ORIGINAL ARTICLE

Processes and prediction of land use/land cover changes (LUCC) driven by farm construction: the case of Naoli River Basin in Sanjiang Plain

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Abstract The fundamental land use/land cover change (LUCC) of Naoli River (NLR) Basin in Sanjiang Plain since 1954 is characterized with a very significant shrink of wetland area, primarily due to agricultural reclamation, especially farm construction. In this paper, LUCC data of six periods were generated to explore the process of LUCC in NLR; the driving factors were discovered and the regression analysis of these driving factors was realized using the Dyna-CLUE model; and the land use pattern of 2020 in NLR Basin was projected under six scenarios. The results showed that the area ratio of wetland decreased from 45.84 % in 1954 to 9.76 % in 2010, and meanwhile, the area ratio of cultivated land (including paddy field and dry land) increased from 8.20 to 57.97 %, and areas of other land use types also changed dramatically. Demographic factors, especially large-scale farm construction, were the key driving factors of LUCC. The projection results presented a general trend of LUCC, with a constant increase of paddy field, a slow decline of dry land, and a gradual decrease of wetland, and wetlands in the downstream area of NLR were identified as the most sensitive to be affected, and badly in need of protection.

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Introduction

Land cover is a natural condition of Earth's surface and subsurface, while land use refers to the manner of human-kind based on natural attributes of land in order to achieve the desired products or service, (Turner and Meyer 1991; Turner et al. 1993, 1995a). LUCC at local scales affects and is affected by climate changes, biodiversity changes, and sustainability of human environment. For the significance of LUCC in global changes, the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global environmental (IHDP) jointly enlist LUCC as one of the core subjects of global changing studies (Turner et al. 1993, 1995a, b; Chen and Sun 1994; Li et al. 2002; Yunlong 2001; Chen and Yang 2001; Shi and Gong 1996; Lambin et al. 1999).

Regional case studies are essential not only for cause researches of LUCC, but also for in-depth investigation of Earth system function through global LUCC modeling. Regional LUCC researches mainly focus on "hot spots" and "key areas" (Lambin et al. 1999), and LUCC modeling is a significant means to deeply explore the complexity of LUCC (Bai and Zhao 1997). Studies on regional LUCC characteristics and its driving mechanism play a scientific part in projection and evaluation of environment change and in understanding the effects of human activities on global changes. Meanwhile, revealing spatial/temporal patterns and changing tendencies of regional LUCC and exploring the driving mechanism of LUCC play a significant role in coordinating relations among people, land and the sustainable use of land resources.

Among all regional LUCC study areas, Sanjiang Plain belongs to "hot spots" and "key areas" and is an important part of global changes researches (Li 1996). Since the beginning of P. R China in 1949, especially after the reform and opening up policy coming into practice in late 1970s, the economic and social outlook of Sanjiang Plain has changed dramatically, and so are its land use patterns. Sanjiang Plain now is a very important national grain production base after 50 years of agricultural development, primarily through transforming wetlands to arable lands. Back to 1893, the cultivated area was 2.9×10^4 ha, accounting for only 0.27 % of the total land area. By 1949, the cultivated area reached 78.6×10^4 ha. Since the starting of large-scale wetland reclamation in 1970s, the cultivated area quickly increased to 352.1×10^4 ha in 1983, and 454.24×10^4 ha in 1994 (Liu and Ma 2002). As a result, the natural wetland ratio in Sanjiang declined from 32.42 % in 1954 to 7.45 % in 2005 (Huang et al. 2009). Due to the wetland protection policy and the reforesting program, the arable land area did not change much in the last 10 years.

The significant decline of wetland area caused many environmental problems, such as loss of biodiversity, non-point source pollution, soil pollution and increasing release of greenhouse gases, and endangered the sustainable development of Sanjiang Plain. The occurrence frequencies of drought and waterlogging disaster in Sanjiang Plain were respectively, 23.8 and 33.3 % in the early period of wetland reclamation (1949–1969), and respectively increased to 33.3 and 47.39 % in the period of large-scale reclamation (1970–1990) (Liu et al. 2002). Dynamic changes of wetland in Sanjiang Plain from 1986 to 2000 resulted in declining of wetland ecological functions (Li et al. 2002). National macro agricultural policy and market were identified as the significant driving factors for LUCC in Sanjiang Plain (Song et al. 2008a).

The exploitation of natural resources to meet human needs such as food, fibre, shelter, etc. is the main driver of LUCC (Turner and Meyer 1994; Lambin et al. 2001; Verburg et al. 2004). Discovering the process of LUCC on regional scales based on remote sensing and GIS, not only helps to understand the driving mechanism of LUCC and accumulate regional cases for global changing studies, but also helps to adjust human activities, optimize resources allocation, and realize sustainable land use. In this study, the process and driving factors for LUCC in the NLR Basin were investigated, and the tendency of LUCC of NLR Basin in 2020 was projected in six scenarios to reveal the need of suitable policies to protect its sustainable development. The NRL Basin, as a national nature reserve, accounts for about 1/4 of Sanjiang Plain, while its wetland area accounts for over 1/4 of that of Sanjiang Plain (Yi and Zheng 1988; Cui and Liu 2001). Such a study would be of importance for studies on LUCC in Sanjiang Plain and global environment changes.

