A Methodology Framework for Regional Land-use Change Studies based on Landsat TM images: A Case Study in Northeast China

Deng Xiangzheng [1,2], Huang Shumin [3], Zhan Jinyan [2] & Zhao Tao [2]

1 Center for Chinese Agricultural Policy, Chinese Academy of Sciences, Beijing 100101;

2 Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences; Beijing 100101;

3 Anthropology Department, Iowa State University, Ames, Iowa 50010-1050, USA,

Abstract: Land-use change is an important aspect of global environment change. It is, in a sense, the direct result of human activities influencing our physical environment. This paper analyzed the land-use change in Northeast China during 1985-2000 based on Landsat TM images. It divides Northeast China into five land-use zones based on the dynamic degree model of land-use: woodland/grassland-arable land conversion zone, dry land-paddy field conversion zone; urban expansion zone, interlocked zone of farming and pasturing and reclamation and abandon zone. The findings include the obvious increase of cropland area, paddy field and dry land increased by 75 and 276 thousand hm^2 respectively; urban areas expanded rapidly, areas of town and rural residence increased by 76.8 thousand hm^2; areas of forests and grassland decreased sharply with the amounts of 1399 and 1521 thousand hm^2 respectively; areas of water body and unused land increased by 148 and 514 thousand hm^2 respectively. This paper also discusses the driving forces in each land-use dynamic zone and finds that some key biophysical factors affect conspicuously the conversion of different land-use types. The relation between land-use conversion and DEM, accumulated temperature (≥10˚C) and precipitation was analyzed and represented. The land-use changes in Northeast China resulted from the changing macro social and economic factors and local physical elements. Rapid population growth and management changes can explain the shaping of woodland/grassland-cropland conversion zone. The conversion from dry land to paddy field in the dry land-paddy field conversion zone, apart from the change of physical elements promoting the expansion of paddy field, results from two reasons: one is that the implementation of market economy in China has given farmers the right to decide what and how they plant their crops, the other factor is originated partially from the change of the dietary habit along with the social and economic development. The conversion from paddy field to dry land is caused primarily by the shortfall of irrigation water, which in turn is caused by poor water allocation managed by local governments. The shaping of the reclamation and abandon zone is partially due to the lack of environment protection consciousness among pioneer settlers. The reason for the conversion from grassland to cropland is the relatively higher profits of farming than that of pasturing in the interlocked zone of farming and pasturing. In Northeast China, the rapid expansion of built-up areas results from two factors: the existence of a small number of towns and the huge potential for expansion of the existing towns and cities. The urban land expanded mainly in areas with a gentle topographic relief and low population density.

Key words: spatial pattern, land use, land-use change, driving force, Northeast China

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Corresponding author: *Deng Xiangzhong (dengxz@ireis.ac.cn)*

1 INTRODUCTION

Land-use/coverage change has become an issue of paramount importance in the study of global environmental changes (Geist & Lambin 2001). As a developing country, China has developed a series of policies influencing the land-use change (Liu Jiyuan et al, 2002; Deng Xiangzheng et al, 2002; Deng Xiangzheng et al, 2003; Deng Xiangzheng et al, 2004). Northeast China is delimited by Sino-Russian and Sino-Korean international boundaries to the north and east. Its western boundary is the aridity isopleth of 1.2 and merges into the vast temperate grassland of Inner Mongolia. Its southern boundary is the 3200 isotherm of accumulated temperature during (≥10˚C) period that demarcates the temperature and warm-temperate thermal zones. Northeast China differs somewhat from North China whose northern boundaries roughly correspond with the Great Wall. Administratively, Northeast China includes the provinces of Heilongjiang, Jilin and Liaoning and a small part of the Inner Mongolia Autonomous Region. It is one of the most important bases of commercial grains and economic crops (soybeans, sugar beets, etc.), as well as the largest timber and petroleum-producing area in China.

2 DATA AND METHODOLOGY

Main data sources are the two-period (1985 and 2000) remote sensing data (Landsat-MSS/TM/ETM digital image). After radiation calibration (Figure 1), the average location errors can be limited to 50 meters (about 2 pixels). The average degree of interpretation accuracy is 98.7%. Furthermore, the degree of interpretation accuracy of arable land and urbanization is 99.0%, which guarantees the high interpretation accuracy for each pixel (about 97.6%).

Supported by the 1km GRID global database, IGBP, IHDP and other international research organizations have implemented a series of researches including land cover dynamics, mechanism and global and regional models (Turner, B.L.II, et al., 1995). The framework of 1km GRID dataset, an efficient and effective data fusion method, is also used in this study (Figure 1). Generation of the 1 km GRID percentage data was processed in ESRI Arc/Info 8.02 software environment and could be described as follows: firstly, we gained land use map (1985 and 2000, at scale of 1:100,000) and land-use change map (1985~2000) based on the interpretation of Landsat TM images and generated a 1km vector data geo-referenced to administrative boundary; secondly, intersecting the land-use/land-use change map with 1km vector data; thirdly, under TABLE model, taking statistical process on each kind of land-use/land-use change area grouped by 1km vector cell ID; lastly, convert the vector data into grid format data with area percentage information of all land-use/land-use change types(Liu jiyuan et al, 2002; Deng Xiangzheng et al 2002).

