Analysis of Agricultural Cultivation Based on a New Landscape Expansion Index: A Case Study in Guishui River Basin, China

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Abstract

Agricultural cultivation is always a global hot topic in agricultural and environmental sciences. The process of agricultural cultivation in Guishui river basin, China from 1978 to 2009 was studied based on landscape ecology principles with six Landsat images. A new landscape expansion index (LEI) was proposed to quantitatively indicate expansion size of farmland patches, and identify their spatial expansion patterns (adjacent expansion pattern and external expansion pattern). The primary conclusions were as follows. First, the expansion patterns of most expanding farmland patches were adjacent expansion pattern for approximately 30 years, whereas the number of adjacent and external expansion pattern patches fluctuated. Second, the values of LEI primarily distributed in the interval of (-1,-0.8), demonstrating that the spatial expansion pattern of farmland patches were largely adjacent expansion pattern on a small scale. Third, values of LEI tended to decrease overall as the expansion scale of farmland was gradually reduced.

Keywords: Agricultural cultivation, Landscape expansion index, Expansion size, Expansion pattern, Guishui river basin, China

1. Introduction

The issue of food and population has always been a serious global problem. With the continuous growth of the world population, the issue on food has worsened (Fancy et al., 2008; Delind & Howard, 2008). To meet the need for survival, large areas of wetlands, woodlands, and grasslands have been converted into farmland (Jaisawal et al., 1999; Keys & McConnell, 2005; Allen & Wilson, 2008). Land reclamation from lake marshes and deforestation were especially widespread in some underdeveloped areas (Chaudhary et al., 2008; Kashaigili & Majaliwa, 2010). Consequently, a series of ecological and environmental problems emerged, including soil erosion, diminishing fertility, ecosystem disturbance and biological diversity decline (Zhang et al., 2011; Mundia & Aniya, 2006; Chen et al., 2008; Prasad et al., 2010; Liu et al., 2011). Related research shows that the combined effects of anthropogenic and natural factors highlighted agricultural cultivation as a problem that seriously affects local ecological environment, especially in some ecologically sensitive areas (Pimentel et al., 2009).

A large number of studies on the process of agricultural cultivation have been conducted (Maclean 2009; Schroth & McNeely, 2011). However, previous studies only focused on the changes in area, spatial position, and spatial structure (Fu & Chen, 2001; Cassano et al., 2009). These studies mainly carried out through compare of farmland data with a long time series, which have certain significance for protecting regional land resource, understanding climate change and realizing sustainable development. However, a long time series analysis is only compare of the amount of farmland in different periods, only reflect the increase or decrease of farmland area, researches on this change process is insufficient, especially because only a limited number of studies have been devoted to the spatial expansion patterns of farmland. And yet, expansion as an important ecological process, different patterns will inevitably lead to dissimilar impact on ecological environment (Turner, 1990), so studies on farmland expansion patterns are very important to solve and mitigate environmental problems caused by agricultural cultivation.

Landscape ecology principles are indispensable in the studies of farmland expansion patterns and have been widely used in agricultural cultivation studies. However, previous studies were mainly focused on landscape patterns and primarily conducted by comparing multi-temporal landscape pattern indices (Zhao et al., 2009; Wang et al., 2009a). These studies were essentially comparisons of static information, but expansion pattern is the expression of dynamic progress, being unable to realize the farmland expression patterns. In order to study landscape expression patterns, Liu et al. (2009; 2010) successively proposed two similar landscape expansion indices, values of LEI were used to identify landscape expression patterns, but they have a drawback in identifying farmland expression patterns. The minimum rectangle bounding box and the buffer area of the expansion patch were the statistical units. The areas of the expanding patch, original patch, and blank district within the statistic units were the primary parameters of the two LEIs' equations. The problem is that the shape of expanding patch affects the shape of the minimum rectangle bounding box and the buffer areas, thereby affects the areas of the expanding patch, original patch, and blank district within statistic units. So, a fixed expanding area may has lots of LEI values because there are lots of expanding patches with different shapes that their expanding area are equal, and the method of using values of LEI to identify farmland expansion patterns is inaccurate.

Hence, a new LEI based on patch expanding area was proposed in this study. Six Landsat images from 1978 to 2009 were taken as bases to study the process of agricultural cultivation in the area of study. The goals are to display quantitatively the dynamic expansion process of farmland in the study area, and to identify the spatial expansion patterns of farmland. The Guishui river basin is an important ecological barrier and water source located in the northwest part of Beijing. It is experiencing drought, rare vegetation, and serious soil erosion. It is also a sand source around Beijing, so it severely constrains the development of Beijing City and its neighboring areas (Wang et al., 2009b). In the last 10 years, this area showed the tendency to dry, and the water area of the Kwanting reservoir in the study area was progressively reduced, whereas farmlands unceasingly expanded. The study on the process of agricultural cultivation is propitious to investigations on changes in the environment of the study area and supports the improvement of the ecological environment.

