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Impact of land use/land cover changes on ecosystem services in the Nenjiang River Basin, Northeast China

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Abstract

Introduction: The Nenjiang River Basin is an important foodstuff base and eco-environmental fragile area in Northeast China. With the rapid rise in human population, human-induced changes in land use/land cover form an important component of regional environment and ecosystem service change. At the local and regional level, the ecosystem service concept can act as a decision support tool for a stakeholder to reach sustainable land use management. However, the prevailing ecosystem service evaluation would produce a biggish warp when it is applied to concrete area. So, it is essential to evaluate ecosystem service change according to the local actuality.

Method: According to 1:250,000 land use/land cover maps of China and the adjusted equivalent value per unit area of ecosystem services in the Nenjiang River Basin, we evaluated the ecosystem service change of the river basin from 1980 to 2005.

Results: The forest and wetland, which are mainly located in the upstream mountainous area of the Nenjiang River Basin, were the two valuable land cover types, accounting for more than three quarters of the total ecosystem service value of the river basin. As for individual ecosystem service, besides the food production, all of the ecosystem service values declined from 1980 to 2005. The total decline of 2.43 billion USD was mainly due to the cultivation of grassland (14.34 % of the area in 1980) and wetland (4.62 % of the area in 1980) in the downstream plain.

Conclusions: Due to the increase in population and the concomitant requirement of grain, the inconsistency between decision-making at the macro-level, and the objective of agricultural production at the micro-level, cultivated land was increased through zealous reclamation of grassland, marginal woodland, and even fallow land. Tremendous land use/land cover changes had caused great damages to the ecological environment such as land degradation and ecosystem service recession. So, the policies of the Grain for Green and Construction of Ecological Province projects should be well-implemented to optimize land use/land cover.

Keywords: Land use/land cover changes; Ecosystem services; Equivalent value; NDVI; Nenjiang River Basin

Introduction

The Nenjiang River, previously be called the Nonni River at the beginning of the Qing Dynasty, means “The Green River” in Mongolian. The river basin used to be the haven of water birds for the wild spreading wetland which was bred by tens of rivers from the Da and Xiao Xing’anling Ranges. But after a hundred years of cultivation, there emerged thousands of large-scale farms accommodating 15.9×10^6 population (Dong, 2013). Especially after the reform era of the late 1970s, the old collective production brigade farming system was abandoned in favor of the household responsibility system to unleash farmers’ incentives for higher productivity and more income (Liu et al. 2004). Large-scale state farms had been established as an important “grain base” through zealous reclamation of grassland, marginal woodland, and wetland. With the rapid rise in human population, human-induced changes in land use/land cover form an important component of regional environment and ecosystem service change. Whereas, at the

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local and regional level, the ecosystem service concept can act as a decision support tool for a stakeholder to reach sustainable land use management (Anna and Sabine 2011). The ecosystem service value assessment should be carried out as soon as possible. In China, the ecosystem service values of large-scale basins all have been evaluated (Liu et al. 2006; Wu et al. 2009; Hou et al. 2013; Bai et al. 2011; Liu et al. 2014). So, it is necessary to evaluate the ecosystem service change of the Nenjiang River Basin to constitute accurate policy for sustaining development. In this study, on the basis of land use/land cover changes and the achievements of other researchers from 1980 to 2005, the ecosystem service value of the Nenjiang River Basin was evaluated through the equivalent value per unit area of Chinese terrestrial ecosystem and the normalized difference

