow chart of data analysis

3.2 Analysis methods

3.2.1 Conversion probability matrix

In Erdas Imagine 8.5, the conversion probability matrix of land use types at each period was derived from spatial overlapping calculation to land cover maps at two connected periods (Shi et al., 2000). The causes of the process of land use changes were analyzed by the results. For the purpose of analyzing the intensity of the dynamics of land use changes, based on the conversion probability matrix, the conversion probability model was developed

$$D_{ij} = \frac{S_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} S_{ij}}$$

In this formula, S_{ij} represents the area of land cover type i changing to land cover type j; D_{ij} represents the probability of land cover type i changing to land cover type j; n represents the number of land cover types.

3.2.2 Relief-Area frequency distribution

Relief is one of the main reasons that lead to the difference in landscapes. In areas that have been impacted greatly by human settlement, topographic characteristics were usually the determining factors that controlled land use spatial distributions (Ispikoudis et al., 1993). In order to indicate the appearance frequency of land use types, and express the distribution characteristics of land cover types under different relief variable gradients such as altitude, slope and aspect, the area-frequency distribution P of all land cover types were calculated under different relief variable gradients

$$P = \frac{A_{ie}}{A}$$

In the formula, e represents the level of altitude, slope and aspect gradient; A_{ie} represents the area of land cover type i under some relief variable gradient e; A represents the area of the whole studied site.

From the above formula, area-frequency distributions were determined respectively under different relief variable gradients.

(1) Altitude-area frequency distribution: taking account of the vegetation distribution rules at different altitudes, as well as the changing characteristics of land use types in low plain areas, the altitude ranges were decided as six levels with sequence from low to high in the studied area, which are 0–100, 100–500, 500–800, 800–1000, 1000–1600, and above 1600 m.

(2) Slope-area frequency distribution: taking account of vegetation distribution characteristics in plain and mountainous areas in an integrated way, the slope range in the studied area was classified into nine levels: under 30° (every 5° was one level); from 30° –50° (every 10° was one level); and steeper than 50° was a level. As a result, all the levels were ranked as 0–5°, 5°–10°, 10°–15°, 15°–20°, 20°–25°, 25°–30°, 30°–40°, 40°–50° and $>50°$.

(3) Aspect-area frequency distribution: we took absolute north as 0°, and hillside was partitioned along the clockwise direction. Including flat areas, the whole studied area was divided into five parts: north aspect represents 0°–45° and 315°–360°; east aspect represents 45°–135°; south aspect represents 135°–225°; west aspect represents 225°–315°; and 0° represents flat area.

4 Results and discussions

4.1 Changing tendency of land cover categories from 1978 to 2001

4.1.1 Area changes

The land cover vegetation distributions in five periods are represented in Fig. 2. From the figure, the characteristics were concluded as follows.

(1) Great urbanization processes occurred mainly in the Haidian District, Chaoyang District, Tongzhou District, Shunyi District, and Changping District. The processes radiated from the urban core zones outwards, and the intensity gradually decreased with the increasing distance from the core zones.

(2) Forests mainly distribute in far suburbs in mountainous areas with higher elevation and relative stability, such as Huairou District, Miyun County, Yanqing County, and Mentougou District. Shrubs extensively spread around mountainous areas and comprise the main landscape with forests in mountainous areas. Grasslands extensively grow in front of the mountain belt and around valleys, forming a special transitional belt between natural vegetation and intensive human activity areas, and their area changed greatly at different periods.

(3) The farmland area has been shrinking and fragmentation is becoming aggravated.

In Fig. 3 and Table 3, all land cover category areas and percentages are shown at five periods. The outputs suggest the following. Dominative land cover categories include forests, shrubs, farmland, built-up and grassland, accounting for more than 90% of the total area. From 1978 to 2001, the most prominent changing tendency of land cover is the gradual decrease of the farmland area and the expanding of the built-up area. The forest area has a remarkable increase, and the coverage percentage rose from 17.2% to 24.7%. The increasing extent is more significant in the periods from 1984 to 1992 and 1996 to 2001, and has a little decline from 1992 to 1996. The shrub area apparently fluctuates in different periods and seems to have a declining tendency in mass; the area of grassland greatly changes also.