2. Methods

2.1 Expression of Landscape Expansion Patterns

A landscape expansion pattern depends on the spatial combination rule of landscape elements, whereas the spatial combination forms of landscape elements play an important role in various ecological processes (McNeely & Schroth, 2006). As a result, landscape spatial expansion pattern is significant for understanding the landscape expansion process (Turner, 1989). Forman (1995) divided the spatial processes of landscape pattern dynamics into perforation, dissection, fragmentation, shrinkage, and attrion, which were primarily used for spatial processes in terms of landscape degradation. He also divided spatial patterns over time into the edge, corridor, nucleus, nuclei, and dispersed patterns. These patterns described the conversion from the original to the new patch type rather than the expansion of the same landscape, which has limitations in expressing the process of landscape expansion.

Currently, related studies on the spatial expansion pattern primarily focus on the urban expansion field. Zhang et al. (2010b) concluded that the expansion patterns of urban construction land are the padding (Figure 1a), spreading (Figure 1b), and leaping patterns (Figure 1c). Liu et al. (2009; 2010) also categorized spatial expansion patterns into three: the padding (Figure 1a), marginal (Figure 1b), and enclave patterns (Figure 1c). In fact, the internal padding (Figure 1a) and marginal expansion patterns (Figure 1b) are forms of adjacent expansion pattern. The difference between these two patterns lies in the direction of expansion, which is either inward or outward. Changes in patch number and area are the direct reflection of different expansion patterns; the adjacent expansion pattern increases the patch area, whereas the external expansion pattern increases the patch number. Consequently, spatial expansion patterns are classified into adjacent (Figure 1a and Figure 1b) and external expansion patterns (Figure 1c) in the present study, depending on whether the expanding patch is adjacent to the original patch or not.

2.2 Definition and Implementation of LEI

LEI is the quantitative expression of the landscape expansion scale, so more attention should be given to the effect of the expanding patch area on LEI. The Equation for LEI is shown as Equation (1):

$$\text{LEI} = \frac{A_p - A_0}{A_p + A_0} \tag{1}$$

where LEI is the landscape expansion index, A_P is the area of the newly expanding patch, and A_0 is the area of the original patch that is adjacent to the newly expanding patch.

The spatial expansion patterns of patches can be correctly distinguished using the value range of LEI, which is (-1,1] as calculated from Equation (1). The landscape expansion pattern will only be an external expansion pattern when A_0 equals 0 and LEI equals 1, that is, no patch is adjacent to the newly expanding patch, similar to expanding patches 1, 2, and 3 that are shown in Figure 2c. The landscape expansion pattern is an adjacent expansion pattern when the LEI equals other values, similar to expanding patches 4 and 5 that are shown in Figure 2b. Within (-1,1), a larger value of LEI results in a larger expanding area compared with that of the original patch and hence a relatively larger patch expansion scale. The area of the newly expanding patch is smaller than that of the original patch when the LEI is less than 0, the two areas are equal when the LEI equals 0, and the expanding area is larger than that of the original patch when the LEI is greater than 0. As shown in Figure 2b, expanding patch 4 has the following values: A_0=554,882 m^2, A_P=4,951,076 m^2, LEI=-0.993; and expanding patch 5 has the following values: A_0=3,892 m^2, A_P =341,924,057 m^2, LEI=0.878.

The LEI quantitatively expresses the landscape expansion process at the patch level. The LEI of the class level (MLEI) is used to express the landscape expansion process of the class level, the Equation for which is Equation (2):

$$\mathrm{MLEI} = \sum_{i=1}^{n} \mathrm{LEI}_i / n \tag{2}$$

where MLEI is the landscape expansion index at the class level, and LEI$_i$ is the LEI for the *i*th expanding patch, whereas n is the number of all expanding patches of this class.

The value range of MLEI also is (-1,1], which can be seen from Equations (1) and (2). The spatial expansion pattern was demonstrated to have an external expansion pattern when the MLEI equals 1. These patterns may all be adjacent expansion patterns or a combination of two kinds of spatial expansion patterns when the MLEI equals other values. MLEI can only reflect the spatial expansion process of a class to a certain extent. Normally, a larger MLEI results in a greater number of patches having an external expansion pattern. The spatial expansion scale of this class will also be greater under the condition that the numbers of all expanding patches and patches with external expansion pattern are all roughly equal.

LEI and MLEI define the landscape expansion progress considering only a single expanding patch and without considering the status and function of the single expanding patch in the entire class. Therefore, the Equation for the area weighted average landscape expansion index (AWLEI) defined in the current study is as follows:

$$\mathrm{AWLEI} = \sum_{i=1}^{n} (\mathrm{LEI}_i * \frac{a_i}{A}) \tag{3}$$

where AWLEI is the area weighted average landscape expansion index, LEI$_i$ is the LEI for the *i*th expanding patch, a_i is the area for the *i*th newly expanding patch, A is the total expanding area of the class, and n is the number of all expanding patches.

The value range of AWLEI is also (-1,1], as can be seen from Equation (3), demonstrating that one expanding patch exists, and its spatial expansion pattern is an external expansion pattern when the AWLEI equals 1. Within (-1,1), the expansion process of the entire class is complex, and the number of expanding patches, the expanding area, and the spatial expansion patterns all affect the value of the AWLEI. Generally, a greater AWLEI results in less expanding patches, a greater expanding area, and a greater number of patches with an external expansion pattern. AWLEI can express the spatial expansion process at the class level to a certain extent, and a larger AWLEI results in a greater spatial expansion scale of this class.