The spatial differentiation of land-use dynamic changes can be represented by the dynamic models of land-use (Liu Jiyuan et al, 2002; Liu Jiyuan et al, 2003), i.e.

$$S = \frac{W_i \times \Delta S_{i-j}}{t \times S_i} \times 100\%$$

Where, S is the dynamic degree of land use change, S_i represents areas of i (land-use type) at the former stage while Wi is the weight of areas proportion, _S_{i-J} of land-use areas from the former stage i to the latter stage j, t is the time lag.

On the basis of the 1km GRID percentage dataset of each kind of land use category, we programmed in the ARC/INFO environment and generalized a certain but single expansion or shrinking tendency for each kind of land-use category at scale of 1km (Figure 2), which shows the main land-use change characteristics of Northeast China during 1985-2000.

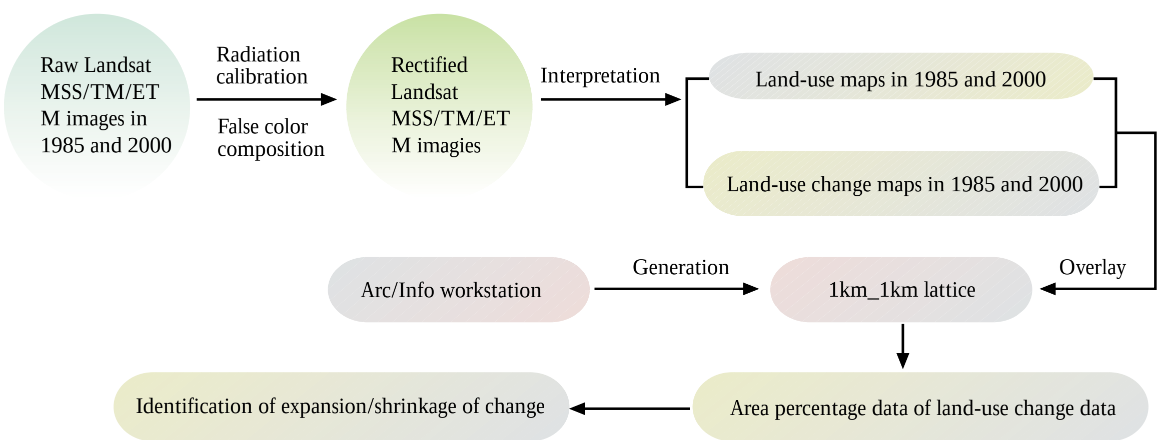

Figure 1 Data sources and handling framework

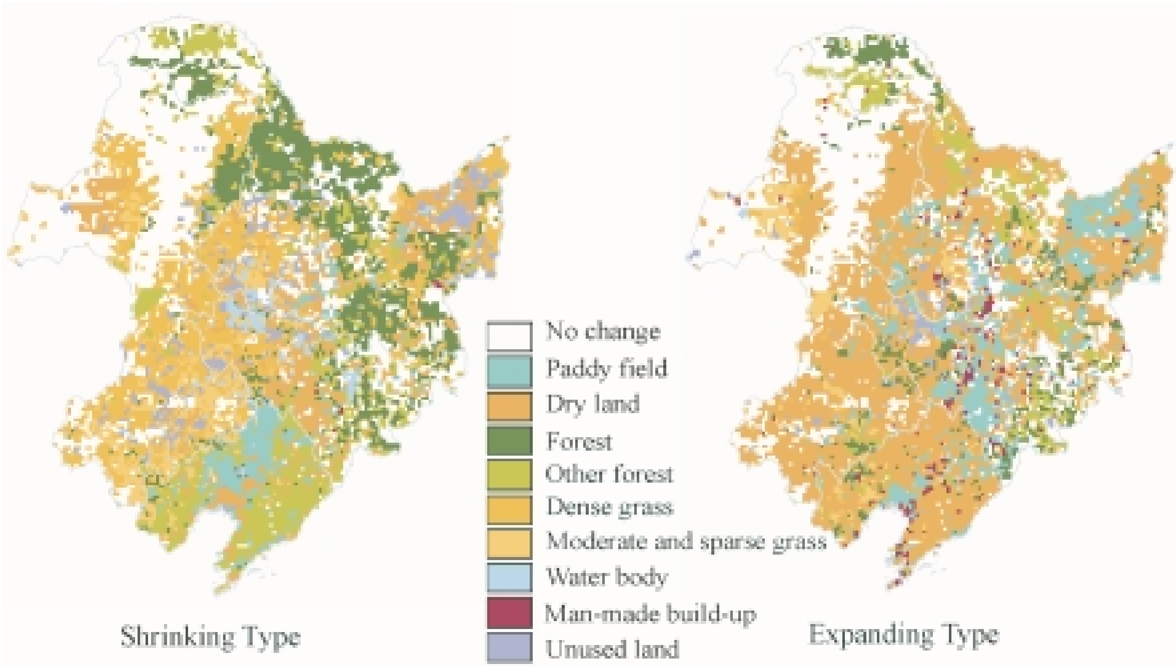

Figure 2 Main land-use change characteristics of Northeast China during 1985-2000

