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Original Research Paper

Effects of Land Use on Ecosystem Service Function of the Songhua River basin in Harbin Region

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ABSTRACT

Rapid land use pattern change has taken place in Songhua River basin of old industry base in northeast region of China over the past decades in Harbin region. In this paper, changes in land use pattern in this region were analysed by using Landsat TM data in 1989 and 2007, to quantitatively explore the spatio-temporal LUCC (land use and cover change) characteristics, and based on this information, the regional ecosystem service value was estimated. Cropland and unused land decreased, while built-up land increased greatly. The greatest change rate occurred in water bodies but the least occurred in cropland. The ecosystem service value increased 4.8496×10^8 yuan, with increasing range of 8.3285%, cropland turned into forestland occurred the greatest positive contribution rate, accounted for 18.9437%, while forestland turned into cropland occurred the greatest negative contribution rate, accounted for 10.2426%. The increase of built-up land impacted the ecosystem service value and ecological environment negatively, and the increase of forestland and water body and the decrease of unused land improved the ecological environment and its ecosystem service values. Those improving the ecological environment were from other types of land use to forestland and water body, however, those worsening the ecological environment were from forest and grassland to cropland and built-up land.

INTRODUCTION

Urbanization process is one of the current new hot researches with the urbanization expansion, because human activities not only expanded their own survival space and at the same time significantly changed the land use statues and properties, but also disturbed land use pattern components, made great impacts on regional environment during land use and cover changes (LUCC) process (Yu et al. 2011) and then initiated many natural phenomenon and changes of ecological process. This process especially resulted in significant environmental consequences, such as forest degradation, sedimentation, air, water and noise pollution, increasing in energy consumption, decreased infiltration and an increase in surface run-off, destruction of wildlife habitat, and reduction in biodiversity (Ronald & Yuji 2011, Braimoh & Onishi 2007, Fu et al. 1998, Song et al. 1995, Urner et al. 1995). Eventually, those phenomena not only greatly lashed the structure, function and spatial evolution of regional ecosystem (Serafy 1998, Wang et al. 2006), but also seriously affected ecosystem service value ability for human being, while the ecosystem service can directly or indirectly offer the products in life and service through the structure, process and function of ecosystem, meanwhile, these products and services are necessities of human survival and warrants of human lives quality (Sutton & Costanza 2002, Costanza et al. 1997). Therefore, the quantitative evaluation of ecosystem service value has become the new focus and forward region of international ecology and ecological economics (Costanza et al. 1998, Wang et al. 2006). Moreover, revealing the urbanization's impacts on the mechanism and rule of ecosystem services has become a hot research of international scientists (Min et al. 2006, Marina 2010, Grimm et al. 2000, Pickett et al. 2001). Studying the LUCC associated with regional ecosystem service value and its change might provide the important significance to study the eco-environment change, keep the ecosystem in balance and coordinate the development between regional economics and environment.

The economic reform since 1978 have made China take part in the increased globalization with the rapid development of China economy and acceleration of the urbanization. Many of the cities in China are now growing more than million peoples, where a large intergradation zone is the rural-urban zone (Addo 2010). This has resulted in making land cross-fusion of urban and rural, accelerating the mutual penetration, and then leading to the obviously contradiction in land use, confusion in spatial layout and fragility in eco-environment. It not only hindered urban construction, and at the same time but affected rural development. Hence, conducting the study on the LUCC in large city is helpful to understand spatial change characteristics and temporal evolution process of

LUCC. Base on this, quantitatively estimating the ecosystem services values of land use and cover change could make urbanization spatial pattern control the ecosystem's dynamics (Liu et al. 2007, Alberti et al. 2007).

Harbin city, as the important old industrial city and important grain production bases in China (Li et al. 2010), located in middle reach of Songhua river, is the rapid urbanization city of northeast region. In this paper, we use the land use map in 1989 and 2007 extracted from the Landsat TM images to detect the LUCC changes and analyse the spatio-temporal pattern of urban expansion and to quantitatively analyse ecosystem value, and then to provide reference on maintaining the structure and function of regional ecosystem and keep ecological city construction and optimize land resources allocating. Thus, it will be helpful to control soil and water loss, maintain the ecological security, plan land use and adjust the regional economic structure.

