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# Spatio-temporal Pattern and Spatial Heterogeneity of Ecotones Based on Land Use Types of Southeastern Da Hinggan Mountains in China

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**Abstract:** Ecotones have received great attention due to its critical function in energy flux, species harbor, global carbon sequestration, and land-atmosphere interaction. This study investigated land use pattern and spatial heterogeneity of the ecotones among agricultural land, forest land, and grassland of the southeastern Da Hinggan Mountains in the northeastern China. The change of these delineated ecotones under different slopes and aridity conditions was analyzed by two landscape indices, edge density (ED) and core area percentage of landscape (CPL), to explore the inter-linkage between spatial structure of ecotones and socioeconomic development and land management. Specifically, the ecotones such as agriculture-forest (AF) ecotone, forest-grassland (FG) ecotone, and agriculture-forest-grassland (AFG) ecotone moved from the arid southeast to the humid northwest. The flat area with small slope is more edge-fragmented than the steep area since the ED decreases as the slope increases. The AF ecotone mostly found in the humid region is moving to more humid areas while the agriculture-grassland (AG) ecotone mostly found in the dry region is moving towards the drier region.

**Keywords:** ecotones; core area percentage of landscape (CPL); edge density (ED); modified moving split window; land use pattern; spatial heterogeneity

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## 1 Introduction

Defined as the transition area between adjacent ecological systems (Holland *et al*., 1991), ecotones have received great attention due to its critical function in energy flux (Cadenasso *et al*., 2003; Hufkens *et al*., 2009), species harbor (Schilthuizen, 2000), global carbon sequestration (Sankey *et al*., 2006), and land-atmosphere interaction (Mather, 2000). Rapid land use change in ecotones, particular the ecotones with intensive human activities, has profound impacts on the environment of these areas (Vitousek *et al*., 1997; Hufkens *et al*., 2009). The study on the spatial pattern and temporal dynamics of ecotones provides critical information to the human-environment interaction research by considering the influence of regional physical environment and human activities (Fu, 1995; Fu and Chen, 2000; Hufkens *et al*., 2009). The ability to monitor and understand the land use pattern of these interlaced areas as well as its spatial heterogeneity, therefore, is necessary for perspective management to optimize environmental and ecological functions of this transitional ecosystem (Norman and Taylor, 2005; Turner II *et al*., 2007).

Ecotones between agriculture, forest, and grassland

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have been regarded as typical areas to indicate variations in environmental factors and land use change (Bartolome *et al*., 2000; Norman and Taylor, 2005). For example, the shift in forest-grassland (FG) ecotones has been correlated with fire suppression, $CO_2$ increasing, and snow accumulation (Kupfer and Caims, 1996; Bachelet *et al*., 2000), while the agriculture-forest (AF) ecotones are critical for biodiversity conservation and livelihoods sustainability (Bawa *et al*., 2007). Most of researches are focused on the two-ecosystem ecotones, such as agriculture-grassland (AG) ecotone (Cheng, 1999; Zhao *et al*., 2002), AF ecotone (Mather, 2000), or FG ecotone (Kupfer and Cairns, 1996; Breshears, 2006; Sankey *et al*., 2006; Díaz-Varela *et al*., 2010; Danz *et al*., 2011). Few researches perform a comprehensive research on monitoring the structure and pattern change in the mixed ecotones among agriculture, forest, and grassland to though these mixtures which are sensitive to land use change are good models to test transition zone concepts (Blondel and Aronson, 1999; Von Arx *et al*., 2002; Dutoit *et al*., 2007). Increasing aware of complex interactions among agriculture, forest, and grassland is stimulating to develop contemporary methods to better understand and quantify the spatial structure and temporal dynamics of these ecotones.

One effective way to understand the physical status and ecological functions of the ecotones is to monitor its spatial pattern and process (Dorner *et al.*, 2002; Turner, 2005; Kent *et al*., 2006). Ecotones could be treated as patches in fragmented landscapes, which linked them to landscape ecology topics such as edge effects, fragmentation process, interior habitat, and its ecological gradients (Ewers and Didham, 2006). Numerous landscape matrices have been proposed to quantify spatial heterogeneity and its temporal dynamics of landscapes (Lele *et al*., 2008). These quantitative landscape indices not only reflect the spatial structures and organization of the landscape (Gustafson and Parker, 1992; O′Neill *et al*., 1999; Viedma and Melia, 1999; Fuller, 2001) but also represent the ecological functions of each individual patch within the landscape (Patton, 1975; Forman and Gordron, 1986; Schumaker, 1986; Gardner et al., 1987; Imbernon and Branthomme, 2001; Tang *et al*., 2005).

A practical difficulty in addressing the change of ecotones is to delineate the spatial extent of each ecotone (Hufkens *et al*., 2009). The general methods delineating the ecotones are based on the overlaid environment factors including average annual precipitation, temperature, aridity, soil, topography, *etc*. (Changnon *et al*., 2002; Chen *et al*., 2007; Yu *et al*., 2007; Danz *et al*., 2011) ignoring the influences from human beings on the ecotones. Although these methods are straightforward and accurate for the ecotone without much human intervention, they are incomplete to apply for the ecotones with complex coupled natural-human ecosystems (Strayer *et al*., 2003). Based on the spatial characterization of ecotones, the delineating methods could be grouped into one-dimensional techniques such as moving split window (Whittaker, 1967), wavelets (Camarero *et al*., 2006), ordination techniques (Choesin and Boener, 2002) and sigmoid wave curve fitting (Timoney *et al*., 1993), and two-dimensional techniques such as clustering techniques (Camarero and Guti, 2002; McIntire and Fortin, 2006), fuzzy logic (Foody and boyd, 1999), and wombing techniques (Fortin *et al*., 2000; Jacquez *et al*., 2000). The one-dimensional method can extract the ecotone position, width, shape and other information according to the distribution of the vegetation along the transect line. The two-dimensional method is no longer confined to the line transect dada and can be oriented to the raster and remote sensing digital images, while it is very sensitive to the image noises and needs large amount of calculation (Pitas, 2000). In response to these deficiencies and shortcomings, this paper presents a moving window algorithm based on land-use types to divide ecotone, which avoids the image noise effectively and reduces the computation obviously.