LEI was proposed in the current study because of its easy calculation and implementation, wherein only ArcGIS is required for simple spatial analysis and statistics. First, two periods of farmland distribution maps underwent “Erase” to extract the area and spatial distribution information of newly expanding patches. Then these newly expanding patches were connected with the late and early distribution maps respective using “Spatial join” to obtain the area of the patches that is adjacent to the newly expanding ones. Lastly, the attribute table of the map was exported to DBF, and LEI, MLEI, and AWLEI were calculated using EXCEL.

3. Study Area and Data Sources

3.1 Study Area

The study area is the Guishui river basin located in the northwest of Beijing, in the northern part of the North

China Plain. The major administrative areas at the county level include Yanqing County of Beijing City and Huailai and Zhuolu Counties of Zhangjiakou City, Hebei Province, and ranges from 39°32′13″N to 41°8′6″N and from 114°55′19″E to 116°37′37″E with an estimated area of 2,387 km^2, whereas the altitude is between 469 and 2,381 m. The specific position is shown in Figure3. The edge of the study area has a high altitude and is primarily hilly, with a low altitude in the central portion, which is a plain, wherein Kwanting reservoir is located. The climate is temperate continental monsoon. During the winter, this area is affected by high pressure from Mongolia, so the northerly wind prevails, and the weather is cold and dry. During the summer, the weather is controlled by continental low pressure, and the southerly wind prevails, making the weather hot and rainy. Mean temperature is approximately 9 °C and mean rainfall is 470 mm mostly in the summer months (from June to August).

3.2 Basic Data and Process

Six Landsat images, which were collected in 1978, 1987, 1993, 1998, 2004, and 2009, were used as basic data for the current study. Data for 1987, 1993, 1998, 2004, and 2009 were TM (Thematic Mapper) images, except for that of 1978, which was an MMS (MultiSpectral Scanner) image. Images were primarily collected in September and October because rainfall is reduced and weather conditions are good during this period. The cloudiness was always less than 5% when the images were collected, enhancing the interpretation of farmland information.

The original images were processed using band combination, enhancement, geometric correction, clipping, and other pretreatments, after which the images of the study area were obtained. Beijing vector stream data with projection of Gauss Kruger and geographic coordinate system of GCS_Krasovsky_1940 is regarded as reference data in the process of geometric correction, and the error is within 0.5 pixel. Visual interpretation and decision tree classification methods were adopted, and farmland information from the six images was abstracted with field surveys, interviews, Google Earth, statistical annuals, and other tools. The farmland in the current study contained paddy fields, dry land, field trees, field roads, and acequia, among others (Peng et al., 2006). First, visual interpretation of the TM images from 2004 to 2009 was conducted using field survey results and high spatial resolution images from Google Earth. For the areas that cannot be analyzed using visual interpretation, the current study employed decision tree classification to categorize uncertain areas based on the study on the farmland spectrum of the area during autumn as done by Gong et al. (2007); the farmland distribution figures for 2004 and 2009 were then obtained. These figures were used as bases, and other images were interpreted using the same method. The results of interpretation were sample-surveyed using statistical yearbooks, county annals (compiled Committee of Yanqing County annals 2006), and land-use maps with 100 m spatial resolution in 1980 and 2005, which were downloaded from the Earth System Science Data Sharing Platform (http://www.geodata.cn/Portal/?isCookieChecked=true). The survey results showed that the accuracy of farmland interpretation was more than 90%, which satisfied the accuracy requirement.

4. Results and Discussions

4.1 Calculation of LEI

LEI was used to study the process of land conversion from natural landscape into farmland with six remote sensing images, the study period was divided into five intervals: 1978 to 1987, 1987 to 1993, 1993 to 1998, 1998 to 2004, and 2004 to 2009. A large expansion of farmland occurred from 1978 to 2009, and the increased area in different intervals fluctuated with a decreasing trend of increasing extent, and a large proportion of the increased area was expanded by an adjacent expansion pattern (Table 1). The spatial distribution of expanding farmland is shown in Figure 4, and the LEI of each expanding patch during each time interval was computed according to the equation (1) mentioned in Section 2.2 (definition and implementation of LEI), and the results are shown in Table 2.

4.2 The Dynamics of Farmland Expansion Patterns

The spatial expansion pattern of farmland was primarily an adjacent one, whereas adjacent and external expansion patterns tended to fluctuate in the five time intervals (Table 2 and Figure 5). In these five time intervals, the number of patches with an adjacent expansion pattern was 504, 615, 613, 650, and 646, respectively, which accounted for 98.05%, 99.03%, 98.39%, 97.74%, and 99.23% of the total number of expanding patches, respectively, and tended to increase first and then decrease, and finally increased again. The number of patches with an external expansion pattern was 10, 6, 10, 15, and 5, separately, accounting for 1.95%, 0.97%, 1.61%, 2.26%, and 0.77%, respectively, initially showing a decrease, followed by an increase, and then finally a decrease. The variation tendencies of the two patterns were opposite (Figure 5).