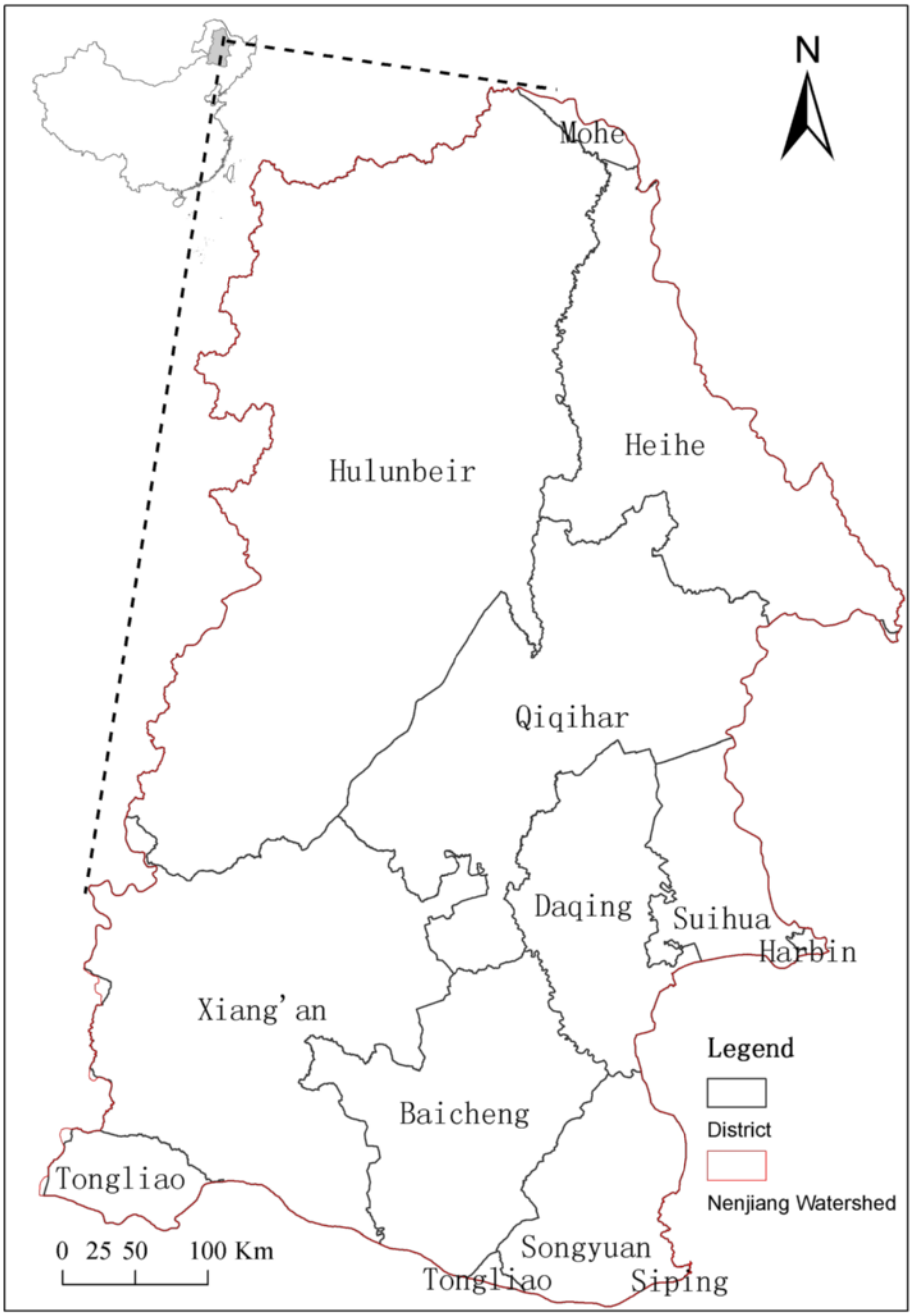

Fig. 1 Location of the Nenjiang River Basin

vegetation index (NDVI). Especially, we hope to achieve three objectives: (1) to reveal the dynamics of land use/land cover changes in the Nenjiang River Basin and its driving forces, (2) to evaluate the ecosystem service change of the river basin from 1980 to 2005, and (3) to map the ecosystem services of the Nenjiang River Basin.

Methods

Study area

The Nenjiang River Basin is located in the midwest of Heilongjiang Province, Northeast China. The Nenjiang River, which originates from the Yilehuli mountain of the Da Xing'anling Ranges, is the northern source of the Songhua River (Sun and Bai 2005). The length of the river is 1370 km with a catchment area of 29.4×10^4 km^2, accounting for 53.8 % of the total Songhua River Basin (total area is 54.6×10^4 km^2).

The basin (Fig. 1) lies on the northern margin of the East Asian monsoon region and has a cold and semi-humid continental monsoon climate with long, cold winters and short, rainy summers. The average annual temperature ranges from −4 to 6 °C. Rivers are frozen from late October to early November and melt in early April (Li et al. 2014). However, spatial and temporal differences in rainfall and temperature vary greatly throughout the basin for its unique geographical position, shape, and terrain features.