The ecotone area at the southeastern Da Hinggan Mountains experienced dramatic land use change due to population growth and agricultural activities (Liu *et al*., 2002; Chang *et al*., 2007; Liu and Gao, 2008). The purpose of this study is to investigate land use pattern and spatial heterogeneity of the ecotones among agriculture, forest, and grassland of the southeastern Da Hinggan Mountains in China. In order to acknowledge the influence from both environment factor and human activities, this study delineated the ecotones based on the land use land cover data derived from satellite remote sensing by using the modified moving split window technique. The change of these delineated ecotones, both in the landscape pattern and spatial heterogeneity, under different slopes and aridity conditions were analyzed to explore the inter-linkage between spatial structure of ecotones and socioeconomic development and land management.

Two landscape indices, edge density (ED) and core area percentage of landscape (CPL), with the inter-complementary ecological meaning were chosen to quantitatively measure the spatial fragmentation and change process.

## 2 Study Area and Data

### 2.1 Study area

The study area (42°55′–51°37′N, 116°22′–126°04′E) is the mountain area in southeastern Da Hinggan Mountains and low tableland in the western of the Northeast Plain in the northeastern China (Fig. 1). The study area is located in the temperate and monsoon climatic zone with a typical continental climate (Ye *et al*., 2001; Wang *et al*., 2010). The average annual precipitation and temperature is about 400–700 mm and –1.1℃–4.4℃ respectively, with a long, extremely cold, and dry winter and short, mild and moist summer. The topographic uplift in the mountain area changes from 130 m in the southeast to 2000 m in the northwest, resulting in an obvious change in temperature and aridity from dry region in the southeast to moist region in the northwest. In addition, the ecotone types in the study area is complicated, including AF ecotone, FG ecotone, agriculture-forest-grassland ecotone (AFG) and AG ecotone from the north to the south.

Historically, the northeastern China was a wide forest area with spare population before the deforestation process associated with the construction of railway and timber production from the first half of the 20th century (Wu and Guo, 1994; Dai *et al*., 2006; Wang *et al*., 2010). The population growth, as well as the expanding food demand, has caused a rapid reduction in grassland and forest during the last 50 years, potentially affecting the future landscape pattern, regional environment and climate. The coexistence of forest, pasture and agricultural land exhibits mosaic and fragmental pattern of land use, making a unique mixing-ecotone landscape in the study area.

### 2.2 Data preparation

In order to understand the influence from both environment and human activities, in this study, the current and historical land use maps derived from Landsat MSS/TM were used to delineate ecotones. To cover the entire study area, Landsat TM images for the study area were acquired mainly in 2008, with a small part collected in 2007 and 2009, while Landsat MSS images were between 1975 and 1978, being acquired in the vegetation growing season of the northeastern China from June to September. All images were geometric corrected to the Albers map projection using the Environment for Visualizing Images (ENVI) software, achieving a spatial accuracy of less than 0.5 pixel root mean square error (RMSE). Manual interpretation was adopted to guarantee the accuracy of data processing and remove the inconsistency among images acquired in different years. Since we only focused on the ecotones among agriculture, forest, and grassland, all the other land cover types

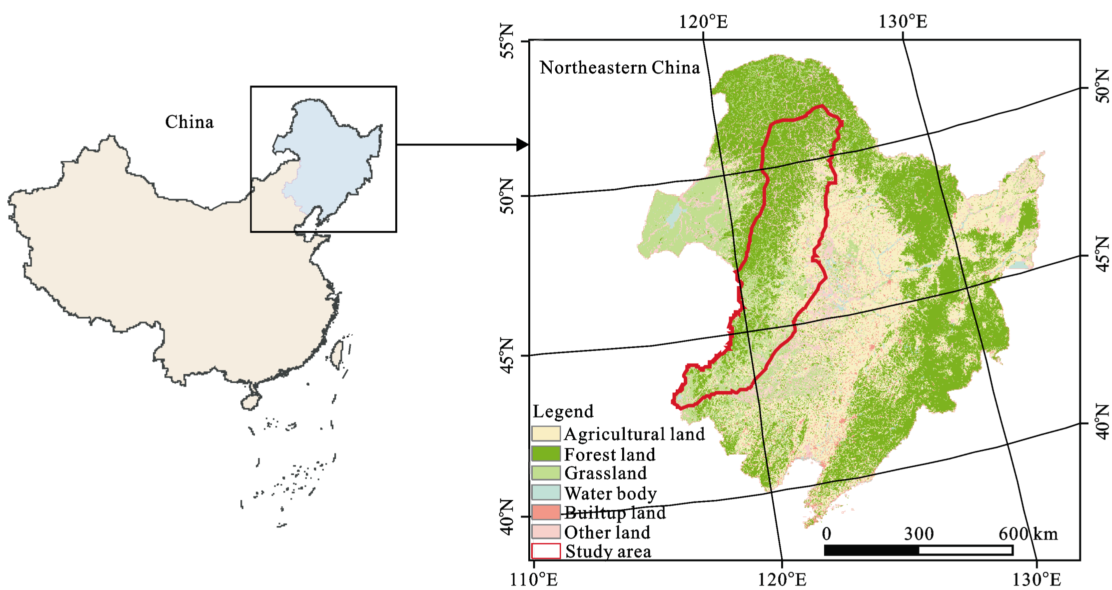


Fig. 1 Location of study area

were set to NODATA. The land use/land cover map was converted and resampled to grid format with the pixel size 100 m × 100 m.

As the change of land use pattern occurred in the study area is dominated by the conversion of cultivated land, and the agricultural land at high altitude terraces increase significantly as well, the correlation between the change of agricultural land and elevation is not significantly. As the adaptation of crops to growth environment, two environment factors, slope and aridity, were chosen to investigate the spatial pattern and heterogeneity in different ecotone areas (Fig. 2). The Shuttle Radar Topography Mission (SRTM) was downloaded from Global Land Cover Facility (GLCF, 2010) and used to derive the slope map at 90 m spatial resolution. The aridity index (AI) map were derived from the accumulated temperature $T$ and precipitation $R$ when the average daily temperature is higher than 10℃ using Equation (1) (Yu *et al*., 2004).

$$AI = \frac{0.16 \times \sum T_{\geqslant 10°C}}{\sum R_{\geqslant 10°C}} \quad (1)$$

where $\sum T_{\geqslant 10°C}$ and $\sum R_{\geqslant 10°C}$ indicate active accumulated temperature and precipitation when average daily temperature is steadily higher than 10℃. The AI represents the ratio between the potential evapotranspiration and precipitation. The accumulated temperature and precipitation was collected from meteorological station and interpolated into grid format by using three dimensions quadric surface modeling coupled with residual interpolation at a significance level of $\alpha$ = 0.001 (Yu *et al*., 2004). Generally, AI of humid climate zone is often lower than 1.00, while 1.00–1.50, 1.50–3.50 and higher than 3.50 are corresponding to semi-humid climate zone, semi-arid climate zone and arid climate zone, respectively.