Materials and methods

Study area

NLR Basin (45°43′–47°35′N, 131°31′–134°10′E) lies in the heart of Sanjiang Plain with a total basin area of 2,507,934 ha with an average altitude of 60 m (Fig. 1). With a temperate continental monsoon climate, the annual average temperature is 1.6 °C. The average temperatures in January and July are −21.6 and 21.6 °C, respectively. Average annual rainfall is up to 565 mm, and the average evaporation rate is 542.4 mm. Due to a low topography with poor surface runoff, widely developed flood plains are conducive to the formation of wetlands. Three important wetlands, the Qixing river wetland, the Waiqixing river wetland, and NLR wetland have developed in this basin. The Qixing river wetland is listed as one of national wetland nature reserves. Main plants are *Carex pseudo-curaica*, reeds and *Carex lasiocarpa*, which all belong to *Calamagrostis anqustifolia* community. There are also a lot of auxiliary species, such as *Caltha palustris, Glyceria spiculosa,* lobed *Actinostemma* herb and *Pedicularis longiflora* etc., (Zhao 1999). Regarding administrative divisions, NLR Basin consists of the whole Baoqing County, parts of Fujin, Raohe, Youyi, Jixian and Shuangyashan, and two state farms (Jiansanjiang and Hongxinglong).

Since the 1950s, the wetland area in NLR Basin has been shrinking at a large scale and leads to the decline of ecological functions of wetland. Wetland reclamation results in cutoff of small rivers and dry-up of lakes (Yi and Zheng 1988). Precipitation was about 180 mm less in recent years than that of 20 years ago, with a decline rate two times of that in the Russian Far East. There was an increase of 39.5 % of drought events during 1970–1990 compared with the period of 1949–1969, and 26 spring drought events during 1949–1999 led to reduction of 0.1 billion tons of grains.

Data sources and processing

Based on field investigation and TM/MSS (Thematic Mapper picture of Landsat 5; Multi spectral scanner picture of Landsat1-3) images as well as topographic maps, a land use/land cover classification system was established, including forest land, grassland, water, wetland, residential land and cultivated land (paddy field and dry land), in reference to the land use/land cover classification system of IGBP and the United Nations Food Agriculture Organization. There were seven types of land use/cover change,

Fig. 1 Study area

including dry land, paddy field, woodland and grassland, water, construction land and wetland.

This study covered a period of 60 years which were divided into six periods, respectively, 1954–1976; 1976–1986; 1986–2000; 2000–2008; 2008–2010. Data sources were different in these periods, and processed in different ways as needed. TM satellite remote sensing images were adopted for the period of 1986–2010 with a resolution of 30 × 30 m per pixel and bands of 4, 3, and 2; in 1976, MSS images were used with a resolution of 80 × 80 m per pixel and in 1954, topographic maps were taken as the data source. Interpretation signs were established based on the image characteristics of wetland in NLR Basin after the registration of land sat TM (ETM) data of 2000 with 1:100000 topographic maps. And then the information of land use/land cover in the study area was obtained. TM images of 2008, 2010, and 1986, MSS images of 1976 were corrected based on the data of 2000. Then compared with the images of 2000, the polygons of changed land use were drawn in order to generate dynamic changing data of the four periods. Since data of 1954 was based on contemporary topographic maps, with some land use types no obvious boundaries, the polygon was drawn based on the classification land boundaries if available or along the lowest contour line if not available. The precision of the land use data in 1986, 2008 and 2010 was 1:10 million. The MSS image in 1976 was not able to complete the required 1:10 million scale accuracy. In order to make up for the defect of insufficient resolution, topographic maps (1:10 million and 1:5 million) of the same period were used for obtaining the second data sources of data. There was a lot of useful land use/land cover information in topographic maps, such as marshes (passable swamp, impassable bog), sand, saline alkali land, woodland (with a variety of symbols and lines). The precision of the land use data in 1976 could reach 1:20 million scale by effective integration. The precision of the land use data in 1954 could reach 1:10 million scale through using topographic map (1:10 million) and physical environmental background maps including terrain, climate, geology, soil, vegetation and hydrology as well as socioeconomic statistical data. Although the spatial data accuracies in 1954, 1976, 1986, 2008 and 2010 were different, the differences did not affect the analysis of land use trends. Social and economic data were used, including statistical yearbook 2010 of Heilongjiang province, agricultural reclamation statistical yearbook 2010 of Heilongjiang province and other statistical data. Finally a land use data of the six periods and a 50 m GRID analysis data were generated by dynamic changing data and data of 1954 and 2010 (Fig. 2), respectively. With the help of GPS, digital camera and portable computer, 600 field points were verified during field visits in 2010. Through on-site verification and correction, the accuracy of the land use data was over 90 %, and the interpretation accuracy of cultivated land, construction land, and water was even more than 95 %.

The analysis method of LUCC

One must interpret the transitions relative to the sizes of the categories in order to identify systematic transitions within the matrix (Pontius et al. 2004). The dynamic degree of one land use type is introduced to analyze time differences. The calculated form was:

$$R = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\,\%$$

In this form, U_a and U_b refer to the beginning and the ending area of a certain land use type, respectively. T refers to time (Liu et al. 2003).