The number of patches with an external expansion pattern decreased over approximately 30 years but increased between 1998 and 2004. This result attributed to the land consolidation of this area in Yanqing County since

1998, during which 64,000 Mu farmland has been reclaimed after 1998 (http://finance.stockstar.com/JL2007071200093780.shtml). The expansion of farmland was primarily located in the surrounding areas of the Kwanting reservoir within the study area and in the transition zone between the plain and mountain. This expansion was achieved by readjusting barren mountains, hills, shoals, and ditches. After 1998, the climate tended to be dry, and the water area of the Kwanting reservoir was dramatically reduced (Zhang et al, 2010a), resulting in the change of a large water area into farmland. These processes increased the proportion of the external expansion pattern in the spatial expansion pattern of farmland.

Meanwhile, this time interval was also the period with the largest number of patches with adjacent and external expansion patterns because both were mutually affected by anthropogenic and natural factors. The time interval with the least number of patches with an adjacent expansion pattern was from 1978 to 1987 (Table 2 and Figure 5). The working condition at this time interval was comparatively not well developed, and capacity for transforming nature was limited. However, the average increased area of each patch is the largest among the five time intervals (Table 1). Actual areas were compared with remote sensing images, and the increased area was found to be primarily expanded based of the original patches with a large scale and small number. The time interval with the least number of patches with an external expansion pattern was from 2004 to 2009, this time interval was the latest in the study period, during which lands suitable for reclamation were insufficient, resulting in a condition unsuitable for a wide external expansion pattern range. Furthermore, marginalization of farmland caused by population and economic factors was also a reason (Liu & Li, 2005). As a result, this time interval has the least number of patches with an external expansion pattern.

4.3 The Dynamics of LEI

LEI is the quantitative expression of the expansion scale of the patches. It was primarily distributed in the interval of (-1,-0.8) during the study period (Table 2), indicating that farmland expansion was achieved through a large number of expanding patches with an adjacent expansion pattern on a small scale. Overall, the LEI and the expansion scale of farmland tended to decrease.

The LEI of expanding patches was primarily in the intervals of (-1,-0.8) and LEI=1 from 1978 to 1987, and the expansion patterns of farmland were largely an adjacent expansion pattern, with small scale and external expansion pattern. During 1987 and 1993, the LEI of expanding patched was still primarily in these two intervals, but the number of expansion patches distributed in the interval (-1,-0.8) significantly increased. The number of patches with an external expansion pattern decreased, indicating that the expansion scale of farmland patches decreased.

During 1993 and 1998, the LEI of expanding patches was primarily in (-1,-0.6) and LEI=1, and the spatial expansion pattern of farmland was principally an adjacent expansion pattern on a small scale; the proportion of patches with an external expansion pattern continued to decrease. Between 1998 and 2004, the LEI of expanding patches was primarily in (-1,-0.8) and LEI=1, whereas the number of patches with external and adjacent expansion patterns increased to some degree; the spatial expansion patterns of farmland was primarily an adjacent expansion pattern on a small scale, with an external expansion pattern.

From 2004 to 2009, the LEI of expansion patches was primarily distributed within the intervals of (-1,-0.4), and the expansion pattern of farmland patches was primarily an adjacent expansion pattern. The LEI tended to have a low value, manifesting that the expansion scale of the patches continuously decreased. The expanding area was significantly less than that of the original patch.

In an overview of the changes in LEI distribution intervals over approximately 30 years, the LEI was primarily distributed in two intervals: (-1,-0.6) and LEI=1. Moreover, the LEI of most expanding patches was distributed in (-1,-0.6), showing that the expansion of farmland was mostly achieved through a large number of adjacent expansion patterns on a small scale, as well as a small number of external expansion patterns.

4.4 The Dynamics of MLEI and AWMLEI

The analysis above is primarily against the dynamic expansion progress of a single patch. To study the overall expansion pattern and scale of class level, MLEI and AWLEI were calculated (Table 3).

The MLEI of farmland first decreased, then increased, and finally decreased over approximately 30 years, whereas the change in MLEI was similar to the number of patches with an external expansion pattern (Table 3 and Figure 5). The reason is that LEI=1 for external expansion patches, which is significantly greater than the LEI of all adjacent expansion patches. The LEI of patches with an external expansion pattern has a more significant effect on the numerical value of MLEI. Therefore, the change in the tendency of MLEI is similar to that of the number of patches with an external expansion pattern. MLEI was smallest during 2004 to 2009. This time interval was the latest in the study period, and the land available for farmland reclamation was relatively less in this period, limiting the potential expansion of farmland. As a result, the scale of farmland expansion was comparatively small, which was primarily a large number of adjacent expansion patterns with a small scale during this period (Table 2). The MLEI was largest from 1978 to 1987, which was early in the study period, during which large areas of land were suitable for farmland reclamation. This condition resulted in a huge potential expansion of farmland. The expansion of the farmland landscape was mostly achieved through a small number of adjacent expansion patterns on a large scale during this period (Table 1 and Table 2). Thus, the MLEI was highest during this time interval.