## 3 Methodology

### 3.1 Ecotone delineation using modified moving split window method

The moving split window was adopted and modified to identify one-dimensional ecotones by comparing the variance between two adjacent sampling windows (Ludwig and Cornelius, 1987) to delineate the ecotones among agriculture, forest, and grassland (Fig. 3a). The ecotone type of the central pixel in the 100 by 100 grids pixel

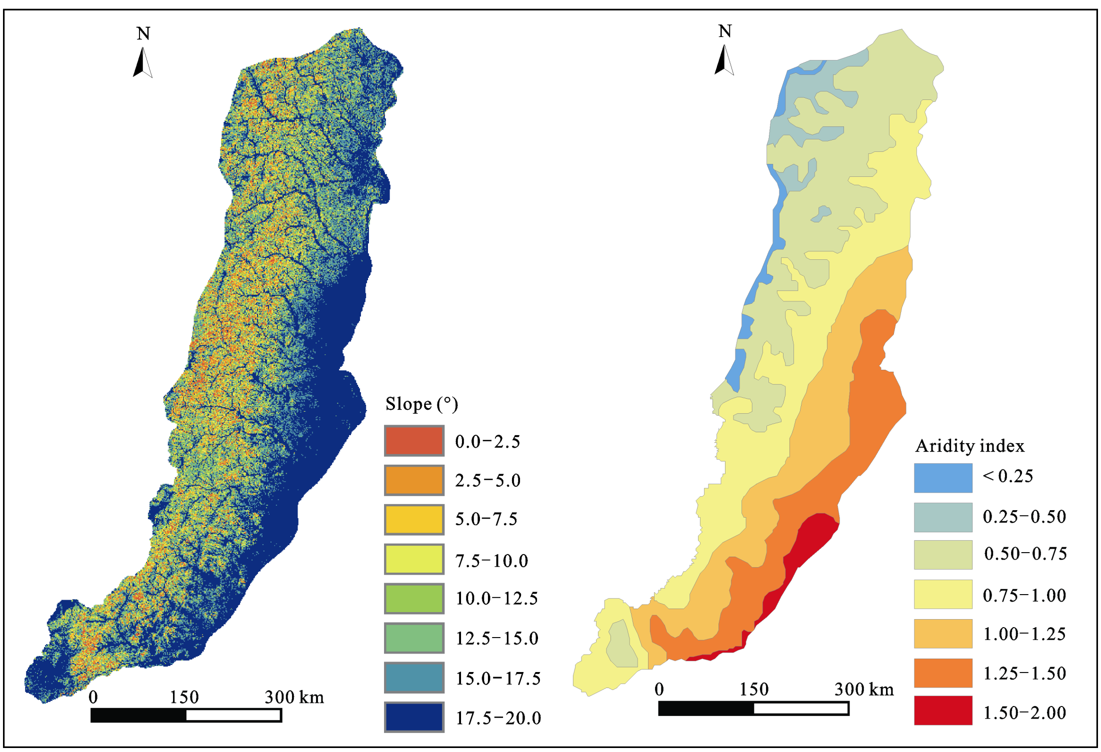


**Fig. 2** Slope and aridity index (AI) maps of study area

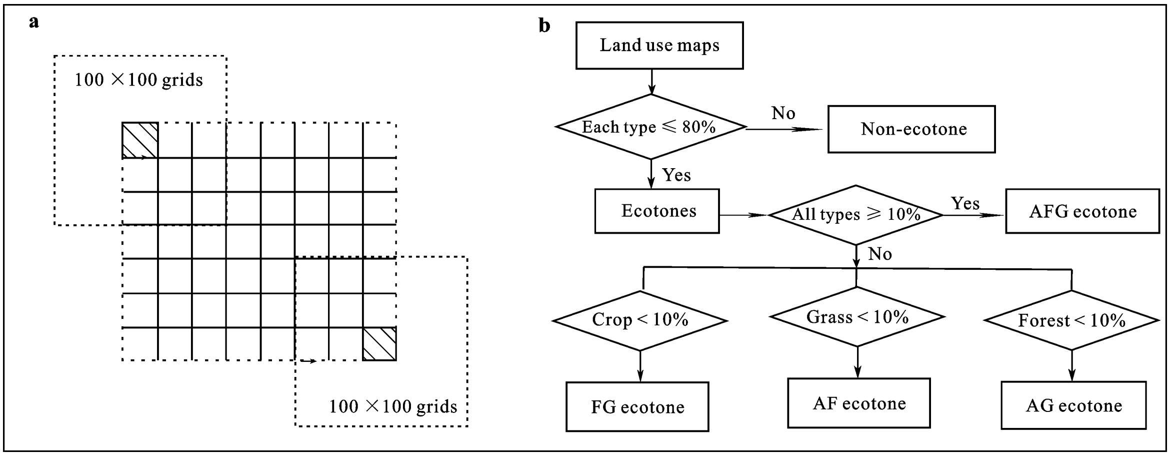


**Fig. 3** Modified moving split window method to delineate ecotones. a, moving window used to assign ecotone types to center pixel; b, procedure for ecotone delineation to center pixel. AF, agriculture-forest; FG, forest-grassland; AG, agriculture-grassland; AFG, agriculture-forest-grassland

window is decided by the percentage of each class within the moving window using the threshold as shown in Fig. 3b.

According to Fig. 3b, within the moving window, if one of the land use types is dominated, and the percent of which is higher than 80%, then we would divide the central pixel into non-ecotone. In contrary, if each land use type is lower than 80%, then we would set the central pixel as ecotones and the second round of classification would begin. In the second round of classification, a threshold (10%) was set and it meant that if the percent of two types or three is higher than 10% then the central pixel would be judged as the ecotones with these types.