Spatial distribution of land use types in six scenarios was analyzed with Shannon diversity index (SHDI) and landscape contagion index (Contag). SHDI, a popular measure of diversity in community ecology, is applied here to landscapes. Contagion is inversely related to the edge density. When the edge density is very low, for example,
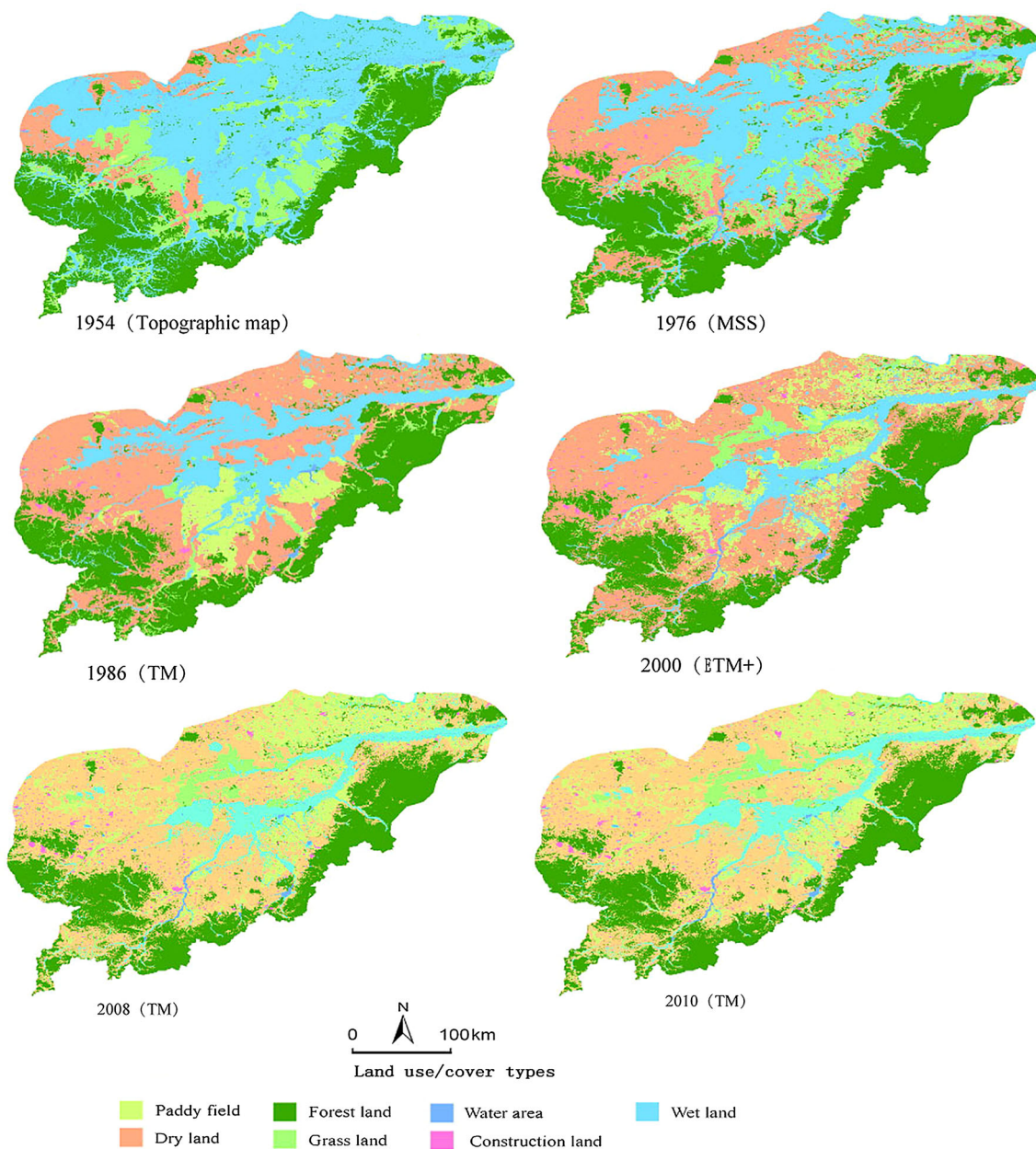
Fig. 2 Process of land use/land cover changes

when a single class occupies a very large percentage of the landscape, contagion is high, and vice versa.

Projection analysis of NLR basin based on dyna-CLUE model

As a cognitive and learning tool, LUCC model helps people to understand and interpret changing rules and characteristics of LUCC (Verburg et al. 2006). The purpose is to understand LUCC mechanism better, and to analyze the changing ratio and spatial pattern effectively. LUCC models can project the future land use changes under

different scenarios (Economic development and environmental protection). Using the Dyna-CLUE model to analyze dynamics of LUCC in NLR Basin, six possible tendencies of LUCC in 2020 are projected. The Dyna-CLUE model is based on dynamic, multi-level, multi-scale land use changes and its spatial distribution projection model, and meanwhile, land use is realized in a multi-level society and ecosystem (Veldkamp and Fresco 1996; Verbrug et al. 1999; Verburg 2006). Dyna-CLUE model mainly consists of two separate modules, namely, non-space requirements module and space allocation module. The former is mainly used to analyze the future demand of

land use, based on dynamics of driving factors for the land use system. The demand data can be obtained by linear regression or SD model or be set up in reference to regional land use plan; the later is mainly used to calculate distribution possibilities of each land use type by the logistic regression of spatial distributions of those driving factors (Verburg et al. 2002). The logistic regression analysis can be realized by converting raster data into text data and then importing them into statistical software such as SPSS.

$$\log\left\{\frac{P_i}{1-P_i}\right\} = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \cdots + \beta_n X_{n,i}$$

P_i is the probability of the i-th grid which has a certain land use type, and n indicates the number of driving factors. Then regression analysis of each land use type is carried out one by one with the certainty that the regression equation conformed to the accuracy requirements (generally greater than 0.7) with ROC curve. To realize projection of land use changes, relevant parameters, such as space policies and restrictions, conversion stability, conversion rules, land use requirements, space allocation, should be input and undergo necessary accuracy tests. Kappa coefficient is calculated to consider various possible errors (Congalton 1991), a is the reference map and b is the projected result.

$$\text{Kappa} = \frac{A\sum_{i=1}^{n} w_i - \sum_{i=1}^{n}(x_{i,a}x_{i,b})}{A^2 - \sum_{i=1}^{n}(x_{i,a}x_{i,b})}$$

A is total area of the study area, n for the total number of land use types. w_i refers to the same i-th land use type area of the two diagrams. And $x_{i,a}$, $x_{i,b}$ indicate, respectively, areas of the i-th land use type in diagram a and b.