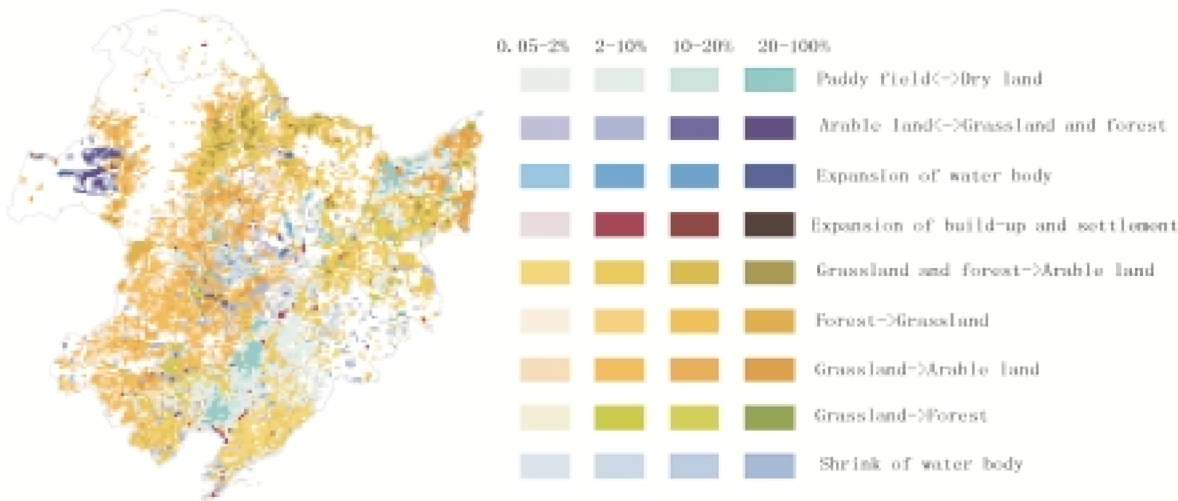

Figure 3 Spatial distribution of land-use dynamic degree

Based on the monitoring of Landsat MSS/TM/ETM images, nine kinds of land-use changes could be detected: P1, P2, P3, P4, P5, P6, P7, P8, P9 (Liu Jiyuan, Deng Xiangzheng et al, 2003). Among these 9 categories, P1 (arable land-arable land) refers to the conversion between paddy field and dry land; P2 results from reusing land as forest or grassland; P3 represents water body expansion (including river, lake, reservoir, glacier, beach land, etc.); P4 mainly refers to other types of land-use being transformed into built-up area; P5 results from deforestation and reclamation; P6 discloses forests being destroyed into grassland; P7 is about grassland or swampy land being reclaimed; P8 mainly refers to the tree planting and afforestation in grassland or swamp land; and P9 represents the conversion from a body of water to cropland, woodland, grassland or unused land.

3 SPATIAL DIFFERENTIATION OF LAND-USE CHANGE

Based on the calculation of dynamic degree model of land-use change (Figure 3), we subdivided Northeast China into 5 zones in land-use dynamic types in light of administrative divisions as well as geographical background maps: (1) woodland/grassland-arable land conversion zone, (2) dry land-paddy field conversion zone, (3) urban expansion zone, (4) interlocked zone of farming and pasturing and, (5) reclamation and abandon zone (Figure 4).

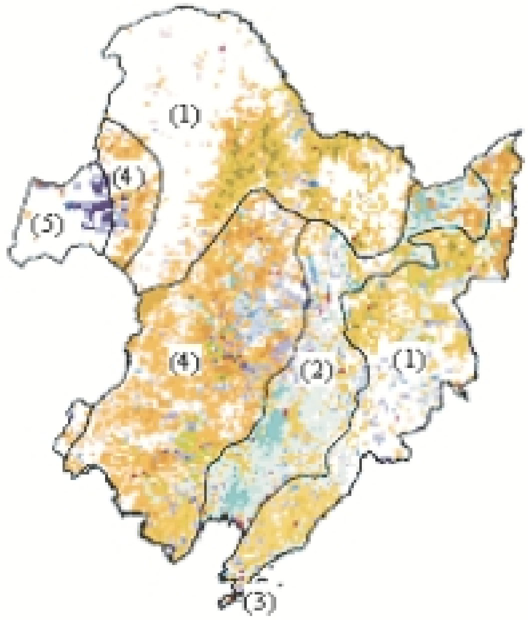

Figure 4 Zones of Northeast China based on land-use dynamic degree model

Land-use change of Northeast China can be generalized as follows (Table 1): increase of cropland area was dramatic, paddy field and dry land increased by 75 and 276 thousand hm^2 respectively; urban areas expanded rapidly, areas of town and rural residence increased by 77 thousand hm^2; areas of forests and grassland decreased sharply with the amounts of 1399 and 1521 thousand hm^2 respectively; areas of water body and unused land increased by 148 and 514 thousand hm^2