Data

The basic data used in this study include (1) 1:250,000 land use/land cover maps of China in 1980 and 2005, which were obtained from data sharing infrastructure of Earth System Science (http://www.geodata.cn/). There are 6 level I categories and 25 level II categories of land use/land cover types. In our study, in order to calculate ecosystem service value for each land cover type identified in Xie et al.'s (2003) ecosystem service valuation model, six level I categories were reclassified as forest, grassland, farmland, wetland, lakes/rivers, and barren land. Wetland and water body was divided into two categories, and residential land and desert were united as barren land; (2) equivalent value per unit area of ecosystem services for terrestrial ecosystem in China (Xie et al. 2003); (3) 1-km^2 resolution of NOAA/AVHRR NDVI index around China in 1998, which was obtained from the Thematic Database for Human-Earth System (http://www.data.ac.cn).

Revising the equivalent value per unit area of Chinese terrestrial ecosystem

For evaluating the global ecosystem value, Costanza et al. (1997) defined the theory and methodology of ecosystem service evaluation clearly from scientific purport. However, it was controversial in China, with some ecosystem services poorly valued or ignored (Zhang et al. 2013). When it was applied to concrete area, the methods would produce biggish warp due to (1) the value of ecosystem services reflected the economic level of developed countries such as the United States and European countries, rather than developing countries such as China; (2) although wetland ecosystems provide significant functions, their value per unit area was overvalued (Zhang et al. 2013). So, to adjust Costanza et al.'s (1997) value coefficients, Xie et al. (2003) constituted the equivalent value per unit area of ecosystem services for Chinese terrestrial ecosystem based on questionnaire investigation from about 200 ecological scholars and some achievements (Table 1).

The equivalent value per unit area of ecosystem services is the latent ability of the ecosystem services

Table 1 Equivalent value per unit area of ecosystem services for terrestrial ecosystem in China

Item	Forest	Grassland	Farmland	Wetland	Lakes/rivers	Barren
Gas regulation	3.50	0.80	0.50	1.80	0	0
Climate stability[a]	2.70	0.90	0.89	17.10	0.46	0
Water regulation and supply	3.20	0.80	0.60	15.50	20.38	0.03
Soil generation and fertility[b]	3.90	1.95	1.46	1.71	0.01	0.02
Waste treatment	1.31	1.31	1.64	18.18	18.18	0.01
Biodiversity protection[c]	3.26	1.09	0.71	2.50	2.49	0.34
Food production	0.10	0.30	1.00	0.30	0.10	0.01
Raw materials	2.60	0.05	0.10	0.07	0.01	0
Recreation, cultural	1.28	0.04	0.01	5.55	4.34	0.01
Sum	21.85	7.24	6.91	62.71	45.97	0.42

[a] Climate stability includes climate regulation and disturbance regulation

[b] Soil generation and fertility includes soil formation, nutrient cycling, erosion control, and sediment retention

[c] Biodiversity protection includes pollination, biological control, refuge, and genetic resources mentioned by Costanza et al. (1997)

produced by unit area of ecosystem. One equivalent value was defined as the economic value produced by 1-ha farmland in China. Thus, Table 1 could be transformed into a table of economic value of ecosystem services for the same year. However, it just provides an average equivalent value per unit area of ecosystem services in China. Proverbially, there exist affinities between ecosystem service value and biomass. The bigger the biomass, the higher the ecosystem service value it has. In addition, NDVI could be used as an indicator of relative biomass and greenness (Boone and Galvin 2000; Freitas and Mello 2005; Loris and Damiano 2006; Zhang et al. 2007). Various authors have related this index to vegetation structures, such as vegetation cover, biomass, and leaf area index, as well as some functional characteristics, such as primary production and carbon balance