Finally, six scenarios were generated with different assumptions: moderate economic development (GDP growth: 5 %) with no environmental protection requirements (scenario 1), moderate economic development with environmental protection maintaining the status quo (scenario 2), moderate economic development with strict environmental protection (scenario 3), high-speed economic development (GDP growth: 10 %) with no environmental protection requirements (scenario 4), high-speed economic development with environmental protection maintaining the status quo (scenario 5), high-speed economic development with strict environmental protection (scenario 6). Here, moderate economic development referred to developing at the speed of land use change from 1954 to 2010. High-speed economic development referred to increasing areas of cultivated land, paddy fields transformed from dry land, and infrastructure construction (towns, roads, and ditches, etc.) for greater economic benefits. Maintaining the status quo for environmental

protection meant that any new production and operating activity should be banned in NLR National Nature Reserve and Qixing River National Nature Reserve, that is, no new cultivated land or construction land. Strict environmental protection referred to that all cultivated land and construction land should be returned to wetland and strict ecological protection strategies should be exercised.

$$\text{Max(Min)}z = c_1 x_1 + c_2 x_2 + \cdots + c_n x_n$$

where Max indicates the maximum, Min refers to the minimum, and c_i is a constant determined by x_i, which is a driving force of LUCC. According to solution of the linear programming mode, area of paddy field and dry land was under 1593268.00 ha, less than 64 % of total area; wetland area (present wetland area in the NLR National Nature Reserve and Qixing River National Nature Reserve) was over 126662.65 ha; water area (total area of NLR, Qixing river, and major reservoirs) was over 9468.75 ha (Table 1); because forest was mainly located in the eastern and southern mountain area under management of forest farms and environmental protection, forestland area was assumed unchanged in six scenarios.

Results

Temporal and spatial process analysis of LUCC in NLR basin

Land use in NLR basin changed dramatically from 1954 to 2010 (Fig. 2). The area ratio of wetlands decreased from 45.84 to 9.76 % while the area ratio of cultivated land (including paddy field and dry land) increased from 8.20 to 57.97 %, grasslands reduced from 15.36 to 4.65 % and forestlands decreased from 29.39 to 25.34 %. Regarding the changes of cultivated land, the area ratios of paddy field and dry land respectively, increased from 0.09 to 14.91 % and from 8.11 to 43.06 %. Calculation of land use dynamics degree showed that land use changed with time obviously (Table 2). Paddy field area continued to increase at a declining rate, which was the highest from 1976 to 1986; dry land area increased at first and then decreased, while reduced gradually after 2000; construction land area increased gradually but the growth rate was slowing, which was the largest from 1954 to 1976; wetland area decreased year by year while the decreasing rate was increasing gradually, and became relatively small after 2008 (Table 2). Once wetlands transformed into cultivated lands, they were rarely converted back to wetlands.
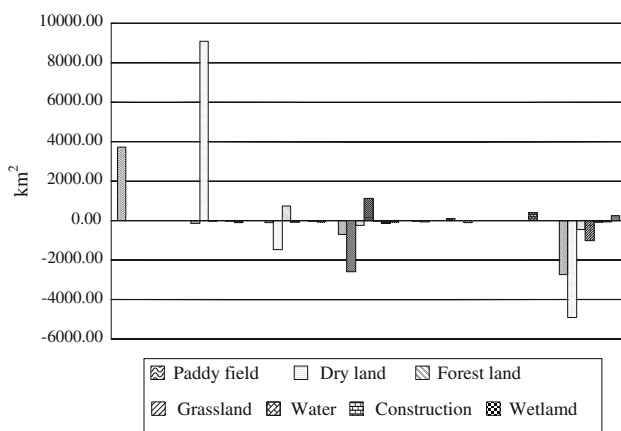
Land use changes from 1954 to 2010 were analyzed using transfer matrix of land use types (Fig. 3). A positive value indicated the area transformed from other land use types while a negative value meant the area transformed

Table 1 Dynamic degree of certain land use type

	Paddy field	Dry land	Forestland	Grassland	Water	Construction	Wetland
Status quo	375200.00	1080643.75	630406.25	113131.25	12756.25	39550.00	237793.75
Scenario 1–3	414454.25	1048658.50	630406.25	113131.25	12629.25	41160.75	229041.00
Scenario 4–6	504237.50	1038187.75	630406.25	83425.75	9406.75	43687.75	180129.50

Table 2 Dynamic degree of certain land use type

	1954–1976	1976–1986	1986–2000	2000–2008	2008–2010
Paddy field	−1.26	1137.91	4.60	2.00	0.04
Dry land	10.76	4.82	0.72	−0.42	−0.03
Forestland	0.09	−0.65	−0.73	0.07	−0.01
Grassland	−1.31	−6.63	1.31	0.89	−0.20
Water	−2.42	−4.47	5.04	4.84	0.00
Construction	14.96	4.90	−0.18	0.99	1.32
Wetland	−1.55	−3.99	−2.79	−1.48	−0.04

Fig. 3 Land use changes from 1954 to 2010

into other land use types. Paddy field, dry land, forest land, and construction land were largely transformed from other land use types, while wetlands, grasslands, and forestlands usually transformed into other land use types.