From the images at different periods, we can conclude that the urbanization process is the main cause that brings the

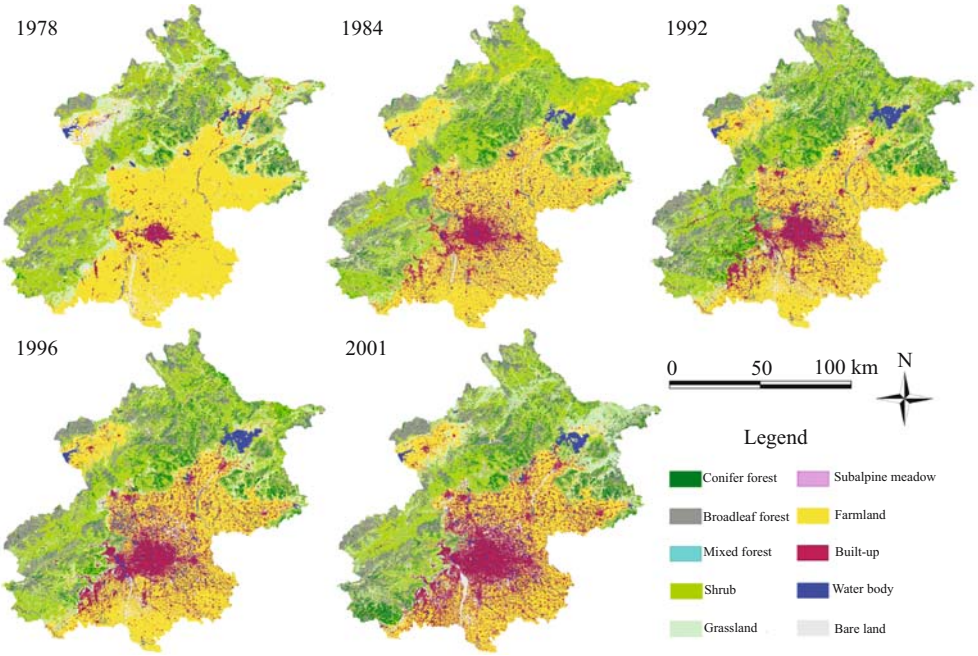

Fig. 2 Distribution of land cover types in Beijing from 1978 to 2001, interpreted from RS images

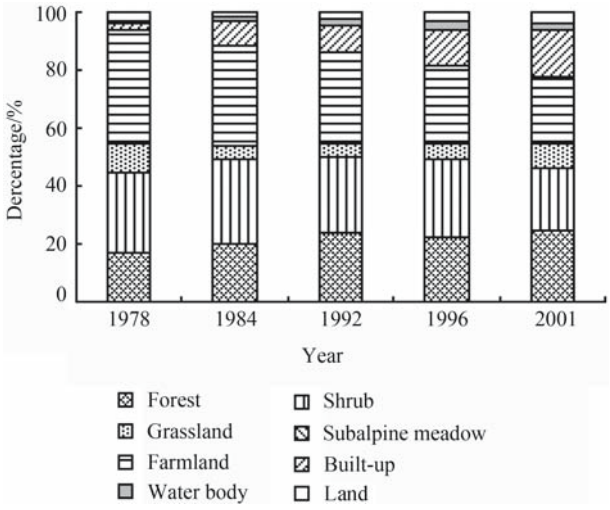

Fig. 3 Land cover changes in the Beijing area from 1978 to 2001

Table 3 Land cover change in the Beijing area from 1978 to 2001

Land cover types	Area /hm²					Transformation rate /(hm² · a⁻¹)
	1978	1984	1992	1996	2001	
Forest	283,117	328,771	389,395	369,518	403,680	5 023
Shrub	445,336	479,746	422,590	434,210	353,817	−3 813
Grassland	173,607	70,088	80,926	86,676	132,938	−1 695
Sub-alpine meadow	280	481	453	425	538	11
Farmland	635,433	564,999	509,021	449,898	381,271	−10 590
Built-up	42,116	136,483	147,100	199,549	264,229	9 255
Water body	16,272	27,522	40,337	44,571	33,688	726
Bare-land	45,173	28,841	39,581	51,779	65,045	828

changes of land use and land cover in the Beijing area. The study on the urbanization process indicates that urbanization is the integrated result of the population's adaptability to topography and communication as well as to outside driving factors such as economy, governance, and ideology (He et al., 2002). In the transitional belt between urban and rural areas, the conjunction promotes the changes of land use and land cover, that of the transfer of urban investment and industries and the instruction adjustment of rural farmland (Wang et al., 2002). On the other hand, in mountainous areas with fewer people, with the implementation of the ecological reconstruction policy in recent years such as the conversion of farmland back to forests, the conversion of farmland for ecological ways is the main cause that brings land use changes (Tian et al., 2003).

4.1.2 The conversion between land cover categories

The conversion probabilities of land cover types from 1978 to 2001 are listed in Table 4. As shown in the table, most areas were preserved in forests, shrub, sub-alpine meadow, farmland, and built-up areas during all periods. The unstable vegetation or land cover categories have large probabilities such as grassland, water body and bare land. From 1978 to 2001, the main changing tendencies of land cover occurred as follows.

(1) Farmland was being converted into built-up areas, which suggests the significant urbanization process. The situation was prominent especially from 1978 to 1984 and from 1996 to 2001, with probabilities of 15.8% and 20.1%, respectively. At the same time, for every period, there were some proportions of conversion occurring from built-up areas to farmland. These phenomena took place normally in the dispersing rural habitations near the transitional belts between urban and rural areas. This is probably the result of industrial structure optimization or production pattern conversion from the dispersing way to the intensive way (Gu, 1999).