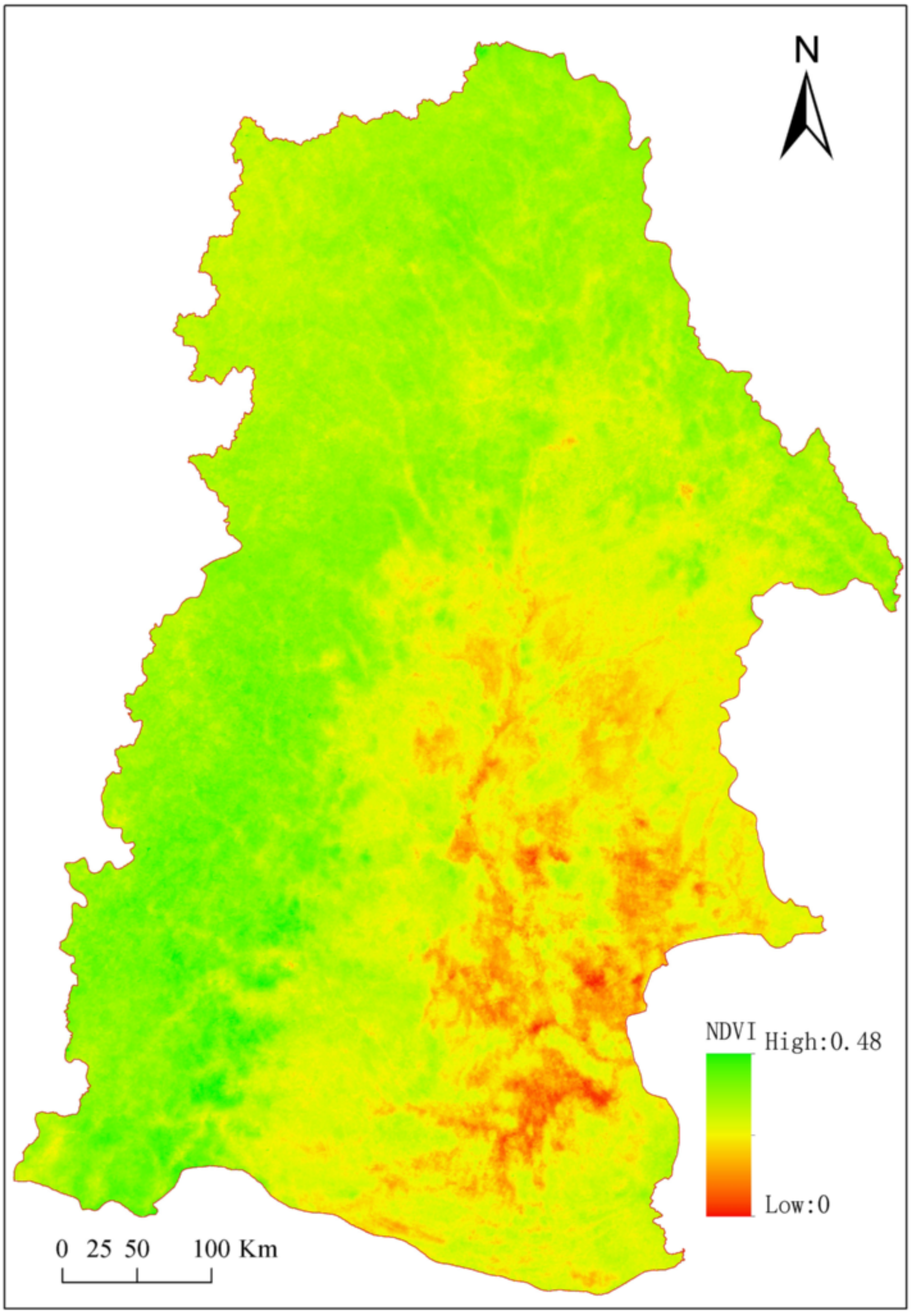

Fig. 2 Average NDVI of the Nenjiang River Basin in 1998

Table 2 The average NDVI of China and the Nenjiang River Basin

Month	China	Nenjiang River Basin
Jan.	0.014	0.031
Feb.	0.015	0.031
March	0.017	0.081
April	0.022	0.066
May	0.039	0.233
Jun.	0.052	0.205
Jul.	0.059	0.343
Aug.	0.059	0.310
Sep.	0.054	0.316
Oct.	0.032	0.205
Nov.	0.023	0.029
Dec.	0.016	0.019