Table 1 Land-use change for each zone in Northeast China during 1985-2000

Units: hm2

Zone	Paddy	Dry land	Forest	Grassland	Water	Built-up	Unused
1	159071	1521795	-1083139	-461580	4899	22537	-160940
2	294151	78205	-141115	-77377	-51091	36950	-139707
3	0	5438	-3463	-2075	-19	23	96
4	295533	1304445	-170889	-1132204	-111433	16257	-201702
5	0	-150137	-318	151913	9184	1015	-11659
Total	748754	2759745	-1398925	-1521320	-148461	76783	-513911

Tables 2 Land-use change for nine change categories of Northeast China from 1985 to 2000

Units: hm^2

Zone	P1	P2	P3	P4	P5	P6	P7	P8	P9
1	153529	70929	25972	28111	1063543	150249	693980	90877	22437
2	1209572	55029	21137	37788	171838	13245	261302	16851	68583
3	0	1363	0	23	2213	2413	4606	246	19
4	241958	297112	34199	16430	177362	278708	1702188	153742	145676
5	0	167073	12002	1015	0	524	17011	206	2819
Total	1605059	591506	93311	83367	1414957	445139	2679086	261922	239534

respectively. It also shows obvious spatial differentiation in land-use change of Northeast China.

There also exists conspicuous spatial differentiation for the nine kinds of land-use change categories in Northeast China (Table 2). Woodland/grassland-arable land conversion zone is located in the interlocked areas of agriculture and forestry, where large areas of natural woods (with areas of nearly 108 thousand hm^2) were felled in order to meet the requirement of cropland increase. Dry land-paddy field conversion zone is characterized by the conversion from dry land to paddy field; the increased paddy field totals 294 thousand hm^2. The interlocked zone of farming and pasturing (characterized by the conversion from grassland to cropland) includes newly reclaimed cropland of nearly 1702 thousand hm^2, among which two thirds come from the conversion of grassland with high shade density, while areas reused as forests or grassland totals 297 thousand hm^2. Therefore, this area, in other words, took on the characteristics of cropland expansion and grassland shrinking. The reclamation and abandon zone is mainly located in the arid and sub-arid area, where the interlaced distribution of reclamation and abandon is common. The cropland increased by a total of 17 thousand hm^2, while the grassland decreased by 30 thousand hm^2. As a whole, there are two directions for grassland conversion: one is cropland; the other is wildness. And the probabilities for the two directions are nearly equal. The urban expansion zone, traditionally, is the farming belt, characterized by the conspicuous expansion of urbanization. This increased build-up area totals 23 hm^2, though the total area of the zone is small, less than 1 thousand hm^2.

4 DRIVING FORCES OF LAND-USE CHANGE

Land-use/coverage change is an important indicator of human activities that have direct bearings on natural resources and the environment (Eric F. Lambin, B. L. Turner, et al., 2001; Peter Klepeis, B.L. Turner , 2001). There are two premises for humans to carry out their land-use activities. One is the favourable environment and resources, and the other is the ability to carry out human activities. Environment and resources comprise regional elevation, annual precipitation, accumulated temperature, etc. Based on the overall features of the physical elements of Northeast China, after analyzing them carefully, we can conclude that some key biophysical factors affect conspicuously the conversion of different land-use types (Figure

5, 6 and 7). Figure 5 tells us that when make a comparison between conversions from "dry land to paddy field" and "other land-use types to built-up areas" and "woodland to cropland", the former responds more strongly than the other types to elevation gradation. For the conversion from dry land to paddy field, an elevation of 127 meters above sea level would be perfect and easy to convert. For conversion from "other land-use types to built-up areas," the best elevation would be 150 meters, and the conversion from "woodland to cropland" 350 meters. Except for the more advantageous elevation value, the trend to descend with curvilinear style is conspicuous for these three kinds of conversion. Based on Figure 6, we can find that, as a whole, with the increase of accumulated temperature during ≥10˚C periods, each kind of conversion shows a trend to increase. Yet, conversion from paddy field to dry land and other land-use types to built-up area, and the water body expansion climbs up to maximal amount with the accumulated temperature (during ≥10˚C periods) of 3139, 1492 and 2210˚C respectively. Comparatively speaking, the increase of annual precipitation affects significantly the conversion from other kinds of land-use to built-up areas, dry land to paddy land, and woodland to cropland (Figure 7). Furthermore, with the increase of annual precipitation, the fluctuation of conversion amounts tends to be more conspicuous, until it stays at an annual precipitation of 427, 357 and 532 mm and gets its corresponding maximal value respectively.

