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Land Use Changes in Northeast China Driven by Human Activities and Climatic Variation

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Abstract: Human-induced land use/cover change (LUCC) forms an important component of global environmental change. Therefore, it is important to study land use/cover and its change at local, regional and global scales. In this paper we conducted the study of land use change in Northeast China, one of the most important agricultural zones of the nation. From 1986 to 2000, according to the study results obtained from Landsat images, widespread changes in land use/cover took place in the study area. Grassland, marsh, water body and woodland decreased by 9864, 3973, 1367 and 10,052km^2, respectively. By comparison, paddy field, dry farmland, and built-up land expanded by 7339, 17193 and 700km^2, respectively. Those changes bore an interactive relationship with the environment, especially climate change. On the one hand, climate warming created a potential environment for grassland and marsh to be changed to farmland as more crops could thrive in the warmer climate, and for dry farmland to paddy field. On the other hand, the changed surface cover modified the local climate. Those changes, in turn, have adversely influenced the local environment by accelerating land degradation. In terms of socio-economic driving forces, population augment, regional economic development, and national and provincial policies were confirmed as main driving factors for land use change.

Keywords: land use change; remote sensing; climate warming; Northeast China

1 Introduction

Land use/cover change (LUCC) results from the alteration of the earth's surface by human beings. With the rapid population growth, such change is taking place at unprecedented rates, magnitudes, and spatial scales (Turner II et al., 1993). LUCC plays a pivotal role in environmental and ecological changes and furthermore contributes to global change (Meyer and Turner II, 1991; Lambin et al., 2001). Changes in land use and land cover have important consequences for natural resources (Houghton et al., 1994; Turner II et al., 1995), and they significantly affect key aspects of earth system functioning. Those changes contribute to local and regional climate change (Chase et al., 1999), as well as to global climate warming (Houghton et al., 1999). They are the primary sources of soil degradation (Tolba and El-Kholy, 1992), and, by altering ecosystem services, affect the ability of biological systems to support human needs (Vitousek et al., 1997). However, the understanding of the natural and social factors that influence land use/cover change is far from complete (Burgi and Turner, 2002; Long et al., 2007).

Northeast China is one of the main agricultural regions in China, whose yield of corn and soybean accounting for more than 30% of the nation's total. In past decades, Northeast China has suffered dramatic land use change as a result of activities of human beings. These changes led to the aggravation of soil and water loss, the decrease of soil fertility in the black soil zone of the central part, the wetland loss in the Sanjiang Plain, and the desertification and grassland degradation in the western part. There were many efforts to analyze climate change, landscape change, and effects of agricultural activities on local environment in Northeast China. Yet quantitative knowledge on the changes in land use

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and in ecosystem services at regional level for the whole area is few. For this reason, three datasets of land use/cover produced from 1986, 1995 and 2000 Landsat satellite images were overlaid in ArcInfo to reveal the land use/cover changes in this paper. In addition, this study aims to elucidate the interactive nature between LUCCs caused by human activities and the environment (e.g., climate) in Northeast China.

2 Materials and Methods

2.1 Study area

Northeast China was selected as the study area in this paper, which includes three provinces of Heilongjiang, Jilin, and Liaoning. As one of the main agricultural regions of the nation, the cultivated land of Northeast China accounts for 20% of the country′s total. In this region, the main crops are spring wheat, spring corn, soybean, rice, beet, etc., grown in the cultivated area which accounts for more than 30% of the whole area of the Northeast China. In the study area, annual precipitation varies widely from 400mm in the west to 900mm along the east coast. This area has a typical temperate continental monsoon climate with an average annual temperature of 1–7℃. The main soils are black soil (Luvic Phaeozem, FAO), chernozem (Haplic Chernozem, FAO), meadow soil (Eutric Vertisol, FAO), Solonetz (Solonetz, FAO), Solonchak (Solonchak, FAO) and aeolian soil (Arenosol, FAO).