Using the raster calculator to analyze spatial dynamics of four land use types with larger changes, namely, paddy field, dry land, construction land and wetland (Fig. 4), changes of all the four types showed a tendency from west to east. Paddy field expanded gradually to the three northeast counties (Baoqing, Fujin and Raohe), including many farms, such as Chuangye, Qianjin and Shengli. Dry land area increasingly grew from west to east, which grew gradually in Baoqing, while reached the maximum in Fujin in 1986 and then was gradually transformed into Paddy field. Construction land also showed an extension from west to east. However, wetland area gradually shrunk from west to east, from north to south, and was mainly distributed in the mainstream basin of NLR and within the NLR National Nature Reserve.

Driving mechanism of LUCC in NLR Basin

Since 1949, reclamation has been the important reason for wetland loss, which has transformed the NLR Basin into one million hectares of fertile farmland. After the 1970s, five mechanized wetland reclamation demonstration sites have been established. As a result, NLR Basin becomes a major grain production and commodity grain base of China. The establishment of state-owned farms plays an unprecedented role in exploring wetlands in NLR Basin (Statistical Bureau of Heilongjiang Land Reclamation Bureau 2010). Temporal and spatial processes of LUCC showed that most wetland was transformed into cultivated land, which was the major characteristic of LUCC. Three counties in NLR Basin were selected to carry out correlation analysis of population data, wetland area, and cultivated land. Population of the three counties increased from 287770 in 1954 to 1091370 in 2010, a 3.62 increase (Heilongjiang Provincial Bureau of Statistics 2010; Statistical Bureau of Heilongjiang Land Reclamation Bureau 2010). Correlation coefficient between wetland area and population curve was −0.939; that between cultivated land and population was 0.924; and that between wetland and cultivated land was up to −0.997. Therefore, changes of wetland area were closely related to changes of cultivated land, while the population increase was the key driving force for the shrinking of wetland area. Selecting major driving forces, such as DEM, slope, and soil organic matter to carry out regression analysis based on SPSS and Dyna-CLUE model, the quantitative analysis model of different land use types was obtained (Table 3).

Dyna-CLUE model in six scenarios

Projection results showed a general trend of continuous growth of paddy field area, slow decline of dry land area,

A: Paddy land; B: Dry land; C: Construction land; D: Wetland
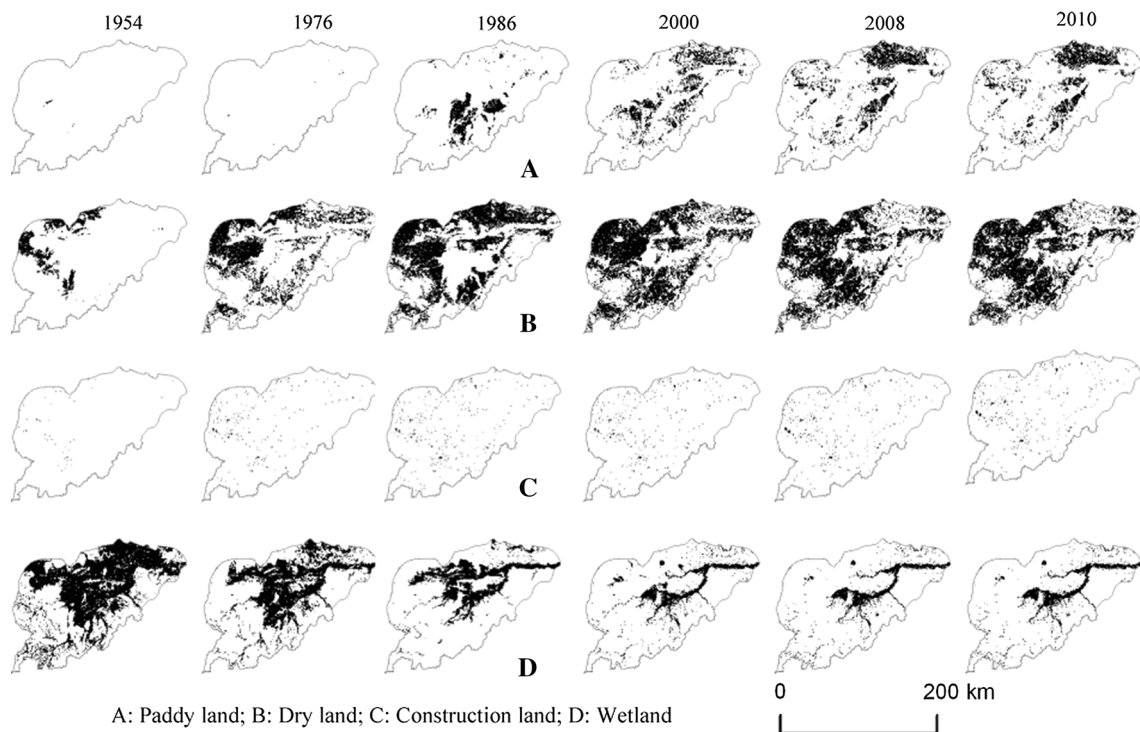
Fig. 4 Spatial changes of the four land use types