### 3.2 Spatial pattern and heterogeneity analysis through landscape index

In order to describe heterogeneity of land use land cover pattern in different ecotones, we chose two landscape metrics that have possess complementary ecological meanings with least mutual correlation, including edge density (ED) (m/ha), and core area percentage of landscape (CPL) (%) (Gustafson, 1998; Tang *et al*., 2005; Tang *et al*., 2008). The indices were calculated with the Fragstats (UMASS, 2004) and ArcGIS software.

Built on the simple ratio between the perimeter and area, the ED is the first index to characterize landscape shape as:

$$ED = \frac{\sum E_i}{\sum A_i} \tag{2}$$

where $E_i$ is total length of edge in land cover type $i$; $A_i$ is the total patch area in land cover type $i$. $ED$ increases from 0 as land cover patch border density increases, indicating more land use patch border length per area.

Different from ED, CPL represents the fragmentation information through the ratio of interior area to total area, i.e., the higher the ratio between core area and total area is, the less fragmented this patch would be (Joseph *et al*., 2004). The CPL was chosen to denote the landscape fragmentation as:

$$CPL = \frac{\sum a_i^{\text{core}}}{\sum A_i} \tag{3}$$

where $a_i^{\text{core}}$ is the core area in land cover type $i$, the interior habitat as an undisturbed area in the ecological meaning; $A_i$ is the total area of landscape in land cover type $i$. To identify the core area of each landscape patch, we smoothed the sharp edge and calculated the core area within each patch.

In this study area, the slope and aridity indices are two major environmental factors determining the distribution of ecotones and their dynamics. The landscape indices were calculated in different zones at different slopes and aridity values to analyze land use pattern/heterogeneity and the changes in each ecotone.

## 4 Results and Discussion

### 4.1 Spatial distibution of ecotone and its change from 1975 to 2008

Figure 4 shows four ecotones, including AF, AG, FG, and AFG, derived from modified moving split window method. Generally, the north of study area is more homogenous than the south. The AF ecotone is mainly distributed in the piedmont of the Da Hinggan Mountains and the edge of the Northeast Plain where the slope is the steepest and the moisture is highest (Fig. 2). The south region is much more heterogeneous than the north region with a gradient from FG, AFG to AG ecotones as the aridity index increases in the southeast direction. It could be explained by the slope requirement of agricultural land. As the elevation increases from the southeast to the southwest, the agricultural land reduces due to the topographical limitation, and forest increases with a gradual increment of orographic rainfall caused by the elevation change.

There is a significant change in the location and area of ecotones from 1975 to 2008. The most significant change is the increase of agricultural land in the east region as well as the modification of forest land to AF ecotone in the west and south region (Fig. 4). The total AF area increased 125% from 1975 to 2008 due to the significant modification from forest area (18 103 km$^2$) though there is some conversion from AF ecotone to agricultural land (2933 km$^2$) in the east region. For the AG ecotone, in which the largest land conversion was from AG ecotone to agriculture area (9965 km$^2$) in the east region while some modifications from AFG ecotone to AG ecotone (9835 km$^2$) occurred in the middle and east region. This cross-shift made the change of the total AG ecotone area relatively small from 1975 to 2008. Meanwhile, a large area of FG ecotone was replaced by the AFG ecotone along its east edge (10 435 km$^2$), which made the total area of FG ecotone decreased 14.55% from 1975 to 2008. A general trend could be derived that the ecotones, particular the ecotones such as AF, FG, AFG, moved from the dry southeast region to the humid northwest region.

In addition to the change of location and area, the inner pattern of land use also changed from 1975 to 2008 in different ecotones. Table 1 shows the change of ED and CPL in different ecotones from 1975 to 2008, revealing the spatio-temporal variation of landscape pattern and its heterogeneity. From 1975 to 2008, the ED increased in all ecotones and CPL decreased in AF and FG ecotones and increased in AG and AFG ecotones. The most obvious increase of ED is found in AF ecotone (from 6.280 to 14.831), which might be caused by the fragmentation and conversion process from the adjacent agricultural land. This trend could be also found in other ecotones such as AG ecotone due to the reclamation in grassland and FG ecotone due to the deforestation. The

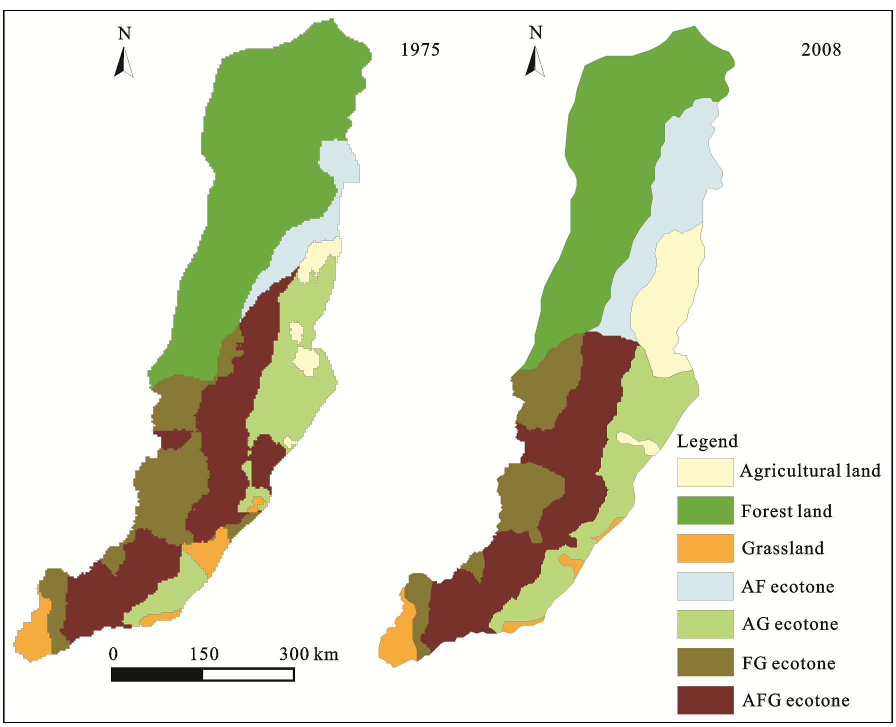


**Fig. 4** Ecotones of study area in 1975 and 2008. AF, agriculture-forest; FG, forest-grassland; AG, agriculture-grassland; AFG, agriculture-forest-grassland

**Table 1** Edge density (ED) and core area percentage of landscape (CPL) of each ecotone in 1975 and 2008

| | AF ecotone | | AG ecotone | | FG ecotone | | AFG ecotone | |
|---|---|---|---|---|---|---|---|---|
| | 1975 | 2008 | 1975 | 2008 | 1975 | 2008 | 1975 | 2008 |
| ED (m/ha) | 6.280 | 14.831 | 7.566 | 9.356 | 8.718 | 10.513 | 14.467 | 16.193 |
| CPL (%) | 30.981 | 21.060 | 32.912 | 35.738 | 30.375 | 28.011 | 30.094 | 32.350 |

Notes: AF, agriculture-forest; FG, forest-grassland; AG, agriculture-grassland; AFG, agriculture-forest-grassland

decrease of CPL in AF and FG further confirmed this fragmentation process between forests and other ecosystems. For the AG and AFG ecotones, the increase of CPL might be resulted from the merge of small patches into larger patches though the patch shape became more irregular.