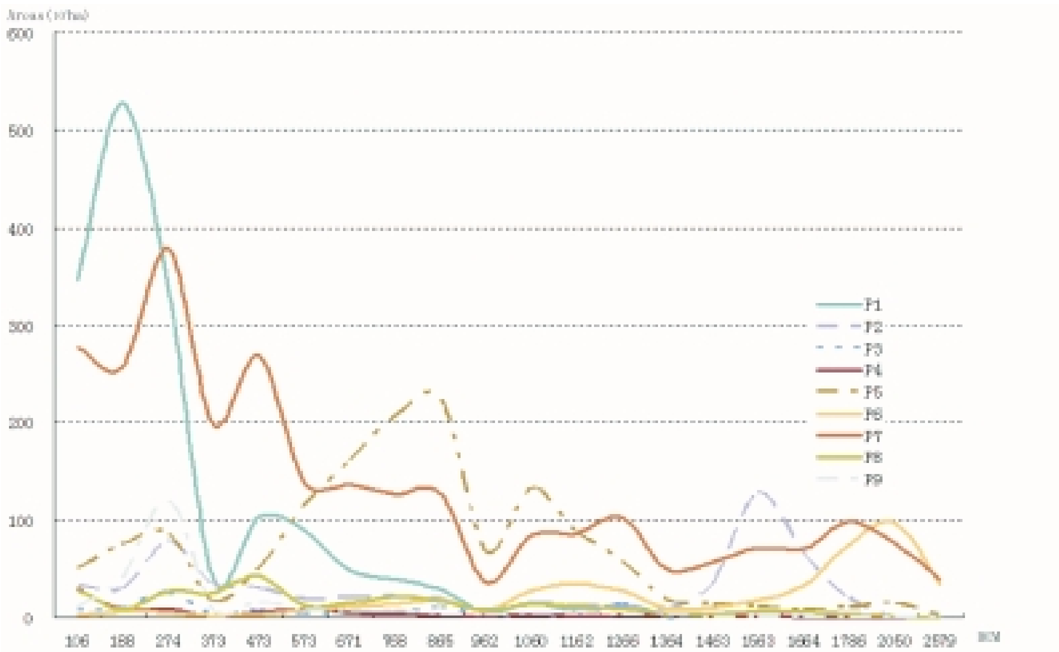

Figure 5 Couplings between land-use changes categories and elevation gradations in Northeast China

Notes: Values listed in the X axis are the breakpoints calculated by the division of the range of DEM value based on the statistical formula(Jenk's optimization) which made the sum of the variance with each of classes mimimal; areas summarized based on each classes were calculated and represented in the Y axis.

Besides the restricting factors of physical elements, social and economic factors also exert profound influences on the land-use change in Northeast China. Just like the spatial distribution of land-use change, the social and economic driving forces also take on the spatial differentiation corresponding to the land-use change. We will use Canonical Correlation Analysis (CCA) to explain the land-use change, considering its necessity and academic significance. CCA aims to determine the significant correlations between two groups of variables. In order to seek the correlation between two groups of variables, their linear combinations should be, firstly, determined and, made the maximal correlation exist. Their linear combinations, however, are underlying, and hard to be noticed, working as unknown variables and named after canonical variables. The significant correlation of the two canonical variables is the canonical correlation and is always represented as "ρ".

In this paper, we use the social-economic factors as the independent variables, covering total population growth (TPG), agricultural population growth (APG), gross output of meat (GOMe), gross output of milk (GOMi), acreage planted of cereal

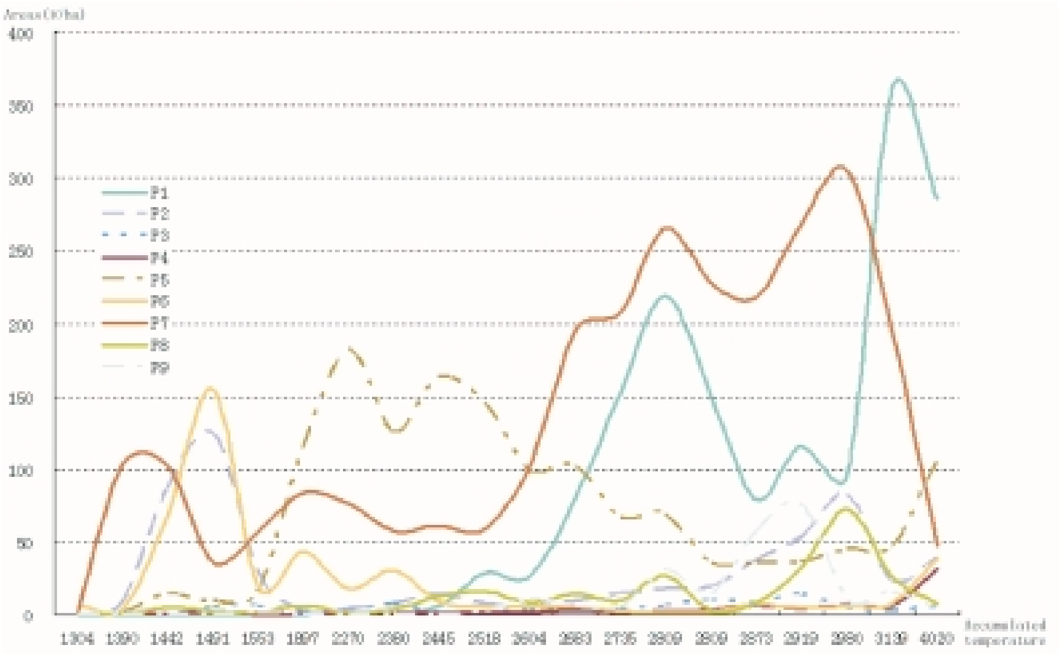

Figure 6 Couplings between land-use categories and accumulated temperature in Northeast China

Notes: Values listed in the X axis are the breakpoints calculated by the division of the range of accumulated temperature(≥10˚C v value based on the statistical formula(Jenk's optimization) which made the sum of the variance with each of classes mimimal; areas summarized based on each classes were calculated and represented in the Y axis.