The AWLEI fully considers the role and function of each expanding patch in the farmland landscape. The potential for farmland reclamation was great in the early stages. However, with increasing farmland reclamation, the potential expansion continuously decreased. The amount of lands for farmland reclamation decreased and so did the scale of farmland expansion. Therefore, the AWLEI decreased (Table 3). It fluctuated in the interval between 1998 and 2004, during which anthropogenic factors, such as land consolidation and intensified farmland reclamation, enabled the expansion scale of farmland patches to increase. On the other hand, 1998 was the breakpoint of the climate in the study area. In 1998, the water area of the Kwanting reservoir reached the maximum, and the climate became dry. The water area substantially decreased, increasing the amount of land suitable for farmland reclamation; the water area that disappeared was also replaced by farmland. Therefore, the AWLEI increased during this period.

As quantitative indices, LEI, MLEI, and AWLEI well express the process of land conversion from natural landscape into farmland in the study area over approximately 30 years. The three indices numerically reflect the same dynamic process of land conversion from natural landscape into farmland. The expansion of farmland occupied a large number of natural landscapes, such as forestry and grassland, and increased the level of land use in this region, so ecological environment go to further deterioration. Although some environmental degradation is caused by natural factors, such as global warming, we can take some measures to alleviate environmental problems in this region. Studies show that forest has functions of water conservation, conserving soil and water, air purification and others, the Chinese government proposed a policy of conversion of cropland to forest in 2003, to encourage replace some land that is inappropriate for farming with forest. In addition, to develop intensive agricultural model, use advanced sprinkler irrigation and drip irrigation technology can significantly reduce water consumption, and improve water use efficiency, which are very useful for improvement of local ecological environment.

5. Conclusions

A new landscape expansion index was proposed to express the farmland expansion patterns in this study, and the LEI was applied to examine the process of land conversion from natural landscape into farmland in the Guishui river basin, China. The major conclusions are as follows:

1) The index can be easily calculated and implemented, which can not only quantitatively indicate the spatial expansion size of patches but can also accurately identify their spatial expansion pattern. In addition, the landscape spatial expansion patterns were classified into adjacent and external expansion patterns based on previous studies.

2) The spatial expansion pattern of most expanding patches was an adjacent expansion pattern over approximately 30 years, and the number of patches with adjacent and external expansion patterns tended to fluctuate. From 1998 to 2004, the number of patches with adjacent and external expansion patterns was largest. The time interval 1978 to 1987 was the period with the smallest number of patches with an adjacent expansion pattern. The smallest number of external expansion patterns was in the period of 2004 to 2009.

3) The distribution range of LEI was primarily in (-1,-0.8) from 1978 to 2009, indicating that the expansion pattern of farmland patches was primarily a large number of adjacent expansion patterns on a small scale. Overall, the LEI tended to decrease, and the expansion scale also decreased. The MLEI is significantly affected by the number of patches with an external expansion pattern, and the MLEI of a farmland landscape displayed the same fluctuation in the number of patches with an external expansion pattern. Overall, the AWLEI tended to decrease. From 1998 to 2004, it fluctuated, and its tendency to increase resulted from a combination of anthropogenic and natural factors.

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Table 1. Increased area of farmland in each time interval (ha)

	adjacent expansion pattern	external expansion pattern	total increased area
1978–1987	15882.79	531.63	16414.42
1987–1993	11127.06	702.38	11829.44
1993–1998	18664.78	389.91	19054.69
1998–2004	14784.10	310.74	15094.84
2004–2009	8015.66	125.56	8141.22

Table 2. Major intervals and proportion of farmland expanding patches' LEI distribution in each time interval

Landscape expansion pattern	LEI intervals	1978–1987		1987–1993		1993–1998		1998–2004		2004–2009	
		patch number	patch proportion	patch number	patch proportion	patch number	patch proportion	patch number	patch proportion	patch number	patch proportion
adjoining expansion pattern	-1–0.8	471	91.63%	594	95.65%	579	92.94%	616	92.63%	620	95.24%
	-0.8–0.6	8	1.56%	6	0.97%	13	2.09%	18	2.71%	9	1.38%
	-0.6–0.4	4	0.78%	2	0.32%	3	0.48%	4	0.60%	8	1.23%
	-0.4–0.2	2	0.39%	5	0.81%	3	0.48%	2	0.30%	4	0.61%
	-0.2–0	4	0.78%	2	0.32%	5	0.80%	4	0.60%	0	0.00%
	0–0.2	5	0.97%	1	0.16%	2	0.32%	3	0.45%	0	0.00%
	0.2–0.4	2	0.39%	0	0.00%	3	0.48%	2	0.30%	2	0.31%
	0.4–0.6	2	0.39%	2	0.32%	1	0.16%	0	0.00%	1	0.15%
	0.6–0.8	4	0.78%	1	0.16%	3	0.48%	1	0.15%	0	0.00%
	0.8–1	2	0.39%	2	0.32%	1	0.16%	0	0.00%	2	0.31%
external expansion pattern	1	10	1.95%	6	0.97%	10	1.61%	15	2.26%	5	0.77%

Table 3. Farmland landscape's MLEI and AWLEI in different time periods

	1978–1987	1987–1993	1993–1998	1998–2004	2004–2009
MLEI	-0.8919	-0.9454	-0.9130	-0.9158	-0.9502
AWMLEI	-0.2256	-0.2948	-0.7162	-0.6074	-0.8000