The different change pattern of ED and CPL in different ecotones also indicated the special spatial pattern and process. In 1975, the ED of AF ecotone was much lower than that of AFG ecotone, while the CPL values of the two ecotones were similar. The different values were caused by the more fragmented shape of AFG ecotone than AF ecotone. The opposite change of AF, FG with AG, AFG in CPL can be attributed to that the AF and FG ecotones contained large area of forest, and fragmentation process of these forest patches dominated the change trend in AF and FG ecotones. For the AG and AFG ecotones, the major change was represented as merge process between agriculture patches into large patches.

The different changes of land use pattern and spatial heterogeneity in ecotones indicated the importance of land use type which was determined by the local physical environment. A further analysis on the variation in different physical environment factors, here referring to slope and aridity index, was performed and presented in the following section.

### 4.2 Ectones pattern and dynamics under different environment factors

#### *4.2.1 Land use pattern change of ecotones among different slopes*

Slope influences the distribution of agricultural land, forest land and grassland on each ecotone, and further affects the heterogeneity of landscape. Each ecotone was classified into nine categories based on the slope as 0°–2.5°, 2.5°–5.0°, 5.0°–7.5°, 7.5°–10.0°, 10.0°–12.5°, 12.5°–15.0°, 15.0°–17.5°, 17.5°–20.0° and > 20.0°. Figure 5 shows the total area of each ecotone at different slope ranges. Obviously, most ecotones are distributed in the area with the slope lower than 15.0° with a minor difference existing among them. For example, over 90% of AG ecotones are found in the slopes of 0–5.0° and around 70% of FG ecotones are found in the slopes higher than 5.0°. Compared to the AG and FG ecotones, the AF and AFG ecotones are more evenly distributed among slopes.

From 1975 to 2008, a significant decrease in area is found in the 0°–5.0° interval for all ecotones with a total area decreasing from 80 738.05 $km^2$ to 80 286.27 $km^2$, while an obvious area increasing is found in 5.0°–15.0° interval from 37 038.99 $km^2$ to 45 515.57 $km^2$. These changes indicate the movement of all ecotones from low elevation land to high elevation land. Among all ecotones, the change of slope distribution in AG is relatively less than the other ecotones since the AG ecotones are mainly distributed in the flat area. The most obvious change trend could be found in AF and FG ecotones with moving from the 0°–5.0° interval to the 5.0°–10.0° interval in AF ecotone and from the 0°–10.0° interval to the 10.0°–15.0° interval in FG ecotone, respectively. This moving trend indicates that the moving of ecotone is highly related to the type of ecotone, that is, each ecotone is impacted differently due to the extensity and intensity of human activities.

To further investigate the spatial pattern of ecotones among different slope categories, we calculated the ED and CPL of each ecotone at different slopes, and the results are shown in Fig. 6 and Fig. 7. In Fig. 6, the highest ED of AF ecotone is found in the region between 2.5° and 7.5°, which is corresponding with the highly fragmented region between agriculture and forest land. Most agricultural land are distributed in the area with the slope lower than 2.5°, while the forest are found in the area with the slope higher than 7.5°. When the slope is higher than 15.0° (class 7 to 9), the ED of AF ecotone became low and stable due to the small total area of AF ecotone in the high slope areas. An obvious increase of ED in AF ecotone is found for all slope categories from 1975 to 2008, especially from 2.5° to