(2) Except for the period from 1992 to 1996, the conversions from shrub to forests had a high proportion, and it coincided with the increasing trend of forested areas. It could be viewed as the result of afforestation and the conversion of farmland back to forests (Tian et al., 2003). In every stage, forests have high preservation proportion, which suggests effective achievement in forest conservation.

(3) Grassland is not a stable category. In every stage, grassland had great changes and mainly converted into shrub and farmland. Bare land also had significant changes and was mainly converted into farmland and built-up areas, which indicates that uncultivated farmland was its main composition.

4.2 The impacts of relief variables to land cover changes

The area-frequency distribution rules of land cover categories are shown in Fig. 4(a)–(c) under different relief variable gradients. The X-axes represents all relief variable gradients. As for the Y-axes, since the distance is large, we adopted a logarithm to the area percentage. The area-frequency curve suggests the frequency of a land cover category under different relief variable gradients and its proportion to the whole area.

4.2.1 The impacts of elevation to land cover category change

The main land cover and vegetation category distributions are shown in Fig. 4(a) in different elevation belt ranges at every stage from 1978 to 2001. From the charts, the distributions can be determined.

(1) The distributions of all land cover categories differ little at every stage. In areas below 100 m, farmland and built-up areas are the main land cover types. With the increase of elevation, their prominences are promptly substituted by shrub and forests. At 100–800 m, the distribution values of P have relatively small distances for all categories, which suggests that the relief condition is relatively suitable for all land cover types. In areas higher than 800 m, forests had prominence.

Table 4 Percentages of land cover transformation in the Beijing area from 1978 to 2001 (%)

Land cover types	Forest	Shrub	Grassland	Sub-alpine Meadow	Farmland	Built-up	Water body	Bare land
				1984				
1978								
Forest	78.3	18.3	1.0	0.0	1.0	0.5	0.1	0.7
Shrub	25.5	61.7	6.1	0.1	4.2	0.9	0.3	1.3
grassland	7.4	47.4	15.6	0.0	24.9	2.7	0.9	1.1
Sub-alpine Meadow	5.8	17.4	0.0	66.2	0.0	0.0	0.0	10.6
Farmland	3.4	3.8	1.5	0.0	70.8	15.8	2.4	2.4
Built-up	1.2	6.1	1.7	0.0	31.7	51.3	5.5	2.4
Water body	3.1	9.7	6.3	0.0	26.7	8.5	41.6	4.0
Bare land	1.4	3.3	5.2	0.4	75.3	8.0	1.0	5.4
				1992				
1984								
Forest	83.8	8.4	1.0	0.0	5.2	0.9	0.4	0.3
Shrub	18.5	70.4	7.2	0.0	1.7	0.9	0.7	0.6
Grassland	7.2	37.8	36.1	0.0	11.8	2.4	2.5	2.1
Sub-alpine Meadow	8.3	16.2	0.0	57.7	0.0	0.0	0.0	17.7
Farmland	2.4	4.9	2.6	0.0	73.6	9.3	2.7	4.5
Built-up	3.2	1.7	1.4	0.0	31.4	56.6	3.0	2.8
Water body	1.9	3.5	0.9	0.0	26.6	15.3	50.3	1.5
Bare land	13.0	10.2	5.7	0.0	34.2	13.5	2.4	21.1
				1996				
1992								
Forest	81.8	12.7	1.7	0.0	1.8	1.3	0.2	0.5
Shrub	8.3	80.4	7.6	0.0	2.2	0.5	0.2	0.8
Grassland	3.7	39.5	40.6	0.0	6.7	4.0	0.4	4.9
Sub-alpine Meadow	6.3	10.8	0.0	76.3	0.0	0.0	0.0	6.7
Farmland	1.5	1.0	1.4	0.0	77.1	13.2	2.1	3.7
Built-up	1.0	1.4	3.7	0.0	13.1	75.0	2.6	3.3
Water body	1.2	1.6	1.7	0.0	13.2	12.7	67.7	1.8
Bare land	1.1	5.0	4.0	0.1	27.3	15.6	2.1	44.8
				2001				
1996								
Forest	82.8	10.9	2.2	0.0	2.1	1.4	0.2	0.5
Shrub	16.3	66.6	14.1	0.0	1.7	0.3	0.1	1.0
Grassland	10.8	17.0	49.6	0.0	12.5	3.5	0.5	5.9
Sub-alpine Meadow	9.9	6.2	0.0	71.5	0.0	0.0	0.0	12.4
Farmland	2.4	1.4	2.6	0.0	66.5	20.1	1.6	5.4
Built-up	1.8	0.6	1.1	0.0	15.5	71.9	2.2	6.8
Water body	2.1	2.6	3.5	0.0	19.7	20.6	44.6	6.9
Bare land	4.7	2.9	10.6	0.8	31.5	23.1	1.3	25.0

(2) Shrub had the biggest frequency in ranges of 100 to 1000 m. The ranges are the extensive distribution areas of *Vitex negundo* var. *heterophylla* group shrubs. *Vitex negundo* var. *heterophylla* is one of the most extensive distribution shrub types in the mountainous areas of Beijing (Chen et al., 1990). The *P*-curve of shrub varies little in ranges of higher than 100 m, which means shrub is an extensive distribution vegetation type. The *P* value of forests increased rapidly in areas higher than 800 m, and is bigger than the values of other types, which suggests the conditions higher than 800 m are suitable for forest growth.