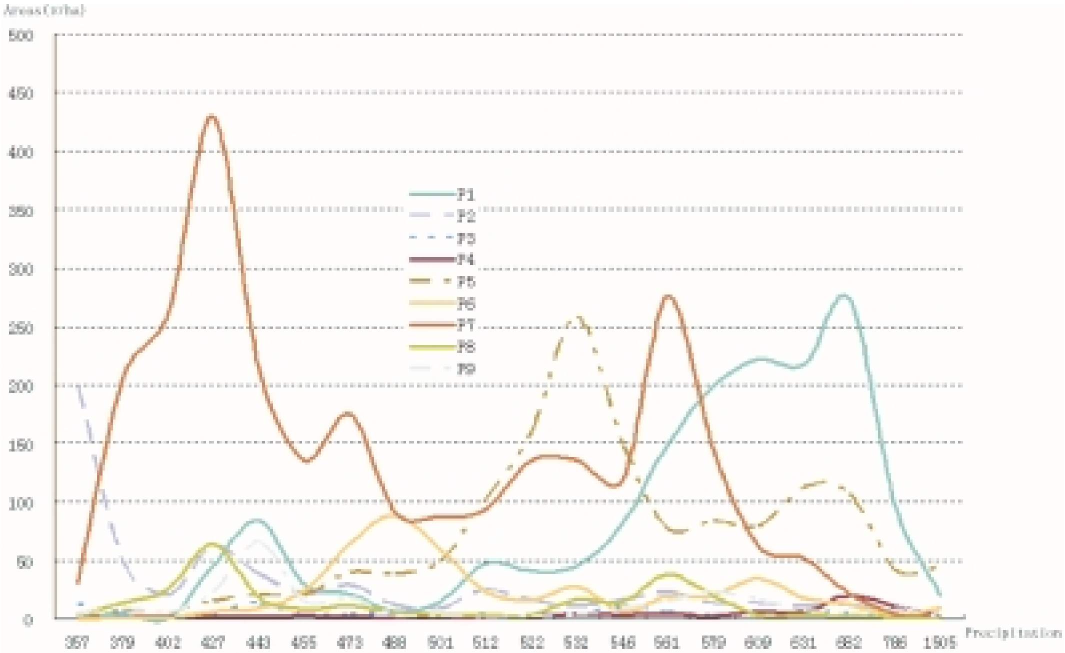

Figure 7 Couplings between land-use categories and precipitation in Northeast China

Notes: Values listed in the X axis are the breakpoints calculated by the division of the range of precipitation value based on the statistical formula(Jenk's optimization) which made the sum of the variance with each of classes mimimal; areas summarized based on each classes were calculated and represented in the Y axis.