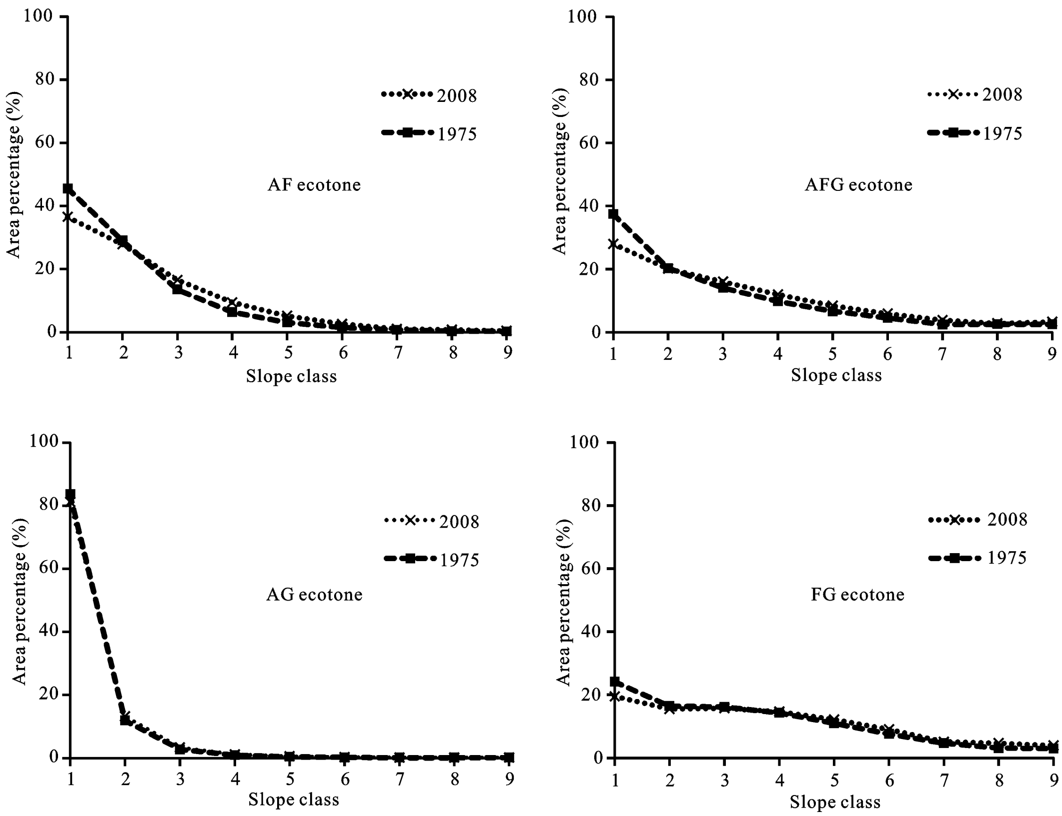


**Fig. 5** Area distribution of ecotones at different slopes. AF, agriculture-forest; FG, forest-grassland; AG, agriculture-grassland; AFG, agriculture-forest-grassland. 1, 0°–2.5°; 2, 2.5°–5.0°; 3, 5.0°–7.5°; 4, 7.5°–10.0°; 5, 10.0°–12.5°; 6, 12.5°–15.0°; 7, 15.0°–17.5°; 8, 17.5°–20.0°; 9, > 20.0°

10.0°. It might be the result of deforestation in the AF ecotone, which created more patches at small size in this region.

Compared to the AF ecotone, the AFG and AG have relatively stable ED values from 1975 to 2008. The highest ED is found in the 2.5°–5.0° internal in both AFG and AG ecotones. During the last 30 years, AFG and AG ecotones showed a slight increase in the small slope area (lower than 7.5°) and little change in the large slope area (higher than 15.0°). The AG ecotone is slightly different from both AF and AFG ecotones because there was no significant increase in ED in the large slope area (slope between 17.5° and 20.0°). The possible reason for it is the AG ecotones have little forest area and over 90% of AG ecotones distribute in the small slope area (slope lower than 5.0°).

The FG ecotone is the only ecotone has obvious bimodal pattern in the ED value, one is found in the 5.0°–7.5° interval and one is in the 15.0°–20.0° interval. These two peak values represent the transition between forest land and grassland could be found in the low slope area and high slope area. From 1975 to 2008, the ED values increased as the slope increase which implies an obvious fragmentation process in the higher slope area, indicating the intensive deforestation in the FG ecotone.

The CPL represents the edge-to-interior index to indicate the interior fragmentation degree in the landscape (Tang *et al*., 2005; 2008). Figure 7 shows the CPL and its change of each ecotone at different slopes from 1975 to 2008. All ecotones decrease in the 0°–15.0° slope class and increase in > 15.0° slope class. The decrease might be caused by the gradual decrease of the total area in all ecotones (Fig. 5). As the slope is higher than 15.0°, the CPLs increase slightly due to the reduction of human activities in the large slope area. The AG ecotone has relatively higher CPL (average CPLs are 1.27 in 1975 and 1.25 in 2008, respectively) than the AF, AFG, and FG ecotones, especially in the area with the slope lower than 10.0°. The lowest average CPL (average CPLs are 0.62 in 1975 and in 2008) is found in FG. This further denotes that the less fragmen- tation in the human-disturbed ecotone (with agricultural land) than the natural ecotone (FG ecotone).

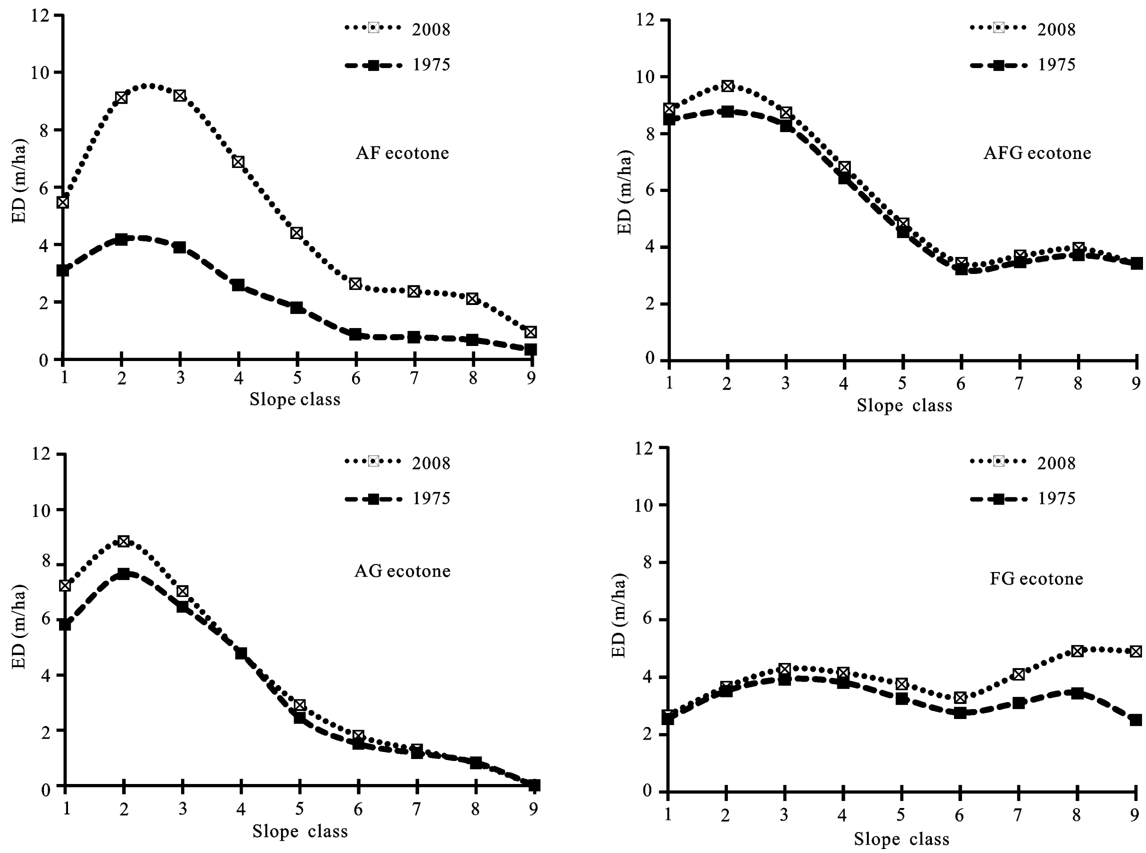


**Fig. 6** Edge density (ED) and its change of each ecotone at different slopes from 1975 to 2008. AF, agriculture-forest; FG, forest-grassland; AG, agriculture-grassland; AFG, agriculture-forest-grassland. 1, 0°–2.5°; 2, 2.5°–5.0°; 3, 5.0°–7.5°; 4, 7.5°–10.0°; 5, 10.0°–12.5°; 6, 12.5°–15.0°; 7, 15.0°–17.5°; 8, 17.5°–20.0°; 9, > 20.0°