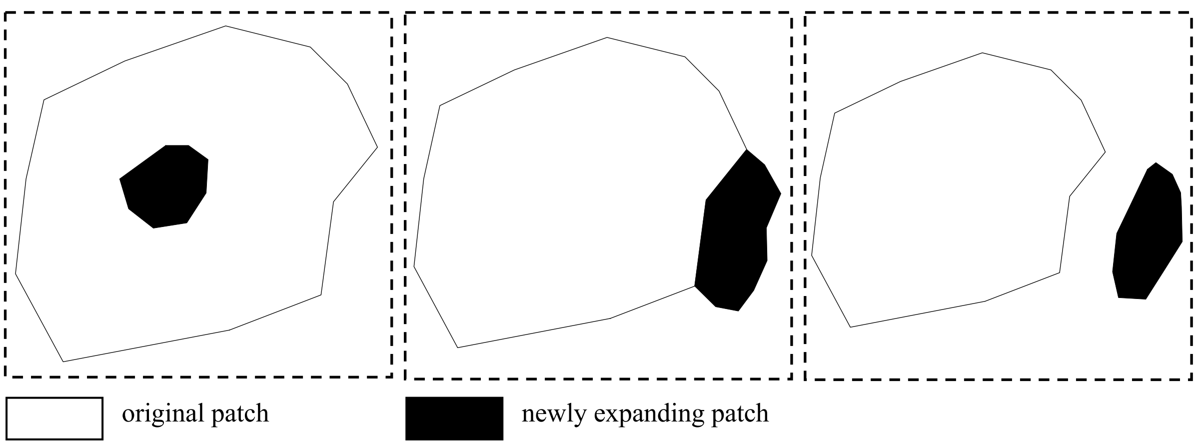

Figure 1. Patterns of landscape spatial expansions. a: internal padding pattern, b: marginal expansion pattern and