2.2 Temporal land use changes

The Arc/Info (ESRI, 1994) GIS (Geographic Information System) software was used in our work for the analysis of land use area change and the transition matrix analysis between land use types from 1986 to 2000. In this study, land use datasets were obtained by incorporating Landsat images of the three provinces of Northeast China during relatively cloud-free days from June to September in 1986, 1995 and 2000. The Landsat images were enhanced by using the linear contrast stretching and histogram equalization to help identify ground control points in the rectification to common Albers coordinate system based on 1∶100,000 topographic maps of China. For each TM/MSS scene, there are at least 20 evenly distributed sites served as Ground Control Points (GCPs). After geometric correction and geo-reference, the Root Mean Squared Error (RMS error) of geometric rectification was less than 45m (about 1.5 pixels of TM image). The land use/cover classification was conducted through visual interpretation to guarantee the consistency and accuracy of data processing. The reference data were collected from field survey or from existing land use map that have been checked in the field.

An effective land use classification system was applied to Landsat image data, according to the classification put forward by Liu J Y et al. (2005). The classified classes in each image were grouped into seven land cover categories: farmland, woodland, grassland, water body, built-up land, marsh, and unused land. Farmland includes paddy field and dry farmland. Woodland includes forest, shrub and others (e.g., orchards). Grassland includes three density dependent types: dense, moderate and sparse grasslands. Water body includes stream and river, lake, reservoir and pond, and bottomland. Built-up land includes urban area, rural settlement and others such as road. Marsh includes lands with a permanent mixture of water and herbaceous vegetation that cover extensive areas. Unused land includes sandy land, saline and bare soil. The accuracy of these data was verified in the field. Field survey and random sample check show that the overall interpretation accuracy for land use classifications interpreated from Landsat images is 90.62%. For farmland, woodland, grassland, and built-up land, the identification accuracy is 92.5%, 94.8%, 89.6% and 88.7%, respectively.

2.3 Spatial land use changes

In this study, we calculated the area-weighted centroids (Ehman et al., 2002) of each land use type to explore their temporal changes. The movement of spatial distribution of land use type was defined as the difference between centroids of the land use type in different periods. This novel application of centroids allows us to quantify the direction and distance of the change by representing the shifts as vectors linking centroids from different periods.

The centroid of land use type was calculated as:

$$X = \sum_{i=1}^{n}(A_i \times X_i) / \sum_{i=1}^{n} A_i \,,\; Y = \sum_{i=1}^{n}(A_i \times Y_i) / \sum_{i=1}^{n} A_i \qquad (1)$$

where X and Y are abscissa and ordinate of each land use type in different periods, respectively; A_i is the area of patch i in the land use type; X_i and Y_i represent the abscissa and ordinate of the patch i; and n is the number of patches.

2.4 Analyses of driving forces

The climate data of 66 meteorological stations were from the Chinese Natural Resources Database (IGSNRR, 2005). To explore socioeconomic driving forces of land use changes, data of total population and GDP of Northeast China during 1986–2000 were from the *China Statistical Yearbook* (NSBC, 1987–2001).

3 Results and Discussion

3.1 Temporal land use changes

Land use change of Northeast China from 1986 to 2000 is shown in Table 1. In the period, paddy field, dry farmland, built-up land and unused land increased, but woodland, grassland, water body and marsh decreased correspondingly, among which grassland and marsh decreased most dramatically.

Table 1 Land use change in Northeast China from 1986 to 2000

	Land use area (km^2)		Change	
	1986	2000	(km^2)	(%)
Paddy field	36631	43970	7339	20.04
Dry farmland	239335	256528	17193	7.18
Woodland	359349	349297	–10052	–2.80
Grassland	59018	49154	–9864	–16.71
Water body	25959	24592	–1367	–5.27
Built-up land	23667	243672	700	2.96
Marsh	33554	29581	–3973	–11.84
Unused land	12406	12466	60	0.48

Compared with other regions of the country, Northeast China experienced dramatic land use changes. Increased human activities led to a great number of losses in woodland and grassland. In the mountainous areas, the main feature is the reclamation of woodland and grassland. However, in Northeast China Plain, the main variation is the mutual conversion between paddy field and dry farmland. From 1986 to 2000, total area of paddy field increased by 7339km^2, with the highest increase rate among all land use types. Dry farmland increased by 17,193km^2, with an increase rate much smaller than that of paddy field. Grassland decreased from 59,018km^2 in 1986 to 49,154km^2 in 2000, with a highest decrease rate among all land use types. Area of marsh, water body, and woodland decreased by 11.84%, 5.27%, and 2.80%, respectively.