MATERIALS AND METHODS

Study region: Harbin city, as the important industrial city with largest area and the second greatest population in province level of China, extend from 44°042 to 46°402 latitude and 125°422 to 130°102 longitude, covering area about 7000 km^2. The northern, eastern and southern region of this study area is higher, extended to western region as new moon shape. The elevation ranges from 84 to 886m. The average temperature is 3.5°C and annual average frost-free period is 135d. Annual precipitation is 545.7mm. Meanwhile, there are many rivers belonging to Songhua river hydrographic net, such as Songhua river, Hulan river and Ashi river etc., obviously, those conditions are very suitable for agricultural development.

Image process and interpretation: Before being classified the Landsat TM image, the first processing works included geometric, radiometric correction and image enhancement. The geometric correction of Landsat TM image in 2007 was carried out in ERDAS IMAGINE 9.2 software by using ground controls (GCPs) selected from the topographic map at the scale of 1:50000. The resultant root mean square errors was generally less than 0.5 pixel, and then false colour composites were generated from bands 5, 4 and 3 as red, green and blue, respectively, followed by using the corrected image as the geo-referenced image to finish the registration of TM image in 1989 through image-to-image. The image enhancement was performed for better visual of land use feature and texture after masking the images, according to the land use classification system by National Land Authority and the present situation and distribution characteristics of land use types. The images were classified using Maximum Likelihood of supervised classification method in ERDAS 9.2 (Leica Geosystems 2009). The database of land use was generated and stored in grid form after building spatial topology, the 6 classes of land use cover were obtained: cropland, forestland, grassland, water bodies, built-up land and unused land. The accuracy assessment was tested by monitored samples from GPS survey.

Land use transition in contribution rate: In this paper, Markov transition matrix for 18 years of time interval was obtained using land cover database in 1989 and 2007 though MARKOV module in IDRISI software, which could quantitatively describe the changes between different two periods of land use covers (Sang et al. 2011). Then, land use transition contribution rate was generated to reveal mutual transition process and law between the different types (Zeng et al. 2003), and to reflect the important differences in certain types transition processes during the whole dynamic transition change process in certain extent, which was calculated as follows:

$$T_{ijt} = \frac{|A_{it} - A_{jt}|}{\sum |\Delta A_{ijt}|} \times 100\% \qquad ...(1)$$

Where, i and j represent the land use types in different periods, t represents the whole transition time from starting period to monitoring period,

$|A_{it} - A_{jt}|$

represents the transition area from i types to j types, $\sum |\Delta A_{ijt}|$ represents the total transition area during studying periods, and T_{ijt} represents the transition contribution rate.

Ecosystem estimate methods: The value coefficient proposed by Costanza has been widely applied to estimate the ecosystem service value (Costanza et al. 1998). However, there is a larger deviation in some data during the studying process. Its estimation of cropland is too low while of wetland is relatively higher. According to the Chinese present situation, referring to the Costanza's research, made the China's terrestrial ecosystem service value in unit area (Table 1) (Xiao et al. 2003, Xie et al. 2003, Xie et al. 2005). Taking into account the current facts and associating with the ESV formula of Costanza, the ecosystem service value was adopted to estimate the regional ecosystem services. The formula of ESV is as follows:

$$\mathrm{ESV} = \sum A_k \times \mathrm{VC}_k \qquad ...(2)$$

$$\mathrm{ESV}_f = \sum A_k \times VC_{fk} \qquad ...(3)$$

Where, the ESV is the ecosystem services value (RMB), A_k represents area of the k types of land use (hm^2), VC_k is the value coefficient of ecosystem service (RMB/hm^2·a), ESV_f is the single ecosystem service value (RMB) and VC_{fk} is its coefficients (RMB/hm^2·a).

Table 1: Ecosystem service value unit area of main land-use categories in study region RMB/hm^2.

Catalog	Crop land	Forest land	Grassland	Water body	Unused land
Gas regulation	442.4	3097.0	707.9	0	0
Climate regulation	787.5	2389.1	796.4	407.0	0
Water conservation	530.9	2831.5	707.9	18033.2	26.5
Erosion control	1291.9	3450.9	1725.5	8.8	17.7
Waste disposal	1451.2	1159.2	1159.2	16086.6	8.8
Biodiversity	628.2	2884.6	964.5	2203.3	300.8
Food production	884.9	88.5	265.5	88.5	8.8
Raw material	88.5	2300.6	44.2	8.8	0

Table 2: Change in area of different land use types and their dynamic degrees.