c: external expansion pattern

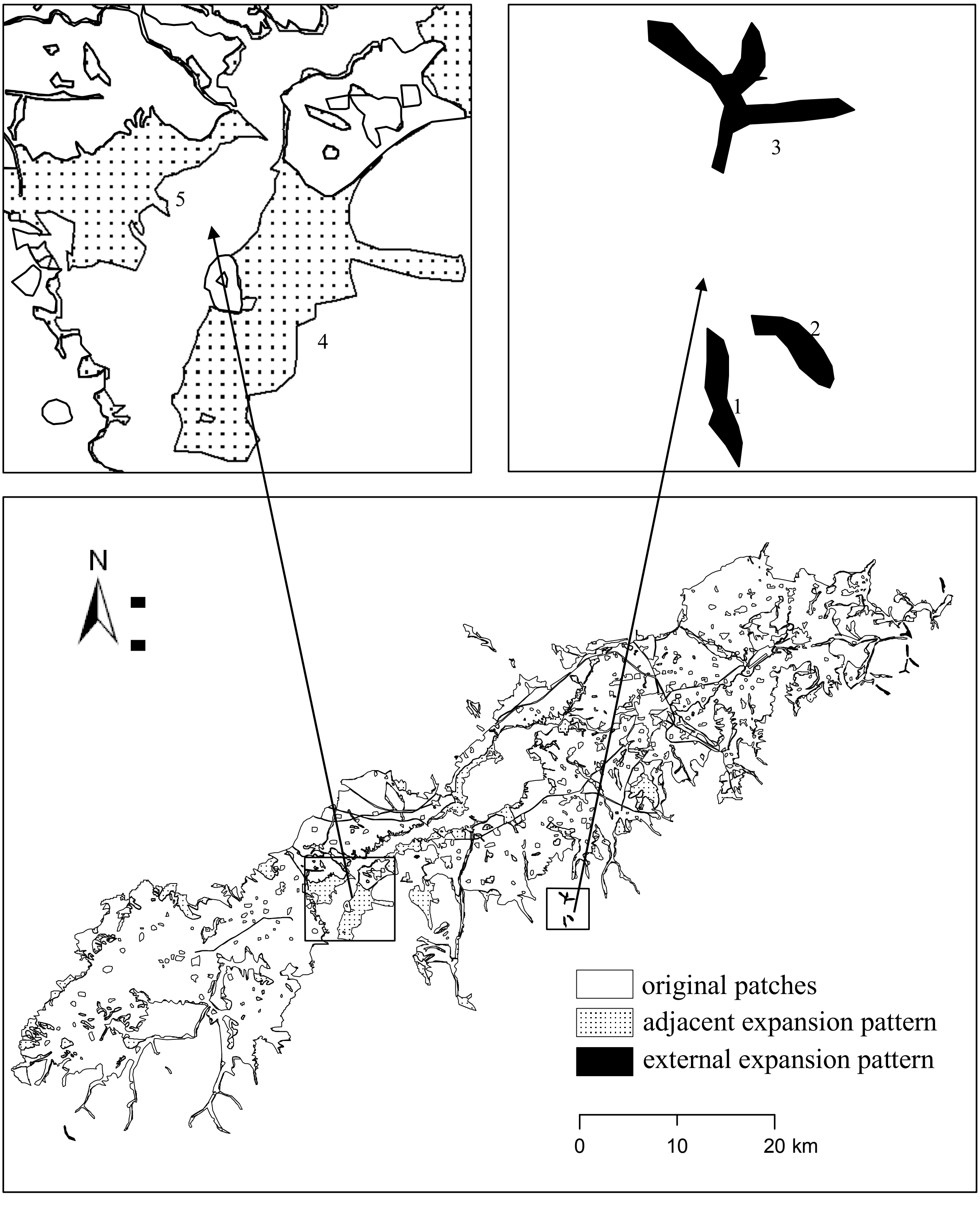

Figure 2. Different spatial expansion patterns of farmland

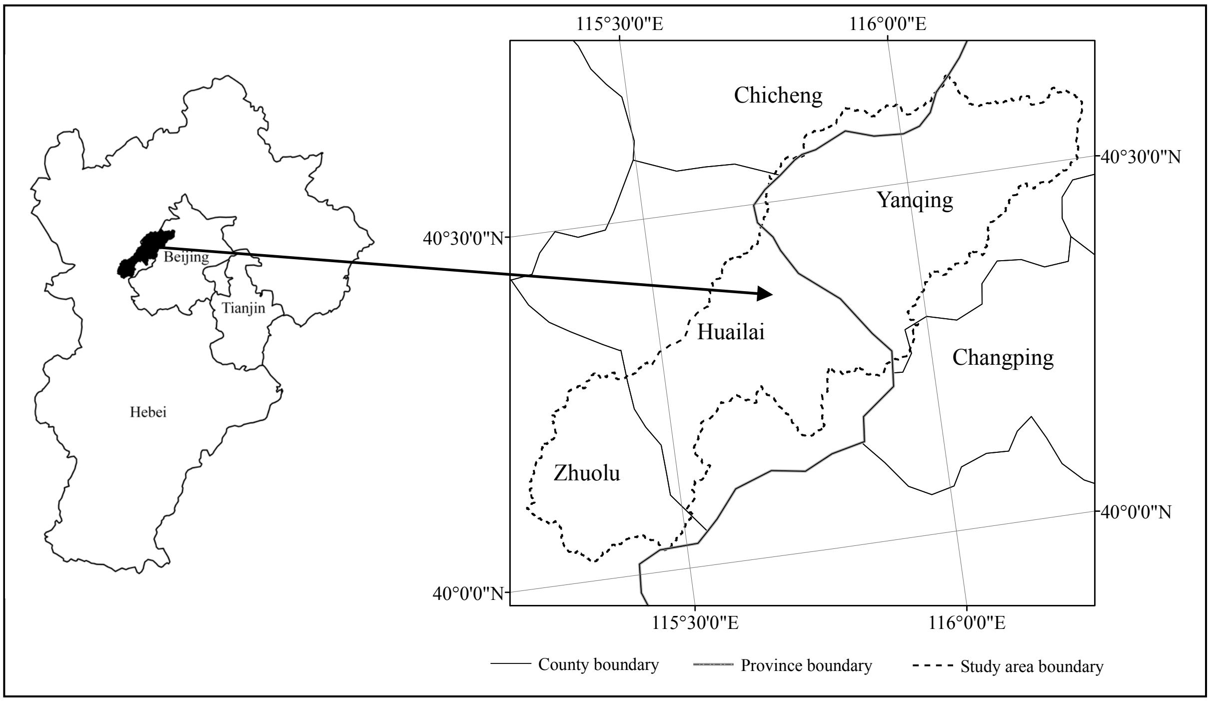

Figure 3. Schematic diagram of the study area

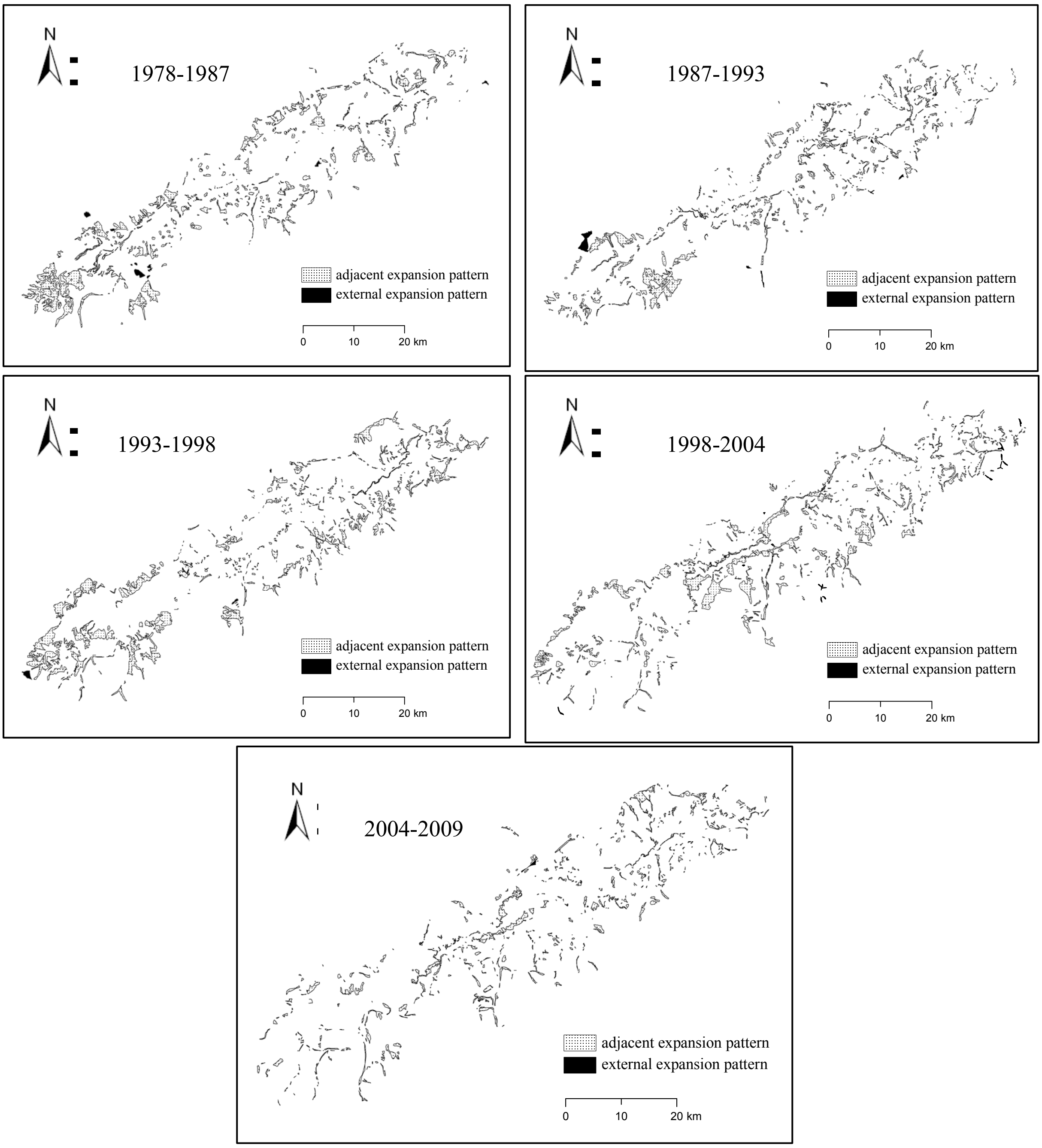