Table 3 Logistic regression results

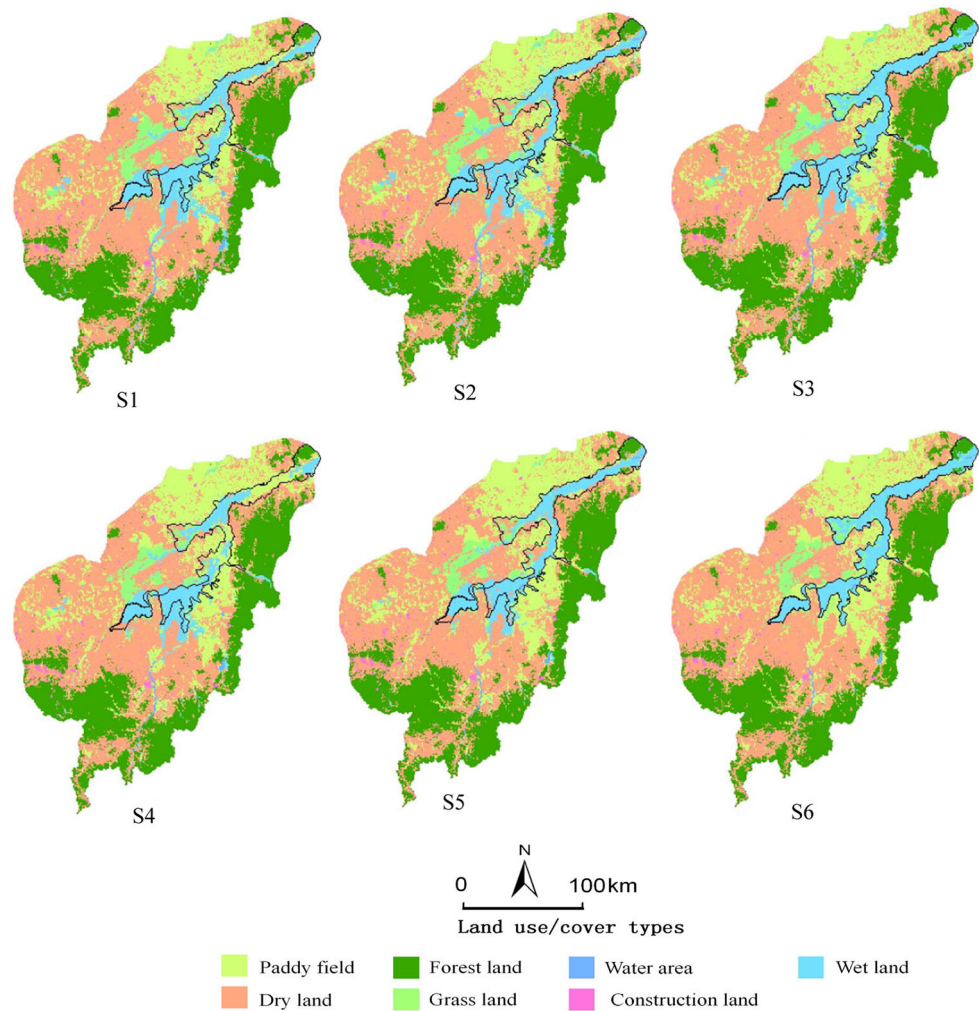|	EXP(β)						
Driving factor	Paddy field	Dry land	Forestland	Grassland	Water	Construction	Wetland
X1	−0.03096	−0.00435	0.02583	−0.00770	−0.01712	−0.00561	−0.01580
X2	0	−0.05002	0.08496	−0.06734	0.05057	−0.05566	−0.12823
X3	0.00002	−0.00007	0.00002	0	0	−0.00005	0.00007
X4	−0.00002	−0.00030	0.00009	0.00009	0.00010	−0.00033	0.00022
X5	0.00002	0.00002	−0.00001	−0.00005	−0.00030	0	−0.00014
X6	−0.00005	0.00001	−0.00004	0.00006	−0.00012	−0.00002	0.00001
X7	0.00035	0	−0.01205	0	0	0	−0.00440
X8	−0.00203	0	0	−0.00187	0	0.01934	−0.00599
X9	2.69013	−0.46378	−2.01791	3.20569	0	0	0
X10	−0.07679	0.01668	0.02363	−0.05646	0	−0.00870	0.01383
Constant	2.32561	1.93395	−2.68410	−0.68019	3.32561	0.57150	0.60693
ROC	0.825	0.743	0.953	0.789	0.892	0.939	0.891

X1 DEM, *X2* slope, *X3* distance from villages/towns or farms, *X4* distance from hamlets or stations, *X5* distance from river, *X6* distance from roads, *X7* population density, *X8* per capita GDP, *X9* total soil N, *X10* soil organic matter, *ROC* relative operating characteristic

and reduction of wetland area under six scenarios confined by assumptions of moderate and high-speed economic development and two environmental protection policies (Fig. 5). For example, under scenario 1, paddy fields increased at 1 %, water decreased at 0.2 %, forestland and grassland area remained unchanged, construction land increased at 0.4 %, and wetland declined at 3.6 %; under scenario 4, paddy fields increased 3 % year by year, dry land descended 0.4 % year by year, forestland areas remained unchanged, grassland reduced 3 % year by year,
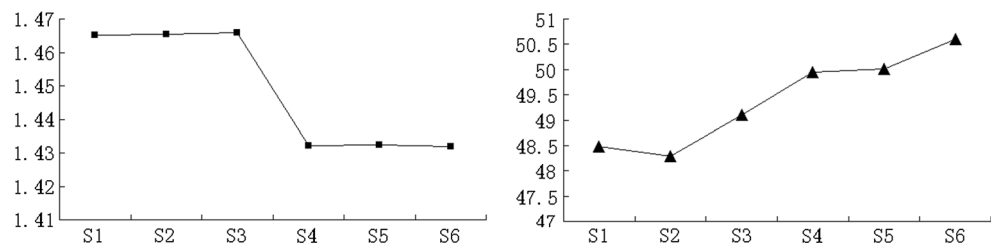
water declined 2 % year by year, and construction land increased 1 % year by year.