(3) Different kinds of forests had big differences in distributions at all elevation ranges. Broadleaf forest is the dominant type at all elevation ranges, and its frequency increases with the increase of elevation, and it has the biggest dominance in 1000–1600 m. Conifer forest has bigger frequencies in 500–800 m and in areas higher than 1600 m. The mixed forest area is the smallest and increases rapidly with the increase of elevation.

In the Beijing area, the forests are mainly plantations in the lower mountainous areas, and mostly consisted of *Pinus tabulaeformis* forests, *Platycladus orientalis* forests, and some planted broadleaf forests. In areas higher than 1000 m, the broadleaf forests mainly consist of *Quercus* forests and *Populu* forests. *Pinus tabulaeformis* forests and *Larix principis-rupprechtii* forests are the most common conifer forests types, and the latter are cold-temperate zone types and mainly distribute in areas higher than 1600 m (Chen et al., 1990). The vegetation distribution rules at different elevation ranges could suggest the detailed vegetation structure at these elevation ranges.

In Table 5, the reserved areas are listed as well as the percentages of main conversion type in the whole area. From the table, the characteristics could be concluded as follows.

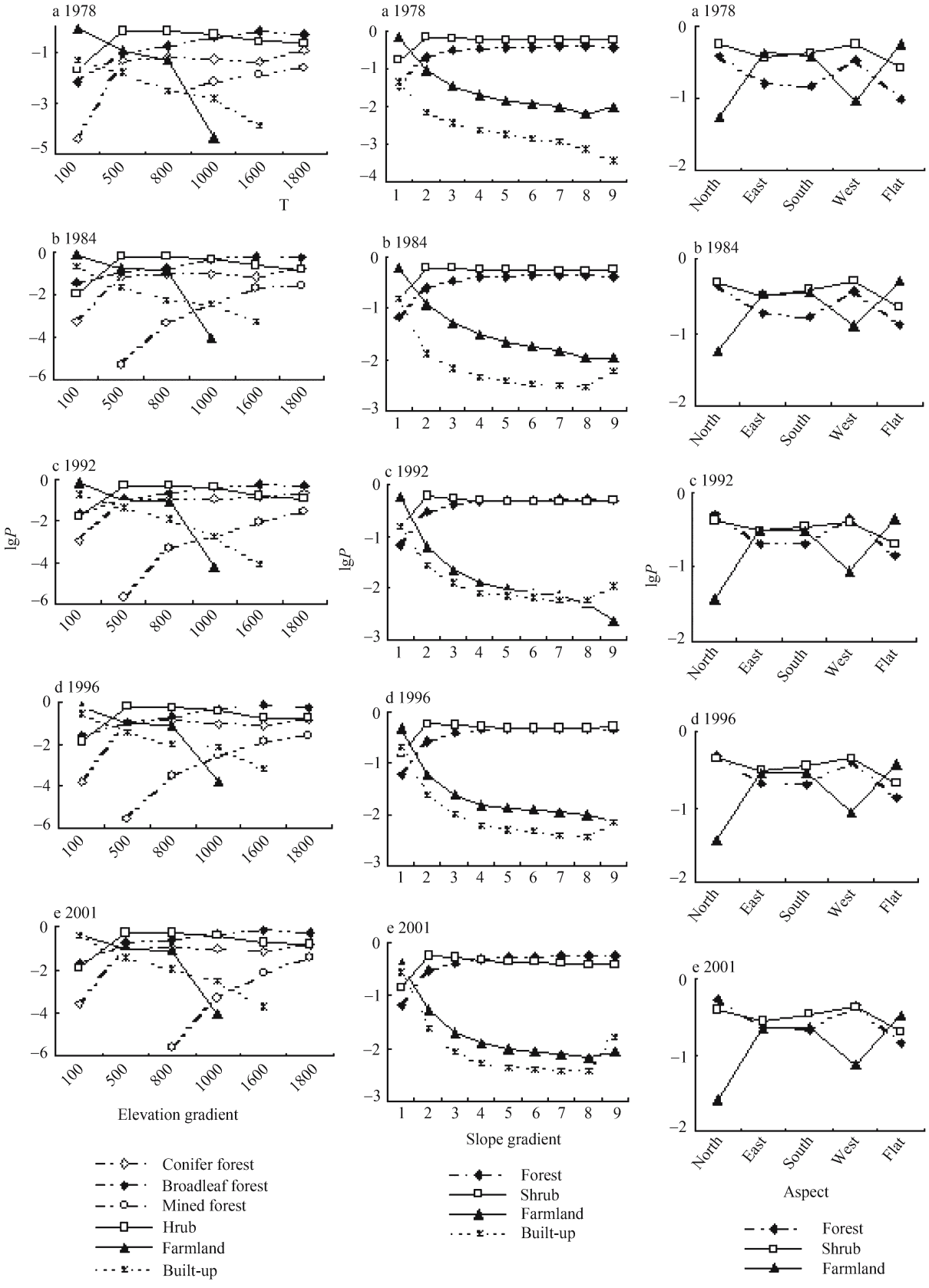

Fig. 4 The frequency-area distributions of land cover in different topographic conditions

Table 5 Land cover transformation in different elevation ranges in the Beijing area from 1978 to 2001

Total area /hm²	Change types	Transformation percentage/%			
		1978–1984	1984–1992	1992–1996	1996–2001
<100 m	Forest	0.3	0.4	1.0	0.5
637131	Shrub	0.5	0.5	0.8	0.6
	Farmland	65.0	57.1	53.5	40.4
	Built-up	3.2	11.2	15.3	20.5
	Farmland to built-up	15.5	6.6	10.3	13.5
	Built-up to farmland	1.5	6.5	2.6	4.3
100–500 m	Forest	10.1	16.0	18.6	17.3
440168	Shrub	47.0	46.8	50.6	46.5
	Farmland	5.3	6.0	6.0	5.1
	Built-up	0.6	0.6	1.3	1.4
	Shrub to forest	7.4	7.7	1.9	8.3
	Shrub to farmland	8.7	2.2	2.4	2.6
	Farmland to shrub	5.9	6.5	1.6	2.5
500–1000 m	Forest	20.7	29.8	34.5	34.2
463940	Shrub	45.0	42.8	42.6	40.4
	Farmland	2.3	5.4	5.4	4.2
	Shrub to forest	13.3	10.5	5.2	8.2
>1000 m	Forest	63.1	65.0	72.6	74.4
96136	Shrub	10.8	12.5	10.9	11.8
	Forest to shrub	7.6	2.9	5.7	5.1
	Shrub to forest	11.6	11.1	5.8	5.4

(1) The areas below 100 m account for 39.9% of the whole area, and are also where the greatest land use changes took place. The dominant land cover types are farmland and built-up areas. The most significant land cover change process is the conversion of farmland to built-up areas. The most remarkable stages are from 1978 to 1984 and from 1996 to 2001, with 15.5% and 13.5% relevant changed areas, respectively, which suggests prominent urbanization.