Land us types	1989		2007		1989-2007	
	Area/km^2	Proportion/%	Area/km^2	Proportion/%	Change value/km^2	Change rate/%
Cropland	4591.86	65.58	4386.91	62.65	-204.95	-0.2480
Forestland	1071.15	15.30	1170.14	16.71	98.99	0.5134
Grassland	295.41	4.22	321.08	4.58	25.67	0.4828
Water body	177.97	2.54	277.08	3.96	99.11	3.0938
Built-up land	540.00	7.71	758.04	10.83	218.04	2.2432
Unused land	325.44	4.65	88.58	1.27	-236.86	-4.0434

RESULTS AND DISCUSSION

Land use analysis: The land use change analysis results from quantity and structure based on GIS software are given in Table 2. Obviously, the land use pattern remained dominated by cropland, forestland and grassland during 1989-2007. The sum total of their proportions exceeded 80% of the total study area, while the cropland, as the matrix landscape, occurred greatest proportion accounting for 65.58% and 62.65%, respectively, followed by forest and built-up land. The other types of land use were relatively small. Forestland, grassland, water bodies and built-up land took on increasing trend during 18 years. The built-up land showed the greatest growth, and water bodies showed the greatest change range accounting for 218.04 km^2 and 3.0938 %, respectively. Owing to the population growth, economic development and urbanization process acceleration, lots of cropland were converted into built-up land, especially the implementation of the economic policy for revitalizing northeast old industrial base during 2001-2005. The increase of forest and grassland was resulted from the implementation of the Grain-for-Green Programme (GGP) by the government started in 1999. However, cropland, mainly including the abandoned land, was converted into forestland in our survey. It indicated the human activities greatly affecting the regional land use types because of the agricultural policy direction and ecological reconstruction in some extent. Owing to the natural factor, water body increased 99.11 km^2 from 177.97 km^2 in 1989 to 277.08 km^2 in 2007. While cropland and unused land showed the same changes, taking on the decreasing trend, the unused land showed the greatest decrease, accounting for 236.86 km^2. The conversion from unused land to cropland and water body was major transition trace, while unused land turning into cropland was due to the constant development of society and economics. The human activities greatly extended the disturbance for unused land, especially wetlands, then changed land use structure and at the same time deteriorated regional eco-environment, eventually, making the ecological system tend to be fragility and sharpened the confliction of natural environment. To a great extent, the potential risk will be accelerated between rapid expansion agricultural land and land use types during the increasing scope and intensity of human activities.

Ecosystem service value change analysis: The ecosystem service value and its change have been analysed in Table 3. The total ecosystem service vales increased to 48.496×10^7 Yuan from 582.288×10^7 Yuan in 1989 to 630.884×10^7 Yuan in 2007. Large amount of unused land has been transformed to cropland and water body and lots of cropland were converted into forestland, water body and grassland. Those transitions from lower to higher ecological value coefficient were the main cause of its increasing, mainly due to the inside agricultural policy adjustment and natural environment change. Obviously, during the rapid urbanization process, built-up land area increased much more than that of forestland, grassland and water body, but transition from cropland to built-up land showed negative effects on the

Table 3: Total ecosystem services value and its change for land use category from 1989 to 2007.

Land use type	Ecosystem services coefficient (yuan/hm^2.a)	1989		2007		1989-2007
		ESV/10^7(yuan)	Proportion/%	ESV/10^7(yuan)	Proportion/%	Change
Cropland	6114.3	280.760	48.208	268.229	42.516	-12.531
Forestland	19334	207.096	35.560	226.235	35.860	19.139
Grassland	6406.5	18.925	3.250	20.570	3.261	1.645
Water body	40676.4	72.392	12.430	112.706	17.865	40.314
Built-up land	371.4	2.006	0.344	2.815	0.446	0.810
Unused land	371.4	1.209	0.208	0.329	0.052	-0.880
Total	73274	582.388	100	630.884	100	48.496

Table 4: Major land use changes and their contribution to ecological environment change.