Scenario 1 indicated that both sides of the middle and lower reaches of NLR were the most sensitive areas to be affected and badly in need of protection, and if not protected properly, those regions would be transformed into paddy field; scenario 2 and scenario 3 presented that paddy field would extend in the middle reach of NLR, mainly centered on Farm 852; scenario 4 showed that both sides of the lower reach of NLR would changed to paddy land,

Fig. 5 Projection results of 2020 in six scenarios

S1   S2   S3

S4   S5   S6

N

0   100km

Land use/cover types

Paddy field   Forest land   Water area   Wet land

Dry land   Grass land   Construction land

Fig. 6 Changes of SHDI and Contag index

especially the south of Farm Hongwei and Farm Shengli; scenario 5 and scenario 6 indicated that with environmental protection strategies, paddy land would expand to the upper and middle reaches, centered on Farm 852, 759 and Youyi. SHDI of scenario 1–3 and scenario 4–6 were quite different and gradually decreased, which indicated reduction of uncertain information, decrease of fragmentation and simplification of landscape. Contag increased gradually from scenario 1 to scenario 6 (Fig. 6), which showed that some superior land use type had a good continuity, and the intensive landscape patterns were gradually replaced by the simplified landscape patterns.

Discussion

Wetland is mostly distributed in humid and semi humid climate areas with hydrothermal conditions suitable for crop growth, soil full of organic matter, and abundant natural resources. All those are good for comprehensive development of agriculture, forestry, animal husbandry, subsidiary production, and fisheries, which makes wetland the most suitable for reclamation activities. Haslam (2003) found that the agriculture production and industrial pollution were the two key reasons for the wetland degradation and loss. OECD and IUCN (1996) reported that the areas of

wetlands on the earth have been lost approximately 50 % from 1900 to now, and the wetlands loss was mainly due to the agricultural production. In the tropical and subtropical zone of Asia, South America and Africa, the percentages of the wetlands used for agricultural production are approximately 27, 6 and 2 %, respectively. About 26 % of wetlands worldwide are used for the agricultural production. In many wetland areas, LUCC is a result of longtime accumulation of individual farm construction (Carmona et al. 2010). However, LUCC in NLR is different from this type. The dramatic LUCC in NLR Basin since 1954 with a very significant shrink of wetland area was primarily driven by the reclamation of wetlands to state-owned farms.

Our research meets a growing need to understand the degradation of the wetland system in Sanjiang Plain. The land degradation and the changes of plant and animals caused by overdevelopment, and put forward the policy of the regional environmental protection for Sanjiang Plain. Through analyzing the area transformation between the wetland and other land use types from 1980 to 2000, the climate of Sanjiang Plain has changed from being cold and wet into being warm and dry due to wetland loss. The large-scale 50-year wetland reclamation in NLR Basin of Sanjiang Plain had close relationship with its hydrological change, and cleared that the human activity was the main driving force for the runoff evolution in this region.

Climate change, population and policy were the main driving forces of wetland changes in NLR Basin (Song et al. 2008b; Wang et al. 2009), but driving forces presented new characteristics after 2000. A study on wetland changes in NLR Basin since 1980s (Liu et al. 2003) indicated that the wetlands were seriously fragmented and gradually degraded directly due to rapid economic development. The study on LUCC of NLR Basin from 1954 to 2000 (Hou et al. 2004, 2006) indicated that the key characteristic of LUCC was that wetlands were reclaimed to cultivated land and that there was certain relevance between the shrinking process of wetland and reclamation policies. Wetlands in different landforms were also reclaimed with different priorities, typically in an order of the higher flood plains, followed by river terraces, finally the lower flood plains (Cai et al. 2011).

In this study, according to history and scenario projection results, major characteristics of land use changes in NLR Basin were analyzed. The shrink of wetland was closely related to natural environment changes, among which climate and hydrology played a greater role. However, most wetlands in NLR Basin were transformed into cultivated lands, rather than other land use types, thus the replacement of wetland by cultivated land was a major characteristic of LUCC in NLR Basin. Driving forces analysis showed that the construction of state farms was a key factor for LUCC in NLR Basin, especially two

Agricultural Reclamation Administration Bureaus, namely Jiansanjiang and Hongxinglong, which account for 1/4 of all farms in Sanjiang Plain. In addition, small reclamation towns were developed around farms, such as Qixing, Chuangye, Qianjin, Shengli, Hongwei, Raohe, Hongqiling, 859, 853, 852, 851, 759, Youyi, 291 (Statistical Bureau of Heilongjiang Land Reclamation Bureau 2010) (Fig. 7). Projections showed that if not protected, wetland in the downstream of NLR would be reclaimed to cultivated land.

Macro agricultural policy was an important driving factor for LUCC in NLR Basin (Liu et al. 2002). Since the 1980s, in order to increase farmers' income, six million ha cultivated land in Heilongjiang province was contiguously expanded with a feature of "frequent foods in the east and droughts in the west", and water management policies like drainage combined with irrigation and flooding control for rice cultivation were adopted in Sanjiang Plain. Primarily through "change dry land to paddy field" projects, strongly supported by the government, rice area in Heilongjiang surged from two hundred and sixty thousand ha in 1980 to one million seven hundred thousand ha in 2000. In the massive process of "change dry land to paddy field" (Heilongjiang Provincial Bureau of Statistics 2010), many wetlands were reclaimed regardless of the availability of local water resources. The transformation of many low-lying wetlands into high-yield paddy fields resulted in regional "overload" of water resources. Such a land use change affects the groundwater (Jiménez-Madrid et al. 2012). The multi-year average underground water table in the Sanjiang Plain has averagely decreased by 1.39 m (from 4.11 to 5.5 m) to restrict the sustainable development of agriculture.