(2) The areas between 100 to 500 m account for 26.9% of the whole area, with shrub and forests mainly occupying the area. The most significant land cover change processes include the conversions of shrub to forests and farmland, and also farmland to shrub. From 1984 to 1992 and 1996 to 2001, the forested area had the most remarkable increase through the conversion from shrub to forests, which was probably due to the afforestation and conversion policies from farmland to forests in the Beijing area.

(3) The areas between 500 and 1000 m account for 28.3% of the whole area, which mainly consists of shrub and forests. The changing areas are much less in this belt and the changing tendency is mainly from shrub to forests. From 1978 to 1992, there was a relative higher conversion tendency from shrub to forest, and it had an important impact to the increase of forested area in this stage.

(4) In areas above 1000 m, which is only 5.87% of the whole area, forests were the most dominant land cover type. The conversions mostly occurred among forests and shrub. Since at every stage the conversion of shrub to forests has higher frequency than the reverse, it shows that forest conservation at higher elevation regions is good.

4.2.2 The impacts of slope to land cover category change

In Fig. 4(b), the *P*-curves are determined which represent the changes of forests, shrub, farmland, and built-up areas along nine slope classes. At 0°–5° class, the greatest frequencies belong to farmland and built-up areas. As the slope classes increase, shrub and forests have more and more frequencies. The changing tendencies of all the land cover categories along slopes are described as follows.

(1) Both the *P*-values of farmland and built-up areas decrease significantly with the increase of slope.

(2) Shrub has the biggest frequencies at 5°–15° slope range, and then its frequency declines with the increase of slope.

(3) Forests have consistent increasing frequencies with the increase of slope, and have the dominance at areas steeper than 25°. The *P*-value distances of forests increase along with that of shrub, which indicates that the area proportion of forests keeps increasing with the increase of slope. This phenomenon suggests that forests grow much better in steeper areas and is probably related to the lesser disturbance from human activities.