(Running et al. 1999; Stoms and Hargrove, 2000; Huete et al. 2002; Kerr and Ostrovsky, 2003), some of which are important features in ecosystem service analysis (Roces-Díaz et al. 2014). So, we could assume a linear relationship between ecosystem service value and NDVI, then, revise the equivalent value per unit area of ecosystem services in the Nenjiang River Basin as follows:

$$Eij = \frac{\mathrm{NDVI}m}{\mathrm{NDVI}n} \times eij \tag{1}$$

Where Eij is the equivalent value per unit area of i ecosystem service for j ecosystem type after revisal; NDVIm is the average NDVI value of the Nenjiang River Basin (Fig. 2, Table 2), and NDVIn is the average NDVI value of China (Zhang et al. 2007); eij the equivalent value before revisal; $i = 1, 2, 3, \cdots 9$, separately denote the ecosystem services; and $j = 1, 2, 3, \cdots 6$, separately denote the land use types.

Evaluating the ecosystem service value

Through contrast analysis by Xie et al. (2003), one equivalent value per unit area equals one seventh of the average foodstuff market value in China. We could calculate the ecosystem service value of one equivalent value per unit area of ecosystem as follows:

$$C = 1/7\sum_{i=1}^{n}\frac{V}{M} \tag{2}$$

Where C is the economic value of one equivalent value per unit area of ecosystem services, V is the economic value of its crop produced by every farm, M the area of its crop, and n the categories of crop.

For lack of data, we took Hu et al.'s (2006) research as reference, of which the Chinese average economic value per unit area of farmland in 2005 was 3629.43 $\mathrm{yuan} \cdot \mathrm{ha}^{-1}$; subtracting the unit area investment (930.33 $\mathrm{yuan} \cdot \mathrm{ha}^{-1}$, including labors, fertilizer, mechanics, and others) and the rent shadow price (2250 $\mathrm{yuan} \cdot \mathrm{ha}^{-1}$), one equivalent value per unit area of ecosystems in China equaled to 449.10 $\mathrm{yuan} \cdot \mathrm{ha}^{-1}$ (58.5 $\mathrm{USD} \cdot \mathrm{ha}^{-1}$) (Xie et al. 2008). Presuming a linear relationship between ecosystem service value and biomass, the biomass factor of China was 1, while the biomass factor of Heilongjiang province was 0.66 (Xie et al. 2005). So, we could set one equivalent value per unit area in the Nenjiang River Basin to 296.41 $\mathrm{yuan} \cdot \mathrm{ha}^{-1}$ (38.61 $\mathrm{USD} \cdot \mathrm{ha}^{-1}$) in 2005.

By all accounts, we could calculate the total economic value in the Nenjiang River Basin by the following equation:

$$\mathrm{ESV} = \sum_{i=1}^{9}\sum_{j=1}^{6} AjEijC \tag{3}$$

Where ESV is the total value of ecosystem services, and Aj is the area of j ecosystem type in the Nenjiang River Basin.

Ecosystem service sensitivity analysis

Because there are uncertainties about the equivalent value per unit area of each ecosystem service for each ecosystem as well as the veracity of Costanza et al.'s (1997) value coefficients, we conducted sensitivity analysis to examine the dependence of our ecosystem service value estimation on the applied equivalent value

Table 3 Total area and area change of land use/cover from 1980 to 2005 (10^4 km^2)

Land use	1980	Percent	Rank	2005	Percent	Rank	Change	Percent	Rank	Trend
Forest	10.20	34.66	1	9.87	33.54	2	−0.33	−3.24	5	↓
Farmland	9.09	30.88	2	10.11	34.39	1	1.02	13.46	1	↑
Grassland	4.78	16.24	3	4.13	14.06	3	−0.65	−11.32	2	↓
Wetland	3.39	11.51	4	3.28	11.17	4	−0.11	−3.11	6	↓
Barren land	1.47	4.98	5	1.56	5.32	5	0.09	9.52	3	↑
Lakes/rivers	0.51	1.73	6	0.46	1.52	6	−0.05	−6.72	4	↓
Sum	29.42	100		29.42	100					

Table 4 Transition matrix of land use types from 1980 to 2005 (transition probabilities in %)