Figure 4. Spatial distribution of expanding farmland patches

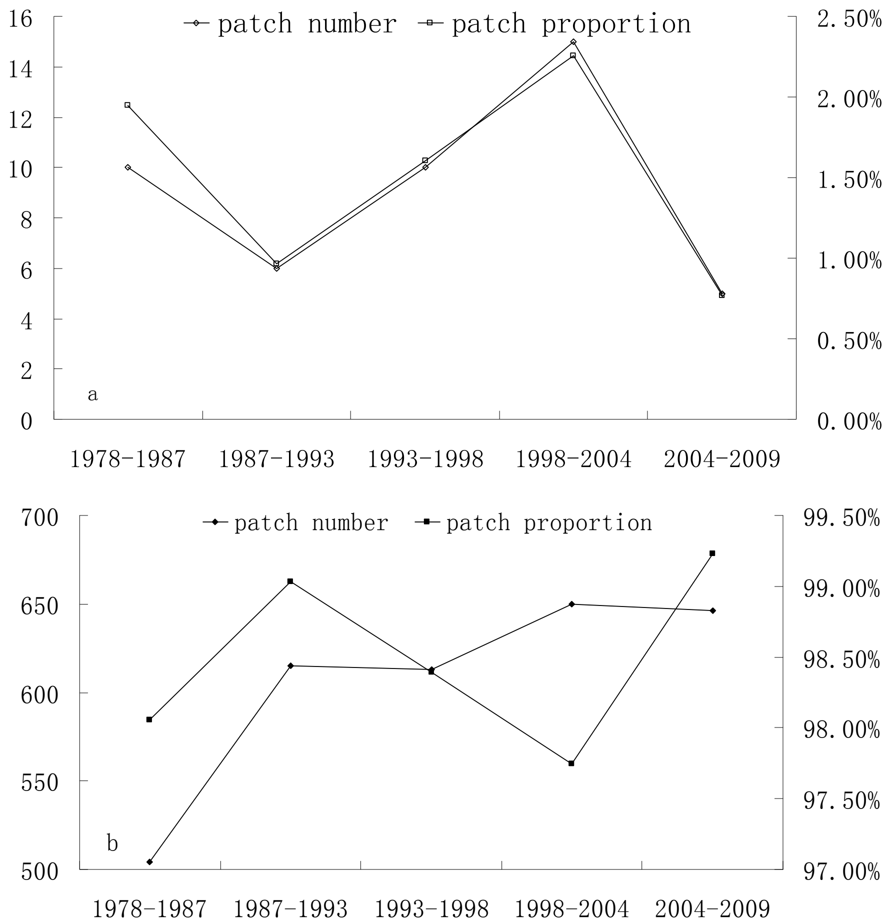

Figure 5. The patches' number of different landscape expansion patterns and their proportion changes (a: external expansion pattern; b: adjacent expansion pattern)