3.2 Spatial land use changes

To further explore shifts of spatial distribution of land use types in the study area, we studied the movements of centroids of each land use type, as shown in Fig. 1.

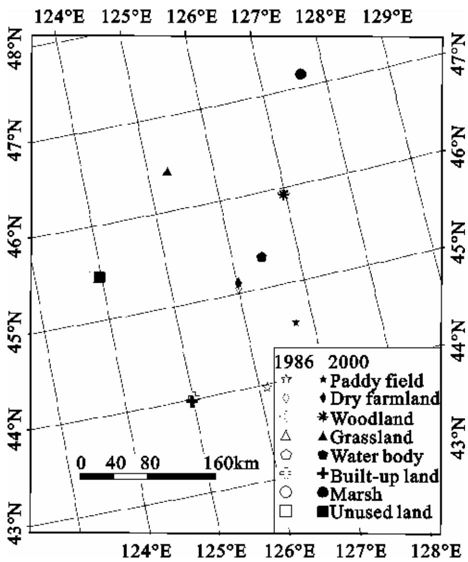

Fig. 1 Movement of centroid of each land use type during 1986–2000 in Northeast China

During the study period, centroid of each land use type shifted under the impact of climate change and human activities (Table 2). Results show that, from 1986 to 2000, centroid of paddy field experienced the longest shifting north-eastward. This phenomenon was related to the climatic warming trend and development of growing rice in the northern part of the region. The centroid of grassland showed a process of shifting north-westward with a distance of 19,908m, which resulted from the reclamation of grassland, mainly in the Songnen Plain. Woodland shifted with the shortest distance of 1775m. Mainly due to the conversion into paddy fields, the centroid of marsh shifted to south-eastward with a distance of 14,234m.

3.3 Land use changes in different provinces

Trends of land use changes in Liaoning Province, Jilin Province and Heilongjiang Province are illustrated in Figs. 2–4.

During 1986–2000, in Liaoning Province, paddy field, woodland and grassland decreased by 21.43%, 3.47%, and 3.22%, respectively. In contrast, dry farmland increased by 9.94%, and built-up land increased by 4.71%. During the same period, in Jilin Province, paddy field

Table 2 Movement of centroid for each land use type from 1986 to 2000

Land use type	Centroid in 1986		Centroid in 2000		Movement (m)
	Longitude (ºE)	Latitude (ºN)	Longitude (ºE)	Latitude (ºN)	
Paddy field	126.117	43.975	126.743	44.584	84367
Dry farmland	126.004	45.054	126.015	45.112	6473
Woodland	126.975	45.943	126.972	45.927	1775
Grassland	125.547	46.371	125.299	46.423	19908
Water body	126.420	45.350	126.447	45.334	2785
Built-up land	125.019	44.022	124.976	43.984	5469
Marsh	127.806	47.083	127.636	47.137	14234
Unused land	123.913	45.467	123.966	45.456	4304