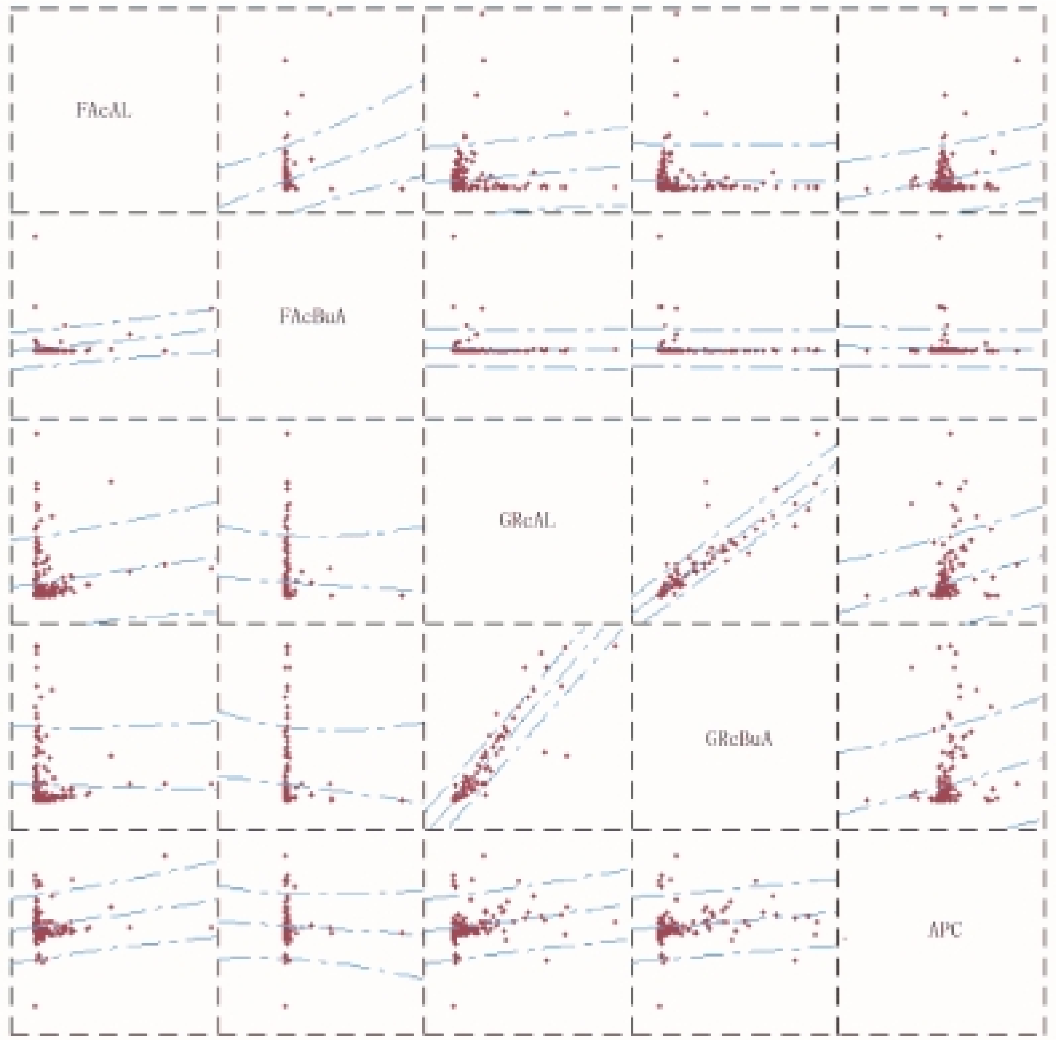

Figure 8 The exploration of the correlation among FAcAL, FAcBuA, GRcAL, GRcBuA and APG

(APC) and gross output of cereal (GOC). In the meantime, we use the typical conversion land-use categories as dependent variables, applying CCA methods to find out the relationship between them. The conversion from dry land to paddy, arable land to built-up areas, forest area to arable land, forest area to built-up area, grassland to arable land, grassland to built-up areas, remaining areas to arable land, remaining areas to forest areas, and remaining area to grassland, are abbreviated as ALcAL, ALcBuA, FAcAL, FAcBuA, GRcAL, GRcBuA, RAcAL, RAcFA and RacGR respectively. The 3-dimenstion (3D) scatterplot is one of the most powerful tools for exploratory data analysis. Figure 8 identified the relationship among FAcAL, FAcBuA, GRcAL, GRcBuA and APG. Before we estimated the canonical coefficients, the correlation among the dependent and independent variables was explored by drawing such kind of 3D scatterplot. Table 3 is the summary table of CCA for the selected socio-economic indices.

Based on Table 3, following conclusions can be drawn: (i) All three selected canonical coefficients are significant at the observed significance level (less than 0.05). The first, second and third canonical coefficients are 0.739, 0.577 and 0.522 respectively. The six independent variables chiefly influence the dependent variables via the three canonical coefficients. (ii) The first canonical component (X_1) can explain 54.6% of the variance of the first component (Y_1) of dependent variables.

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The first component of the dependent variables, however, can explain 17.506% of the variance of dependent variables. This means the independent variables by the first canonical components (X_1 & Y_1) can explain 9.559% of the variance of the dependent variables due to the existence of overlapping value (9.559%; abbreviated by Pct Var CO in Table 3, the same below). (iii) The second canonical component (X_2) can explain 33.3% of the variance of the second component (Y_2) of dependent variables. In contrast, the first component of dependent variables, however, can explain 14.274% of the variance of dependent variables, i.e. the independent variables by the second canonical components (X_2 & Y_2) can explain 4.755% of the variance of the dependent variables due to the existence of overlapping value (4.755%). (iv) The third canonical component (X_3) can explain 27.2% of the variance of the third component (Y_3) of the dependent variables. The third component of the dependent variables, however, can explain 13.351% of the variance of the dependent variables, i.e. independent variables by the third canonical components (X_3 & Y_3) can explain 3.631% of the variance of the dependent variables due to the existence of overlapping value (3.631%). (v) The overlapping value aggregated from the three canonical components totals 17.945%. In other words, the six independent variables can explain 17.945% of the total variance of the dependent variables via the three pairs of canonical components (X_1 & Y_1; X_2 & Y_2; X_3 & Y_3). Therefore, a reasonable conclusion can be safely made that some typical conversion categories have been driven by the selected indices. Further analyses for the structural coefficients, shows that the regression coefficient between TPG and APG, as well as ALcBuA, ALcBuA, FAcAL, FAcBuA, GRcAL, GrcBuA with APC, has passed the t test ($p<0.001$) as means population growth, especially the agricultural population growth, together with the increase of acreage planted areas.

Table 3 The summary of CCA between land-use change and the selected socio-economic factors

Independent Var.	X_1	X_2	X_3	Depend Var.	Y_1	Y_2	Y_3
TPG	0.615	0.053	0.713	AlcAL	-0.486	-0.160	-0.498
APG	0.699	0.181	0.614	ALcBuA	-0.369	-0.665	0.612
GOMe	-0.468	-0.206	-0.175	FAcAL	0.381	-0.575	-0.363
GOMi	0.190	0.060	-0.045	FAcBuA	0.169	-0.630	-0.506
APC	0.641	-0.670	-0.188	GRcAL	0.672	-0.220	-0.286
GOC	-0.223	-0.195	-0.294	GRcBuA	0.603	-0.139	-0.283
				RAcAL	0.382	-0.124	-0.149
				RAcFA	0.112	0.037	-0.038
				RAcGR	0.237	0.072	-0.074
Pct Var CO	0.26355	0.09483	0.17321	Pct Var DE	0.17506	0.14274	0.13351
Pct Var DE	0.14390	0.03159	0.04711	Pct Var CO	0.09559	0.04755	0.03631
				Sq. Cor.	0.546	0.333	0.272
				Canon Cor.	0.739	0.577	0.522