Transformation types	ESV difference/ 10^7RMB	Contribute rate/%	Transformation types	ESV difference/ 10^7RMB	Contribution rate/%
Forestland → cropland	-14.9318	10.2426	Cropland → forestland	27.6164	18.9437
Forestland → grassland	-1.7169	1.1778	Grassland → forestland	1.6986	1.1651
Forestland → water body	-0.6907	0.4738	Water body→ forestland	0.8621	0.5913
Forestland → built-up land	-2.3026	1.5795	Built-up land → forestland	1.5909	1.0913
Forestland → unusedland	-0.2154	0.1477	Unused land→ forestland	1.2783	0.8768
Cropland → grassland	0.2506	0.1719	Grassland → cropland	-0.2098	0.1439
Cropland → water body	21.5471	14.7804	Water body→ cropland	-9.5825	-6.5732
Cropland → unused land	-1.0597	0.7269	Unused land→ cropland	9.4382	6.4742
Cropland → built-up land	-14.4089	9.8839	Built–up land→ cropland	2.9484	2.0225
Unusedland → water body	26.6959	18.3123	Water body→ unusedland	-6.7365	4.6210

whole ecosystem service values. It indicated that forestland and water body played the very important role in positive effects on the increasing regional ecosystem service value. Forestland, grassland, water body and built-up land took on increasing trend in ecosystem service value. Water body showed the greatest growth, accounting for 40.314 × 10^7 Yuan, followed by forestland with 19.139 × 10^7 Yuan; built-up land showed the least growth, accounting for 0.810 × 10^7 Yuan. Cropland showed the greatest decrease, accounting for 12.531 × 10^7 Yuan. It was clear that increasing area of forestland, grassland and water body not only made up for the ecosystem service value for decreasing area of cropland and unused land, but made the net change results during whole study period. From this study, we can see the changed trend of whole ecosystem service values and its composite with very higher ecological value coefficient remained unanimous.

Land use contribution analysis: According to the analysis results in the Table 4, land use and their change took effects differently with both increasing and decreasing on ecosystem service value due to LUCC. Those transitions with the positive number of ESV differences from in other types of land use to in forestland, water body and grassland showing positive function in ecosystem service and improving the eco-environment. Those worsening the eco-environment were from forestland, grassland and water body to cropland, built-up land and others, showing the passive function for ecosystem service value. The transition from cropland to forestland showed the greatest contribution rate, accounting for 18.9437%, with ESV difference of 121.484 × 10^7 Yuan. It indicated that this regional land use tended to be rationalization and regional ecological environment improved gradually through the implementation of agricultural policy and ecological reconstruction, followed by from unused land to water body with ESV difference of 26.6959 × 10^7 Yuan, owing to seasonal precipitation effects. The monsoon rain increased water and inundated the unused land area, mainly locating at the north region of Songhua river, especially tidelands. The transition from cropland to water body showed the third greatest contribution rate, accounting for 14.7804 %. When taking into account the ecosystem service value decreasing, the transition from cropland to forestland showed the greatest contribution rate, accounting for 10.2426 % and reduced 14.9318 × 10^7 Yuan, under the double pressure of society economics and human activities, especially driving the simple and short-term economical benefits, cropland reclamation from deforestation seriously occurred in some regions. The phenomenon of unreasonable land use style still remained. It seemed that we should enlarge great extent to implement "Cropland to Forestland" project, followed by the transition from cropland to built-up land, accounted for 9.8839 % and decreased 14.4089×10^7 Yuan due to the great population growth and urbanization process acceleration in recent years. The remarkable population growth resulted in the increasing pressure on cropland for housing, business premises and public services and facilities, and then directly expanded the contradiction between grain safety question and urban expansion. Generally, the decrease of cropland and increase of built-up area affected regional eco-environment negatively, while the increase of forestland, grassland and water body improved the eco-environment and its ecosystem service values.

CONCLUSIONS

1. During the whole studying period, the area of forestland, grassland, water body and built-up land showed different extents in increasing, built-up land occurred with the greatest growth form 540 km^2 in 1989 to 758.04 km^2 in 2007, while the area of cropland and unused land took on constantly decrease, unused land occurred the greatest decrease, accounting for 236.86 km^2, water body occurred with the greatest change rate while cropland occurred the least.
2. The ecosystem service value from 1989 to 2007, quantitative analysed through studying regional LUCC, increased form 582.388×10^7 Yuan to 630.884×10^7 Yuan, revealed that the transition from one type of land use with lower ecological value coefficient to another type of land use with higher ecological value coefficients, which was the main cause of its increasing, while the transition from cropland to forestland occurred with the greatest positive contribution rate, accounted for 18.9437 %, followed by from unused land to water body. The conversion from cropland to forestland land showed the greatest negative contribution rate, followed by cropland to built-up land.
3. The increase of built-up land affected ecological environment negatively, while the increase of forestland and water body improved the ecological environment and service values. Those improving the ecological environment were from other types of land use to forest, grassland and water body, while those worsening the ecological environment were from forest and grassland to cropland and built-up land.

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