Land use type in 1980	Land use type in 2005						
	Grassland	Farmland	Barren	Forest	Wetland	Lakes/rivers	Sum
Grassland	80.96	14.34	1.41	2.00	1.20	0.10	19.05
Farmland	0.26	98.80	0.12	0.59	0.19	0.04	1.20
Barren land	0.04	0.15	99.72	0.02	0.02	0.05	0.28
Forest	1.93	2.75	0.01	95.26	0.04	0.01	4.74
Wetland	1.06	4.62	0.69	0.08	93.39	0.16	6.61
Lakes/rivers	2.24	2.52	0.06	0.03	7.72	87.43	12.57

per unit area of ecosystem services. The equivalent value for each ecosystem was adjusted by 50 % (Wang et al. 2006). The coefficient of sensitivity (CS) was calculated as:

$$\mathrm{CS} = \left| \frac{(\mathrm{ESV}j - \mathrm{ESV}i)/\mathrm{ESV}i}{(Ej - Ei)/Ei} \right| \tag{4}$$

Where ESV is the estimated value of ecosystem services, E the equivalent value per unit area of ecosystem services, and i and j represent the initial and revisal value, respectively. $\mathrm{CS} > 1$ indicates that ecosystem service value estimation is elastic to the equivalent value, while $\mathrm{CS} < 1$ means inelastic to the equivalent value and accuracy of the equivalent value.

Results

Land use/land cover changes

As shown in Table 3, the two largest land use types were forest (10.20×10^4 km^2, about 34.66 % of total area in 1980; 9.87×10^4 km^2, about 33.54 % in 2005) and farmland (9.09×10^4 km^2, about 30.88 % of total area in 1980; 10.11×10^4 km^2, about 34.39 % in 2005) in this region.

From 1980 to 2005, the most notable changes of land use/land cover were an increment in farmland and a decline in grassland. In 1980, grassland covered 4.78×10^4 km^2, about 16.24 % of the total area; it decreased 11.32 %, about 6430 km^2, which is about 257 km^2 per year by 2005. The area of lakes/rivers, forest, and wetland all decreased from 1980 to 2005. Meanwhile, farmland increased 13.46 %, about 1.02×10^4 km^2, which is about 411 km^2 per year. Barren land also increased 985 km^2, which is about 39 km^2 per year.

Results of the transition matrix in Table 4 indicated the area increment or decline of each land use type. It was clear that between 1980 and 2005, the transition replacement rates of grassland and lakes/rivers were higher at 19.05 and 12.57 %, respectively. About 14.34 % of grassland and 4.62 % of wetland in 1980 were transformed to farmland; 7.72 % of lakes/rivers was changed to wetland, because of 5 years of continuing drought after the big flood of the Nenjiang River in 1998 (Dong, 2013).

Changes in ecosystem services

According to Table 1 and Eq. (1), we calculated the equivalent value per unit area of ecosystem services in

Table 5 Equivalent value per unit area of ecosystem services in the Nenjiang River Basin

Item	Forest	Grassland	Farmland	Marsh	Water	Barren
Gas regulation	16.28	3.72	2.33	8.37	0.00	0.00
Climate stability	12.56	4.19	4.14	79.52	2.14	0.00
Water regulation and supply	14.88	3.72	2.79	72.08	94.77	0.14
Soil generation and fertility	18.14	9.07	6.79	7.95	0.05	0.09
Waste treatment	6.09	6.09	7.63	84.54	84.54	0.05
Biodiversity protection	15.16	5.07	3.30	11.63	11.58	1.58
Food production	0.47	1.40	4.65	1.40	0.47	0.05
Raw materials	12.09	0.23	0.47	0.33	0.05	0.00
Recreation, cultural	5.95	0.19	0.05	25.81	20.18	0.05
Sum	101.60	33.67	32.13	291.60	213.76	1.95

Table 6 Total economic value of each ecosystem from 1980 to 2005 (billon USD)

	1980	Percent	Rank	2005	Percent	Rank	Change	Percent	Rank	Trend
Forest	40.00	40.03	1	38.71	39.70	1	−1.29	−3.24	5	↓
Wetland	38.14	38.16	2	36.95	37.90	2	−1.18	−3.11	6	↓
Farmland	11.27	11.28	3	12.55	12.87	3	1.28	11.32	2	↑
Grassland	6.21	6.21	4	5.37	5.51	4	−0.84	−13.46	1	↓
Lakes/rivers	4.21	4.21	5	3.81	3.91	5	−0.40	−9.52	3	↓
Barren land	0.11	0.11	6	0.12	0.12	6	0.01	6.72	4	↑
Sum	99.94	100.00		97.51	100.00		−2.43	−2.43		

the Nenjiang River Basin, and the results were listed in Table 5.