The area percentages of land cover category reserved areas and changed area in the slope range are listed in Table 6 in terms of ranges of 0°–5°, 5°–10°, 10°–20° and >20°. The main characteristics are concluded as follows

(1) An area of 54.8% of the whole studied site was classified into the slope range of 0°–5°. The dominant land cover categories include farmland, built-up areas and shrub. The land cover changes are complex in the area and the most significant change is from farmland to built-up areas.

Table 6 Land cover transformation along slope gradient in the Beijing area from 1978 to 2001

Total area /hm^2	Change types	Transformation percentage/%			
		1978–1984	1984–1992	1992–1996	1996–2001
0–5°	Forest	2.3	3.4	4.4	3.6
897 107	Shrub	10.4	10.6	11.9	11.0
	Farmland	49.2	45.4	42.8	32.7
	Built-up	2.3	8.4	11.9	15.5
	Others	9.8	10.2	12.2	14.8
	Shrub to forest	1.6	1.5	0.6	1.4
	Farmland to built-up	11.1	5.5	7.4	10.0
	Built-up to farmland	1.4	4.7	2.1	3.4
5°–10°	Forest	14.7	20.4	24.2	22.9
115 164	Shrub	49.7	48.9	51.2	49.7
	Farmland	3.4	3.6	3.8	2.6
	Forest to shrub	5.1	3.0	4.9	4.8
	Shrub to forest	9.6	8.5	4.0	7.2
	Shrub to farmland	7.1	1.9	1.6	1.7
10°–20°	Forest	23.8	32.6	37.4	36.7
330 572	Shrub	46.5	44.8	45.1	43.1
	Farmland	0.8	0.8	1.0	0.6
	Forest to shrub	9.0	3.3	5.2	5.1
	Shrub to forest	12.3	10.7	5.6	8.8
>20°	Forest	28.9	37.9	43.3	42.5
294 534	Shrub	43.4	41.0	41.1	36.9
	Farmland	0.2	0.3	0.5	0.3
	Forest to shrub	9.8	3.7	6.5	5.5
	Shrub to forest	12.9	11.8	4.4	10.6

(2) The 5°–10° slope range covers about 7% of the total studied area, and the main land cover types are shrub and forests. The dominant land cover change processes are the mutual conversions between forests and shrub, as well as shrub to farmland. Except from 1992 to 1996, the converted area of shrub to forests is larger than the reverse, through which the forests area increased.

(3) The 10°–20° slope range covers about 20.2% of the studied area, and the main land cover types are still shrub and forests. The dominant land cover change processes are the mutual conversions between these two categories. From 1978 to 2001, the forest area increased greatly, except for a small decline from 1992 to 1996.

(4) About 18% of the studied area belong to slope ranges steeper than 20°, most of which are covered with forests and shrub. The dominant land cover change process is from shrub to forests.

4.2.3 The impacts of the aspect to land cover category change

The impacts of the aspect on vegetation distribution mainly come from the growing conditions of sunlight, water and so on. It has a smaller impact to built-up areas. In Fig. 4(c), the *P*-value changes of forests, shrub and farmland with aspects are reflected at different stages. The charts show that aspect has a great impact on the distributions of the three land cover categories. The east aspect, south aspect and flat land have small distances of *P* values, which suggests that the three kinds of conditions are suitable to those land cover categories. Comparatively, forests and shrub have larger frequencies at the north and west aspects. Farmland has the biggest frequency in flat areas.

The area percentages of land cover category reserved areas and changed areas at all aspects from 1978 to 2001 are listed in Table 7. The main characteristics are concluded as follows.

(1) Only 6.6% of the studied area is at the north aspect, and the main land cover categories are forests and shrub. In all stages, the forest area keeps increasing. The most significant land cover changes are the mutual conversions between shrub and forests. Except from 1992 to 1996, the frequencies of shrub conversion into forests are greater than the reverse.

(2) The east aspect has about 25.1% area of the total studied site. Shrub and farmland make up the main landscape; forests have some proportion as well. In these areas, the land use changes are not significant.

(3) The south aspect covers about 22.4% of the studied area. Shrub, farmland and forests consist the main landscape. Among them, forests have the biggest increasing tendency.

(4) The west aspect covers about 12.7% of the studied area. The landscape mostly consists of forests and shrub. The significant changing types are the conversions between both of them.