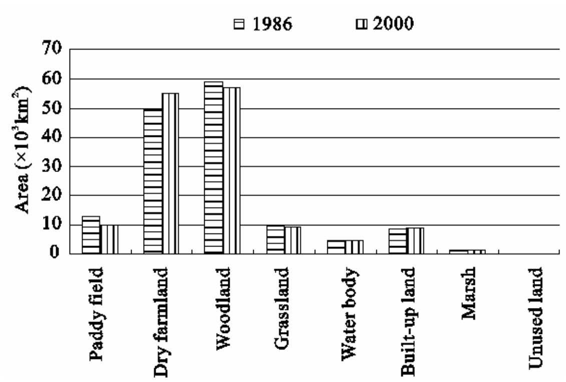

Fig. 2 Land use change trend of Liaoning Province from 1986 to 2000

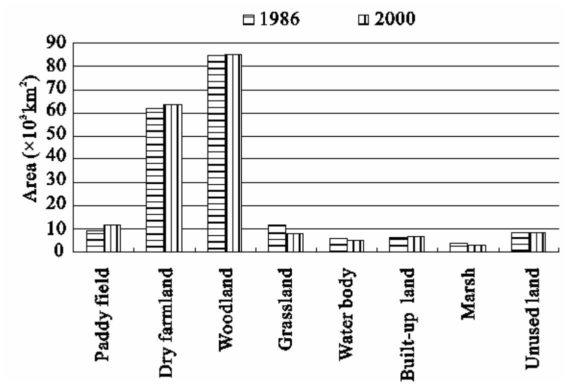

Fig. 3 Land use change trend of Jilin Province from 1986 to 2000

increased by 29.19%. In contrast, grassland, water body, and marsh decreased substantially by 31.60%, 12.59%, and 15.41%, respectively. From 1986 to 2000, in Heilongjiang Province, paddy field and dry farmland increased by 51.46% and 8.37%, respectively. The increased paddy field and dry farmland were mainly converted from woodland, grassland and marsh. Results indicate that grassland decreased by 15.59%, and marsh decreased by 11.51%.

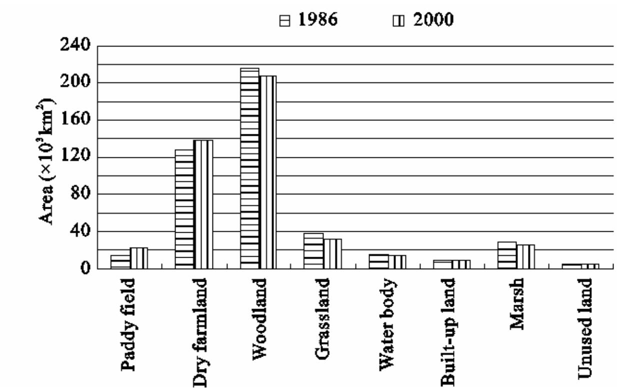

Fig. 4 Land use change trend of Heilongjiang Province from 1986 to 2000

3.4 Main driving factors of land use changes

3.4.1 Climate variation

In Northeast China, temperature is the most critical climatic variable that controls the latitudinal distribution of crops. For instance, rice can only be cultivated in the places where the average annual temperature is higher than 1℃. Reminiscent of the global trend of climate warming, temperature in Northeast China has risen steadily over the last decade as demonstrated by Fig. 5. This diagram indicates a definite trend of warming from 1986 to 2000 in spite of a wide yearly fluctuation. The following regression relationship was established between average annual temperature and year:

$$y=0.0737x-141.6 \qquad R^2=0.3853$$

where y is average annual temperature, x is year.

Judging by the large R^2 value of 0.3853, this model is rather accurate in indicating the rising trend in annual temperature.

Associated with this warming trend the growing season was prolonged, and the 1℃ isotherm of average annual temperature gradually shifted northward during 1986–2000. Consequently, far more areas than ever be-

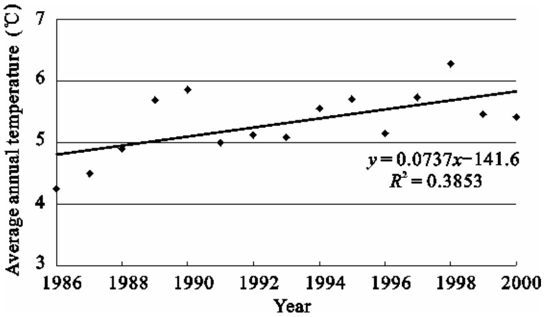

Fig. 5 Rising trend of average annual temperature during 1986–2000

fore have an average annual temperature of 1℃ or higher. Such a rise in temperature enables the cultivation of rice in more northern areas than before. As a matter of fact, climate warming has created the potential for the northward expansion of paddy field. This expansion accounts for the changes from non-irrigated dry fields into paddy field in the northern provinces of Heilongjiang and Jilin. As a result, previous marsh or even grassland in those provinces has been reclaimed as farmland, resulting in the dramatic decrease of marsh in those two provinces.