Based on Eq. (3), we calculated the changes of ecosystem service value in 1980 and 2005 (Table 6). From Table 6, the two valuable land use types were forest (40.00 billion USD, about 40.03 % of the total value in 1980; 38.71 billion USD, about 39.70% of the total value in 2005) and wetland (38.14 billion USD, about 38.16 % of the total value in 1980; 37.90 billion USD, about 37.90 % of the total value in 2005) in this region, accounting for more than three quarters of the total basin ecosystem service value.

Although the area of farmland ranked the second and wetland ranked the fourth in Table 3, the total ecosystem value of farmland ranked below wetland's, obviously, because of its lower equivalent value per unit area. During the past 25 years, the total economic value of grassland decreased the most, about 13.46 % of the total value in 1980, as well as lakes/rivers, forest, and wetland. Meanwhile, the total economic value of farmland and barren land increased 11.30 and 5.88 %, respectively, because of their increasing total area.

On the whole, the land use/land cover changes in the Nenjiang River Basin had led to a total net decline of 2.43 billion USD, about 97.2 million USD per year in ecosystem service value from 1980 to 2005.

We also calculated the effects of land use/land cover changes to individual ecosystem services during the past 25 years (Table 7). Except for the economic value of food production, all kinds of ecosystem service values declined from 1980 to 2005. The most notable value decline was water regulation and supply service, about 0.64 billion USD; the next were waste treatment service and climate stability, because the warming and drying trend of the basin has influenced seasonal streamflow and altered the annual hydrograph of the basin; the decrease of streamflow in the lower basin (mainly alluvial plains) has caused wetland degradation, desertification, and soil salinization (Zhang and Guo 2008; Du et al. 2009).

Ecosystem service sensitivity analysis

When the equivalent value for each ecosystem was adjusted by 50 %, respectively, changes of total values in the Nenjiang River Basin and coefficient of sensitivity (CS) for each land use type were calculated (Table 8).

As shown in Table 8, the 50 % adjustment to equivalent value of forest had the most impact on the total estimated ecosystem service value, the total value changed ±20.00 billion USD $\cdot$ a^{-1} and ±19.07 billion USD $\cdot$ a^{-1} on the initial result of 1980 and 2005 respectively,

Table 7 Total economic value of each ecosystem service from 1980 to 2005 (billion USD)

	1980	Percent	Rank	2005	Percent	Rank	Change	Rank	Trend
Waste treatment	18.92	18.93	1	18.49	18.97	1	−0.43	2	↓
Water regulation and supply	18.83	18.84	2	18.18	18.65	2	−0.64	1	↓
Climate stability	17.61	17.62	3	17.18	17.62	3	−0.43	3	↓
Soil generation and fertility	12.24	12.25	4	12.02	12.33	4	−0.22	7	↓
Biodiversity protection	9.90	9.91	5	9.65	9.90	5	−0.25	4	↓
Gas regulation	9.00	9.01	6	8.76	8.99	6	−0.24	5	↓
Recreation, cultural	6.17	6.17	7	5.95	6.10	7	−0.22	6	↓
Raw materials	5.01	5.01	8	4.87	4.99	8	−0.14	8	↓
Food production	2.27	2.27	9	2.40	2.46	9	0.14	9	↑
Sum	99.94	100		97.51	100		−2.43		

Table 8 The magnitude of changes in total economic values and CS (billion USD · a^{-1})