The change of CPL for all the ecotones is much less than that of ED from 1975 to 2008, and the changes of CPL can only be observed in the small slope area (slope < 7.5°) of AF and AFG ecotones. The difference between CPL and ED indicates that the fragmentation processes in these ecotones usually occur in the edge area which increases the ED instead of the CPL of these ecotones. It is actually corresponding with the initial analysis of the ecotones pattern and dynamics in Fig. 4.

#### *4.2.2 Land use pattern change of ecotones among different aridity conditions*

The aridity index was another important factor that impacts the spatial pattern and distribution of the ecotones in the study area. In this study, we divided the study area into five regions depending on the aridity index value as 0.50–0.75, 0.75–1.00, 1.00–1.25, 1.25–1.50, and 1.50–2.00 with an increasing aridity condition. Table 2 shows the area percentage of each ecotone under different aridity condition. Most AF ecotones are distributed in the humid climate condition with lower aridity index between 0.50–1.25, while the AG ecotones mainly distribute in the dry region with higher aridity index between 1.00–2.00. Compared to AG and AF ecotones, the FG and AFG ecotones are distributed in both humid and arid region.

From 1975 to 2008, there was a general trend found among these ecotones: the AF, FG and AFG ecotones moved from drier region to wetter region while the AG ecotone moved from wetter region to drier region. This trend could be corresponded with the movement of AF, FG and AFG ecotones from the southeast to the northwest region, replacing large area of forest in the high elevation region with ample precipitation. The AG ecotone extends to the higher arid area in the south area due to the replacement of grassland by agricultural land.

Table 3 shows the change trend of ED and CPL in different aridity zones. A general pattern could be found among different aridity index zone: from dry region to humid region, there is an increasing fragmentation pattern with an increasing ED and decreasing CPL except the AF ecotones which is mainly distributed in the humid area. It indicates that most ecotones have moved

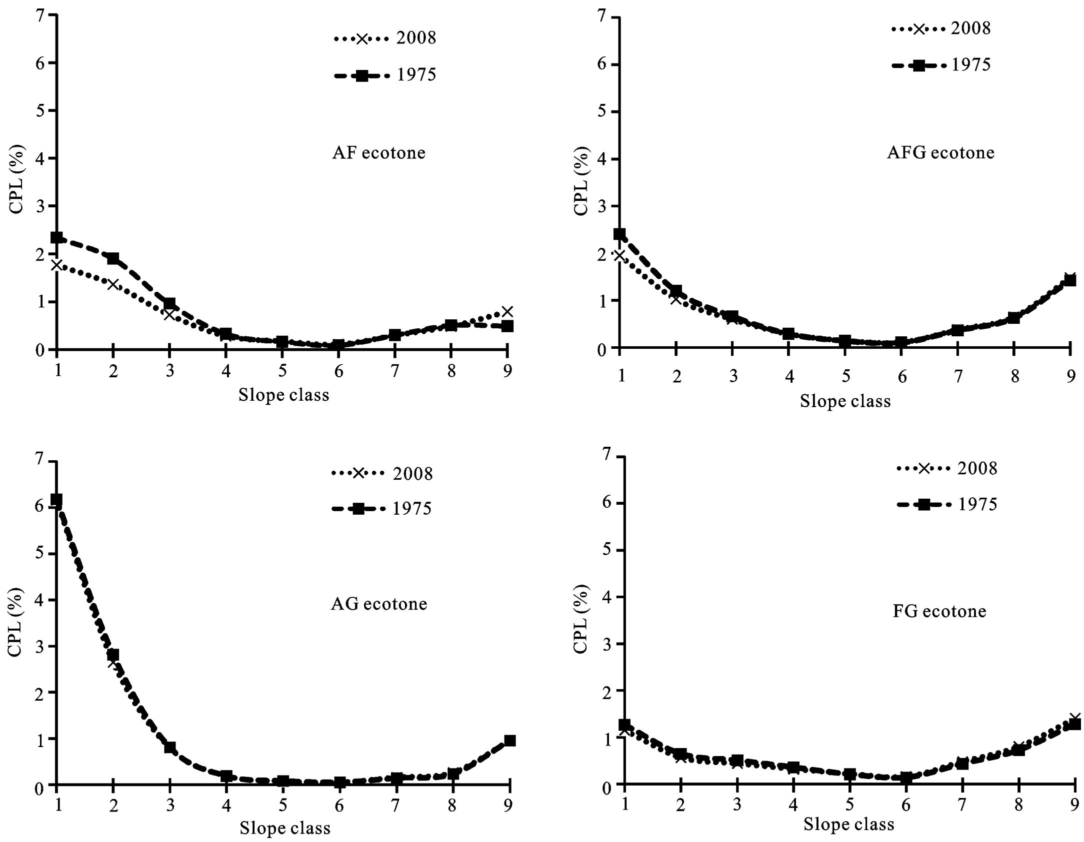


**Fig. 7** Core area percentage of landscape (CPL) and its change of each ecotone at different slopes from 1975 to 2008. AF, agriculture-forest; FG, forest-grassland; AG, agriculture-grassland; AFG, agriculture-forest-grassland. 1, 0°–2.5°; 2, 2.5°–5.0°; 3, 5.0°–7.5°; 4, 7.5°–10.0°; 5, 10.0°–12.5°; 6, 12.5°–15.0°; 7, 15.0°–17.5°; 8, 17.5°–20.0°; 9, > 20.0°