(5) Flat areas have the biggest area with a proportion of about 33.2%. The dominant land cover categories are shrub

Table 7 Land cover transformation in different aspects in the Beijing area from 1978 to 2001

		Transformation percentage/%			
Total area /hm^2	Change types	1978–1984	1984–1992	1992–1996	1996–2001
North	Forest	29.0	38.9	43.8	43.5
108 398	Shrub	37.1	35.6	36.7	34.0
	Farmland	2.3	2.5	2.4	1.5
	Built-up	0.1	0.3	0.3	0.2
	Others	1.7	2.4	2.2	2.1
	Forest to shrub	8.8	3.9	6.4	4.9
	Shrub to forest	13.8	11.2	4.1	8.9
East	Forest	11.2	15.2	17.1	17.2
410 363	Shrub	26.6	26.7	27.3	24.5
	Farmland	28.6	25.6	25.2	18.3
	Built-up	0.9	3.4	1.3	1.5
	Others	5.3	6.6	6.7	7.8
	Forest to shrub	4.0	2.1	2.9	2.6
	Shrub to forest	6.1	4.3	2.7	5.3
South	Forest	9.8	13.7	16.5	15.5
366 444	Shrub	31.8	30.7	31.3	29.4
	Farmland	27.5	25.6	25.7	19.5
	Built-up	1.2	2.4	0.9	1.7
	Others	5.1	6.7	6.4	7.4
	Forest to shrub	4.4	1.7	3.3	3.4
	Shrub to forest	5.5	5.5	2.7	4.9
West	Forest	23.9	32.5	38.1	36.1
208 626	Shrub	37.8	35.1	34.0	35.2
	Farmland	6.0	6.8	6.3	5.1
	Built-up	0.1	0.3	0.3	0.5
	Others	2.2	2.9	3.5	3.6
	Forest to shrub	9.5	2.7	6.4	5.3
	Shrub to forest	11.5	11.9	3.3	7.6
Flat	Forest	6.8	9.4	11.1	10.3
543 546	Shrub	16.1	15.8	17.3	16.3
	Farmland	39.6	36.7	33.0	25.8
	Built-up	1.2	5.7	8.5	11.8
	Others	8.9	9.5	12.2	14.6
	Shrub to forest	3.7	3.5	1.2	2.7
	Shrub to farmland	5.0	1.3	1.1	1.4
	Farmland to built-up	8.4	4.7	6.8	7.1
	Built-up to farmland	1.2	3.6	1.8	3.2

and farmland, while forests and built-up areas are posterior to them. The changes of land cover are relatively complex. The significant one is urbanization, which is the conversion from farmland to built-up areas.

5 Conclusions

Land cover changes are integrated impacts of natural conditions such as relief, climate, soil and so on, as well as socio-economic factors such as urbanization, traffic and so on. Among them, the relief condition is one of the primary natural factors that can decide the changes of land cover in the Beijing area. Nevertheless, because of the complexity of the relief conditions in Beijing, as well as the relatively simpler land cover changes than in the plain area, the studies on land use and cover changes using relief conditions is uncommon.

In recent years, some researches studied the relationship between land use and topographic types through multi-period RS images and small-scale topographic maps (Tian et al., 2003). The results indicated that the greatest changes on land use and land cover takes place at plain areas that have been strongly impacted by human activities; while the disturbance is relatively smaller in highlands and mountainous areas, the land use changes are smaller as well. However, as for the small-scale, the topographic types could not be classified in detail. As a result, the changing tendencies of land use types could not be analyzed deeply. Some studies also analyzed the relationship between land use changes and topographic conditions in partial areas (Sun et al., 2004). However, the study scopes are usually small and the time spans are short. This study acquired the following conclusions based on quantitative studies of land cover changes in the whole Beijing area through studying multi-period RS images and middle-scale topographic maps.

(1) Shrub, forests, farmland, and built-up areas are the main land cover categories in the Beijing area. From 1978 to 2001, the forest area kept increasing variably, with coverage increasing from 17.2% to 24.7%. The significant changes are the shrinking of farmlands in plain areas and the expanding of built-up areas. The analyzed results of conversion matrix to main land cover categories indicated the following: major areas of main land cover categories were reserved; the most significant changing trends were the conversions from farmland to built-up areas and shrub to forests, which suggested the fast urbanization process and afforestation.

(2) Altitude has a deep impact on distribution of land cover categories. In areas with elevations lower than 100 m, farmland and built-up areas are the main land cover types; while in areas above 100 m, shrub and forests are the main land cover types. Shrub has the biggest frequency in 100–1000 m range, and forests have dominance in areas above 800 m. The analyzed results of different elevation ranges indicated that urbanization is the key land cover change in areas below 100 m. In areas above 100 m, main land cover changes are the conversion from shrub to forests, and it is the primary area that the forests area increased. The distribution rules of the vegetation types based on altitude also reflect the vegetation compositions in different elevation ranges.

(3) Slope has a great impact on land cover categories. Built-up areas and farmland distribute in areas with slopes smaller than 5°. In areas with slopes higher than 5°, shrubs have extensive distribution. Forests have more distribution frequencies with the increasing of slope and have dominance in areas with slopes steeper than 25°. The analyzed results to land cover changes at different slope ranges indicated that 0°–5°range is the area with the most significant land cover changes and the changes are mainly urbanization. There are two remarkable stages: one is from 1978 to 1984, and the other is from 1996 to 2001. In other ranges, the remarkable conversion occurred as shrub to forests.