3.4.2 Human activities

To explore the socio-economic driving factors of land use changes, many aspects need to be considered. In this study, because detailed information for all factors could not be found, only some variables that could be regarded as proxies for the explanatory factors were selected. For example, "population" could be the representative of the "the utilization degree of resources and environment", "the gross domestic production" could be the representative of "human economic activities".

Land use and land cover changes are particularly related to the increase of population and intensive agriculture (Verburg et al., 1999). From 1986 to 2000, total population of Northeast China increased from 94.3×10^6 persons to 106×10^6 persons by 12.13% (Fig. 6). In the study area, due to the increase in population and the concomitant requirement for grain, the reclamation of farmland increased, which accelerated the cultivation of grassland and marsh. In the same period, the gross domestic production (GDP) increased from 123×10^9 yuan (RMB) to 979×10^9 yuan by about seven times (Fig. 7). Substantial increase of GDP indicated the boost of economy and accelerated the infrastructure construction, which made agricultural development more easy and indirectly led to the increase of paddy field and dry farmland and loss of woodland, grassland, water body and marsh. In addition, economic boost inevitably increase the built-up land area due to more and more requirement of residence.

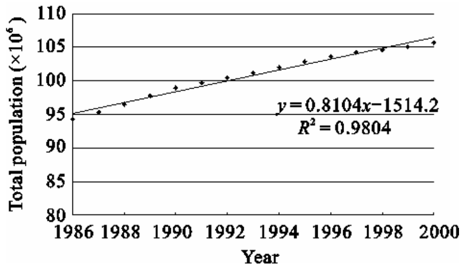

Fig. 6 Change of total population in Northeast China

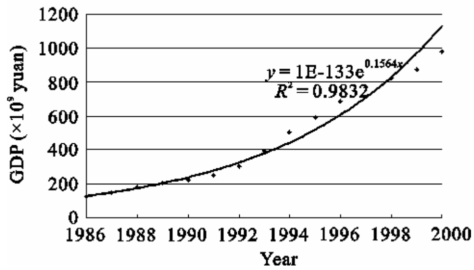

Fig. 7 Change of GDP in Northeast China

Similar to the rest of China, policies of central and local government put direct and important effects on land use and cover changes in Northeast China. In the early 1980s, the collective farming system was replaced by household contract responsibility system and farmers were given incentives to get higher productivity and more income. This decentralized decision-making in agricultural production afforded farmers more freedom in looking after their own interest. However, as users of the land (but not its owners), farmers still had to honor grain production quotas imposed by the government. From then on, the central government attached great importance to food self-sufficiency. Under this policy, cultivated land was increased through zealous reclamation of grassland, marginal woodland, and even fallow land (Liu Y S et al., 2005).

However, after market-oriented reforms being introduced to the agrarian sector by the late 1990s, Northeast-grown maize and soybean were not so profitable as other crops in the market. Thus, each of the three provinces started to diversify its agricultural operation by growing rice. While correcting the legacy of the former planned production, land use/cover underwent even more changes accordingly on the regional scale. Such changes have caused severe shortage of water resources and raised the issue of how to allocate limited resources rationally to bring maximum return while minimizing the adverse impact on the environment.

Fortunately, from the late 1990s, the ecological functions of woodland, grassland and wetlands were recognized widely, and thus national and provincial ecological projects such as "grain to green", "construction of ecological province for Jilin Province and Heilongjiang Province", etc. were adopted, which lessened the rate of reclamation of natural land cover.

4 Conclusions

By analyzing the change rule of land use and land cover in Northeast China from 1986 to 2000, we can see that the structure of land use varied and more and more human activities led to the reduction of grassland, marsh, water body and woodland. During the same period, paddy field, dry farmland and built-up land increased by 20.04%, 7.18% and 2.96, respectively. Climate variation created a potential environment for natural ecosystems to be turned into farmland. Population augment, regional economic development, and national and provincial policies were confirmed as main socio-economic driving factors for land use change. The results obtained in this study should be of importance for land use planning and land resources protection in Northeast China.

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