**Table 2** Area percentage of each ecotone in different aridity index zones (%)

| | 0.50–0.75 | | 0.75–1.00 | | 1.00–1.25 | | 1.25–1.50 | | 1.50–2.00 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1975 | 2008 | 1975 | 2008 | 1975 | 2008 | 1975 | 2008 | 1975 | 2008 |
| AF ecotone | – | 17.42 | 86.33 | 77.85 | 13.67 | 4.73 | – | – | – | – |
| AG ecotone | – | – | – | – | 30.32 | 19.50 | 61.70 | 62.60 | 7.98 | 17.90 |
| FG ecotone | 11.74 | 27.41 | 64.03 | 60.87 | 17.76 | 10.60 | 3.81 | 1.12 | 2.66 | – |
| AFG ecotone | 2.17 | 3.01 | 23.25 | 31.68 | 46.11 | 45.50 | 25.67 | 18.83 | 2.80 | 0.97 |
| Total | 3.74 | 9.94 | 33.53 | 39.36 | 32.10 | 24.52 | 26.85 | 21.69 | 3.77 | 4.49 |

Notes: AF, agriculture-forest; FG, forest-grassland; AG, agriculture-grassland; AFG, agriculture-forest-grassland

**Table 3** Edge density (ED) (m/ha) and core area percentage of landscape (CPL) (%) in different aridity index zones for each ecotone

| | | 0.50–0.75 | | 0.75–1.00 | | 1.00–1.25 | | 1.25–1.50 | | 1.50–2.00 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1975 | 2008 | 1975 | 2008 | 1975 | 2008 | 1975 | 2008 | 1975 | 2008 |
| AF ecotone | ED | – | 18.628 | 5.893 | 13.965 | 8.343 | 14.302 | – | – | – | – |
| | CPL | | 21.463 | 31.332 | 27.667 | 28.539 | 36.563 | | | | |
| AG ecotone | ED | – | – | – | – | 10.009 | 14.622 | 6.530 | 7.855 | 5.624 | 7.883 |
| | CPL | | | | | 29.202 | 31.264 | 35.977 | 36.563 | 31.542 | 39.051 |
| FG ecotone | ED | 10.762 | 13.489 | 8.897 | 9.584 | 8.164 | 8.553 | 4.307 | 3.320 | 3.665 | – |
| | CPL | 28.249 | 23.204 | 28.752 | 29.024 | 36.415 | 41.854 | 41.118 | 31.293 | 36.434 | |
| AFG ecotone | ED | 15.456 | 16.503 | 16.493 | 18.406 | 15.455 | 16.425 | 11.124 | 11.730 | 7.281 | 10.923 |
| | CPL | 30.536 | 29.254 | 27.678 | 29.515 | 31.044 | 33.000 | 31.422 | 37.225 | 27.815 | 29.251 |

Notes: AF, agriculture-forest; FG, forest-grassland; AG, agriculture-grassland; AFG, agriculture-forest-grassland from the drier area to more humid area as well as from the plain area to the mountain area. A clear increasing pattern in ED at each ecotone from 1975 to 2008 further confirms this shift.

The change trend of ED and CPL of each ecotone at aridity index zones in Table 3 also describes the different change pattern among ecotones. Obviously, the AF ecotones are more fragmented in the drier region as the ED in 1.00–1.25 region is higher than that in 0.75–1.00 region, while the CPL is lower. This might be caused by the human activities in the agriculture area. But the variation in 2008 was significantly lower than in 1975, indicating that with the increase of arable land at the drier region, large tracts of arable land make a decreasing trend in the degree of fragmentation. This trend could be further found in the decreasing CPL in 0.75–1.00 interval region but increasing CPL in 1.00–1.25 interval region, which might be resulted from the high CPL in agriculture-dominant patches.

It is also interesting to notice that both ED and CPL increased in AG ecotones from 1975 to 2008. Compared to other ecotones, the AG ecotones have relatively larger patch size and higher CPL. The increase of both ED and CPL indicates that the fragmentation process of the AG ecotones usually occur along the patch edge. Another reason for the constant increase of CPL is the combination between the north AG ecotone with the south AG ecotone (Fig. 4) which might reduce the total patch number of AG ecotone.

Compared to the AF and AG ecotones, the change trend of FG and AFG ecotones is less obvious. It can be found that the FG ecotone show a decreasing CPL in both humid region (0.50–0.75 region) and arid region (1.25–1.50 region), which might be corresponded with the fragmentation in forest-dominant area in the humid region and grassland-dominant area in the dry region, respectively. As the transition region between the AG ecotone and FG ecotone, the AFG ecotone has obviously higher ED than other ecotones and experienced an increasing trend of both ED and CPL for all aridity zones except a slight decreasing CPL in the humid region (0.50–0.75). The change might be resulted from the transition from forest upland in the northwest to agriculture lowland in the southeast.

## 5 Conclusions

This study mainly explored the land use pattern and spatial heterogeneity of the ecotones in the southeastern Da Hinggan Mountains in the northeastern China. A modified moving split window method was applied to delineate the ecotones based on the land use land cover types derived from satellite landsat images. Focused on the local proportions of land use/land cover types, we delineated four ecotones in the study area as AG, AF, FG and AFG. The landscape index with complementary ecological meaning, ED and CPL, was used to quantify land use/land cover pattern variations at each ecotone at different zones of slope and aridity index from 1975 to 2008.

In the study area, most ecotones undergone the fragmentation process in the edge area due to the significant increase of the ED. The AF and FG ecotones have a decreasing CPL, while the AG and AFG ecotones have an increasing CPL, which further indicates the impact of human activities on the human-intervened patch such as agricultural land and grassland. The flat area with small slope is more edge-fragmented than the steep area since the ED decreases as the slope increases. The agriculture-dominated ecotones, such as AG, AF, and AFG econtones have higher CPLs than the FG ecotones. The AF ecotones are mostly found in the humid region and are moving to more humid region while the AG ecotones are mostly found in the dry region and moving towards the drier region. This process is associated with the deforestation process and expansion process of agricultural land.

Our method and results provided insights into regional land use land cover pattern. For the further research, a more sophisticated moving split window method with detailed overlaid physical and social factors with land use and land cover should be developed to acquire more accurate ecotone maps. The comprehensive analysis between ecotone change and socioeconomic development could help us understand the spatial distribution of ecotones as well as its fragmentation process. This study only chose slope and aridity index as two major environmental factors for the landscape pattern analysis while some other environmental factors such as temperature which might be critical to the distribution of ecotones were not included. A further quantitative analysis between the spatial distribution ecotone, physical environment, socioeconomic development will be conducted in the following studies.

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