(4) The aspect has a big impact on the distribution of vegetation and farmland. Forests and shrub mainly distribute at the north and west aspects; while farmland mainly distribute at the east aspect, south aspect, and flat areas. The biggest land cover change took place in the flat areas, with the main conversion from farmland to built-up areas.

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References

Beijing Municipal Agricultural Regionalization Committee Office (1988). Beijing Agricultural Resources and Regionalization Atlas. Beijing: Surveying and Mapping Press, 57–68 (in Chinese)

Chen L Z, Bao X C, Chen A L, Hu Y H, Kong F Z, Miu Y G (1990). Study on vegetation ecology in Tianjin and Beijing region. In: Institute of Botany and Institute of Zoology, eds. Study on the Biology and Ecology in Tianjin and Beijing Region. Beijing: Marine Press, 1–14 (in Chinese)

Chen L Z, Bao X C, Li C G (1963). Characteristics of vegetation and their relations with forestry and side-production in mountain areas in Huairou, Beijing. Acta Phytoecologica et Geobotanica Sinica, 3: 75–96 (in Chinese)

Department of Biology, Beijing Normal University (1958). Vegetation of Shangfangshan and Its Utilization. Beijing: Beijing Normal University Press (in Chinese)

Gu Z L (1999). Study on phenomena and mechanism of land use/cover change in Beijing. Journal of Natural Resources, 14: 307–312 (in Chinese)

He C Y, Shi P J, Chen J, Zhou Y Y (2001). A study on land use/cover change in the Beijing area. Geographical Research, 20: 679–687 (in Chinese)

He C Y, Shi P J, Chen J, Xu X L (2002). Process and mechanism of urbanization in the Beijing Area. Acta Geographica Sinica, 57: 363–371 (in Chinese)

Huo Y Z, Yang Z M, Meng D Z (1989). Physical Geography in Beijing. Beijing: The Publishing House of Beijing Normal College (in Chinese)

Imbernon J (1999). Pattern and development of land use changes in the Kenyan highlands since the 1950s. Agriculture, Ecosystems and Environment, 76: 67–73

Ispikoudis I, Lyrintzis G, Kyriakakis S (1993). Impact of human activities on Mediterranean landscape in western Crete. Landscape and Urban Planning, 24: 259–271

Land Environmental Protection Department of Beijing Municipal Planning Committee (1988). Land and Resources of Beijing. Beijing: Beijing Science and Technology Press (in Chinese)

Li J D, Li B, Yang C (1959). Vegetation of Beijing. Journal of Peking University, 5(2): 397–406 (in Chinese)

Li X B (1996). A review of the international researches on land use/land cover change. Acta Geographica Sinica, 51: 553–558 (in Chinese)

National Bureau of Statistics of China (2001). China Statistical Yearbook 2001. Beijing: Statistics Press

Qi Y, Henderson M, Xu M, Chen J, Shi PJ, He CY, William S G (2004). Evolving core-periphery interactions in a rapidly expanding urban landscape: The case of Beijing. Landscape Ecology, 19: 375–388

Ramankutty N, Foley J A (1999). Estimating historical changes in land-cover: North American croplands from 1850 to 1992. Global Ecology Biogeography, 8: 381–396

Reid R S, Kruska R L, Muthui N , Taye A, Wotton S, Wilson C J, Mulatu W (2000). Land-use and land-cover dynamics in response to changes in climatic, biological and socio-political forces: The case of southwestern Ethiopia. Landscape Ecology, 15: 339–355

Shi P J, Gong P, Li X B (2000). Methods and Practice of Land Use/ Cover Change. Beijing: Science Press (in Chinese)

Sun L, Chen H W, Pan J W (2004). Analysis of the land use spatiotemporal variation based on DEM, Beijing Yanqing Country as an example. Journal of Mountain Science, 22: 762–766 (in Chinese)

Tian G J, Zhang Z X, Zhou Q B, Zhao X L, Wang C Y, Liu B, Tan W B (2003). Research on dynamic Land-use pattern of Beijing by Remote Sensing and GIS. Remote Sense Information, 1: 7–10 (in Chinese)

Turner B L, Meyer W B (1991). Land use and land cover in global environmental change: Considerations for study. International Social Science Journal, 130: 669–680

Turner B L, Moss R H, Skole D (1993). Relating Land Use and Global Land Cover Change: A Proposal for an IGBP-IHDP Core Project. International Geosphere-Biosphere Program Report No.24, Stockholm

Turner B L, Skole D, Sanderson S (1995). Land Use and Land Cover Change (LUCC) Science/ Research Plan. IGBP Report, No.35, Stockholm

Wang J A, He C Y, Dong Y C, Gao L, Xu W (2002). Analysis of land use/cover driving forces in the urban fringe of Beijing City. Advance in Sciences, 17: 201–208 (in Chinese)

Wu C J, Guo H C (1994).Chinese Land Use. Beijing: Science and Technology Press