Market was another important driving factor for LUCC in NLR Basin (Yunlong et al. 2011). Now cultivating rice can increase $3.3 per ha than cultivating corn or soybean. Currently, to pursuit short-term interest, transforming dry land into paddy field to plant rice prevails in Sanjiang Plain (Statistical Bureau of Heilongjiang Land Reclamation Bureau 2010). For example, the area of dry land decreased from 1116786.4 ha in 2000 to 1078927.7 ha in 2010, which could provide peasants about 1.67×10^6 income in NLR Basin.

Culture and law were main driving forces of land use change (Azous 2001). The importance of wetlands is known by people gradually. In order to protect wetland resources and maintain ecological equilibrium, China established two nature reserves, namely, NLR Nature Reserve and Qixing River Nature Reserve in NLR Basin. NLR Nature Reserve, established in 1998, was approved as a national nature reserve in 2002; Qixing River Nature Reserve was established in 1991 with the approval of government of Baoqing County, and was promoted to a national nature reserve in 2000 and was enlisted into
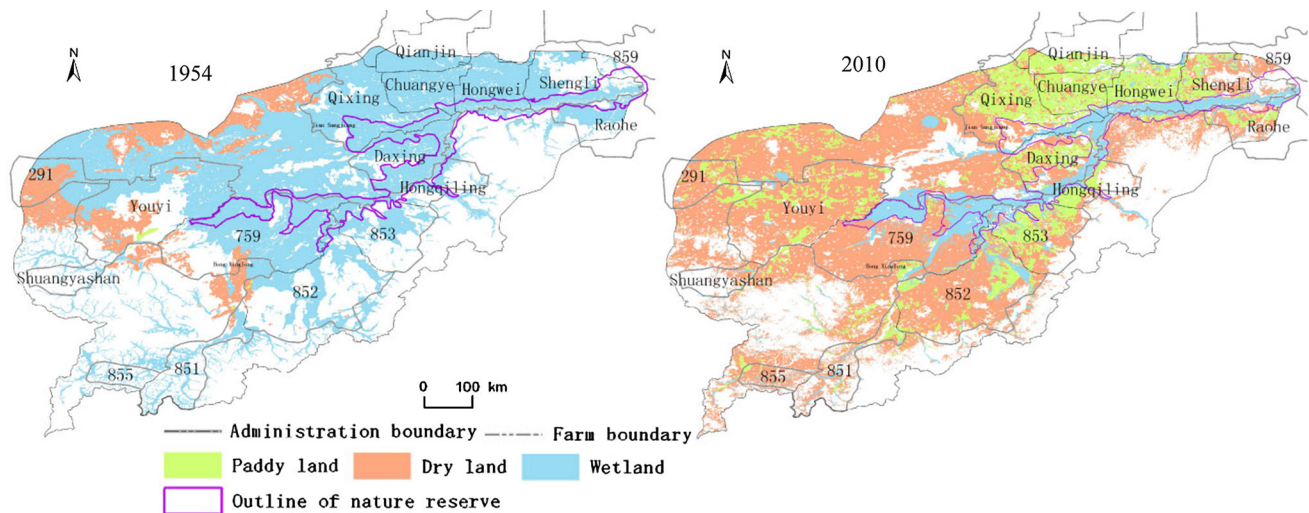
Fig. 7 Overlay of farm locations, nature reserve area and paddy field, dry land and wetland in 1954 and 2010

international important wetlands in 2011. After 40 years of reclamation, only 522,600 ha of wetlands left, including 458,000 ha of natural wetlands and 64,600 ha of constructed wetlands. Massive reclamation occurred between the 1960s and the 1980s. With the policy of stopping all reclamation of wetlands, grasslands and forestlands in the "Great Northern Wilderness" coming into practice in the new millennium, the development of NLR Basin also proceeded into a period of adjustment-returning cultivated land to forestland, grassland, and wetland. The pattern of LUCC in NLR Basin appeared stable and large-scale land reclamation never happened again.

Conclusions

Analysis of six-period land use changes showed that the area ratio of wetland in NLR Basin decreased from 45.84 % in 1954 to 9.76 % in 2010, with a fast rate from 1976 to 1986, and meanwhile, the area ratio of cultivated land (including paddy field and dry land) rose from 8.20 to 57.97 % and construction area increased gradually, but the changing degree of land use decreased after 2000.

Reclamation activity is the most fundamental reason for wetland shrink. The quantitative expression of land use types in NLR Basin and ten driving factors laid the foundation for projection of LUCC in NLR Basin.

Land use pattern of 2020 in NLR Basin was projected in six scenarios. Projection results show a general trend of continuous growth of paddy field area, slow decline of dry land area, and reduction of wetland area. The wetlands in the middle and lower reaches of NLR were identified as the most sensitive areas to be affected and badly in need of protection, and if not protected properly, those regions will be transformed into paddy field.

Possible impacts, such as topography, economic policy, and market demand on land use changes in NLR Basin are discussed. It is pointed out that in the near future, hydrology and topography, policy and market demand will be the key driving forces for land use changes in NLR Basin.

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