Rapid population growth and management changes can explain the shaping of woodland/grassland-cropland conversion zone. Yet, the differentiation between its northern and southern regions should also be noticed. Its northern region has become one of the most concentrated areas of "out-census" population. Since the family planning policy was implemented in the 1970s, large numbers of farmers from China's other provinces converged here with the aspiration to have more sons, so as to ensure their old age security as there was no effective social security system in that time in rural China. And now, their "sons" have grown up, with nearly identical life style as their fathers--to illegally fell trees or reclaim grassland, which led to the decrease of woodland and grassland areas and the consequential increases of cropland areas.

The southern region of the Northeast, however, with its dense forest centres, has different developments. After the government carried out "forestry protection" policies, large numbers of farmers were forced to abandon farmland inside protected zones. Some farmers began to reclaim land outside the forest centres, with the conspicuous trend to stretch their farmland toward forestry centres until they encroached upon protected forests. In addition, some forestry centres have no other industries to develop but to continue to organize laid-off workers to reclaim marginal land. The above-mentioned reasons led directly to the conversion from forestry and grassland to cropland.

There are two kinds of conversion from paddy field and dry land: conversion from dry land to paddy field as well as from paddy to dry land in the dry land-paddy field conversion zone. The former, apart from the change of physical elements change promoting the expansion of paddy field, results from two reasons: one is that the implementation of market economy in China has given farmers the right to decide what and how they plant their crops. Since the market prices of rice are higher than those of corn and wheat, more and more farmers choose to convert their dry land to paddy field. Another factor in this change originated partially from the change of the dietary habit along with the social and economic development. More and more people begin to consume rice over wheat, which leads to the increased demands for rice in grain markets, thus further promoting the conversion from dry land to paddy field. The conversion from paddy field to dry land is caused primarily by the shortfall of irrigation water, which in turn is caused by poor water allocation managed by local governments. It can be imaged: if farmers in the upper reaches of a river use most of available river water, those in the middle and lower reaches just can only depend on rains to irrigate their rice paddies. In arid seasons or a dry year, these farmers in the middle and lower reaches would have to convert their paddy fields to dry farming, that is, replacing rice with wheat or corn to assure their harvest. As a whole, the above-mentioned situations have resulted in the shaping of the paddy field-dry land conversion zone.

The shaping of the reclamation and abandon zone is partially due to the lack of environment protection consciousness among pioneer settlers. As we all know, the population density in Northeast China is comparatively lower than the national average. The early settled pioneers engaged in wonton deforestation and land reclamation. The black earth abundant with humus could assure good harvest for several years. Yet it is also liable to lose fertility without continual fertilization. The local settlers always abandoned their land after exhausting its fertility, and turned to reclaim new black earth somewhere else. This, undoubtedly, led to the increases of abandoned cropland. In addition, the lack of supervision and directions from the government further sped up the process of illegal reclamation and irrational abandonment of cropland.

Comparing profits received from farming with pasturing, the former is 179 times higher than the latter. The reason for the conversion from grassland to cropland is the relatively higher profits of farming than that of pasturing in the interlocked zone of farming and pasturing. Again, benefiting from the implementation of the market economy, some "herdsmen" begin to throw away whips and pick up hoes to regain more profit, which leads to the conversion from grassland to cropland. Another reason is the existence of population pressure in the transitional zone of farming and pasturing. As we know, pasturing has lower population carrying capacity than farming. This further induces, or promotes, the conversion from grassland to cropland. Besides, the variation of air temperature and precipitation is another factor in determining this kind of conversion.

Urbanization, in some sense, is a necessity accompanying social and economic developments (Fridolin Krausmann, 2001). Since China is one of the largest developing countries in the world, the expansion of built-up or resident areas will last for a long time to come. In Northeast China, the rapid expansion of built-up areas results from two factors: the first is its small number of towns; the second comes from the huge potential for expansion of the existing towns and cities. It is noticeable that urban expansions in the Northeast are characterized by gentle topographic relief and low population density. Physiognomy, transportation and economy exert great influences on the urban expansion.

5 CONCLUSION

There exists conspicuous spatial differentiation in land-use change of Northeast China during 1985-2000, and the spatial differentiation of land-use dynamics reveals the features of land-use change patterns and their hidden driving forces. The regional land-use change is a collective outcome influenced by physical environment, global change and human activities. Consequently, great emphases should be laid on the following aspects: monitoring of land-use change, analyzing the driving forces affecting changes, identifying global changes influencing land-use, model-building for predicting land-use change, and studying the effect of land-use change on the biogeochemical cycles of terrestrial ecosystem. For the moment, we have set up a continual and long-term monitoring system of land-use change, with multiple tasks being incorporated, e.g. studying the influence of human activities on land-use change and on global environment, and studying their corresponding biogeochemical cycles supported by our abundant data accumulation.

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