Change of equivalent value		Change of total values		CS	
		1980	2005	1980	2005
Forest	E ± 50 %	119.94 ~ 79.94	116.86 ~ 78.16	0.4003	0.3970
Grassland	E ± 50 %	103.04 ~ 96.84	100.20 ~ 94.82	0.0621	0.0551
Farmland	E ± 50 %	105.58 ~ 94.30	103.78 ~ 91.24	0.1128	0.1287
Wetland	E ± 50 %	119.01 ~ 80.87	115.99 ~ 79.03	0.3816	0.3790
Lakes/rivers	E ± 50 %	102.05 ~ 97.83	99.42 ~ 95.60	0.0421	0.0391
Barren land	E ± 50 %	100.00 ~ 99.88	97.57 ~ 97.45	0.0011	0.0012

while the CS fluctuated between 0.4003 and 0.3970, correspondingly; the next was wetland. Adjustment to farmland, grassland, lakes/rivers, and barren land had little impact and the CS ranged from 0.0011 to 0.1287.

Overall, the CS of these analyses were less than 1 under all scenarios, which indicated that the total ecosystem service value of study area were relatively inelastic with respect to the given equivalent value per unit area of ecosystem services in the Nenjiang River Basin. The equivalent value and ecosystem service evaluation in this study were acceptable.

Ecosystem service space distribution

In order to show the space distribution of ecosystem services in the Nenjiang River Basin, the maps of ecosystem services in 1980 (Fig. 3) and 2005 (Fig. 4) were drawn, and the average ecosystem service value of each city was calculated in Table 9.

From Figs. 3 and 4 and Table 9, we could get that the average ecosystem service value in the Nenjiang River Basin decreased gradually from the northwestern upstream mountainous area to the southeastern downstream plain. The higher valuable area are located in the Da and Xiao Xing'anling Ranges, such as Mohe, Hulunbeier, and Heihe city, while the lower valuable area are Baicheng, Songyuan, and Suihua city in the downstream plain. However, the Xing'an League, which also belongs to the Da Xing'anling mountainous area, is of a lower average ecosystem service value due to four great grassland reclamation activities from the 1950s (Pan et al. 2002; Su et al. 2005). According to statistics, the area of farmland in the Xing'an League increased about 44.21 % from 1996 to 2000 and 6.63 % from 2001 to 2005 (Ying, 2009).

The average ecosystem service value all decreased from 1980 to 2005, except for Mohe and Tongliao city. The highest decline happened in Qiqihar city, from 25.96 USD · ha^{-1} in 1980 to 24.13 USD · ha^{-1} in 2005, decreasing about 1.82 USD · ha^{-1} · a^{-1}. Next were Heihe and Daqing city, where large-scale farms were built in the past.

Discussion

Driving forces of land use/land cover and ecosystem service change

The Nenjiang River Basin is an important foodstuff base and eco-environmental fragile area in Northeast China. Because temperature shows an increasing trend of 0.3 °C per decade in the recent 50 years in Northeastern China (Luan et al. 2007; Ju et al. 2007), exceeding the warming amplitude of global average temperature obviously (Liu, 2007), the 1 °C isotherm of average annual temperature gradually shifted northward during 1986–2000 (Wang et al. 2009); the growing season was so prolonged that rice could be cultivated in more northern areas than ever before. The previous wetland or grassland, even non-irrigated dry fields, was reclaimed as paddy field under encouragement policy, resulting in the dramatic decrease of grassland or wetland and increment of farmland.

However, annual and seasonal precipitation in Northeastern China shows slightly decreasing trends, especially in summer precipitation (Ren et al. 2000; Lu, 2009). In the Nenjiang River Basin, the warming and drying trend has influenced the seasonal streamflow and altered the annual hydrograph of the basin. The decrease of streamflow in the lower basin (mainly alluvial plains) has caused wetland degradation, desertification, and soil salinization (Zhang and Guo 2008; Du et al. 2009; Feng et al. 2011).

Land use and land cover changes are particularly related to the increase of population and intensive agriculture (Verburg et al. 1999). Due to the increase in population and the concomitant requirement of grain, the building of farmland not only accelerated deforestation and cultivation of grassland and wetland but also resulted in damages to the ecological environment such as land degradation and ecosystem service recession.

According to the study by Han et al. (2005) in Zhaoguang Farm, which was the first mechanical farm built in Heihe city in late 1950s, the vegetation has changed from natural vegetation to cropweed, to rotation of corn-soybean-wheat, or to rotation of corn-soybean.

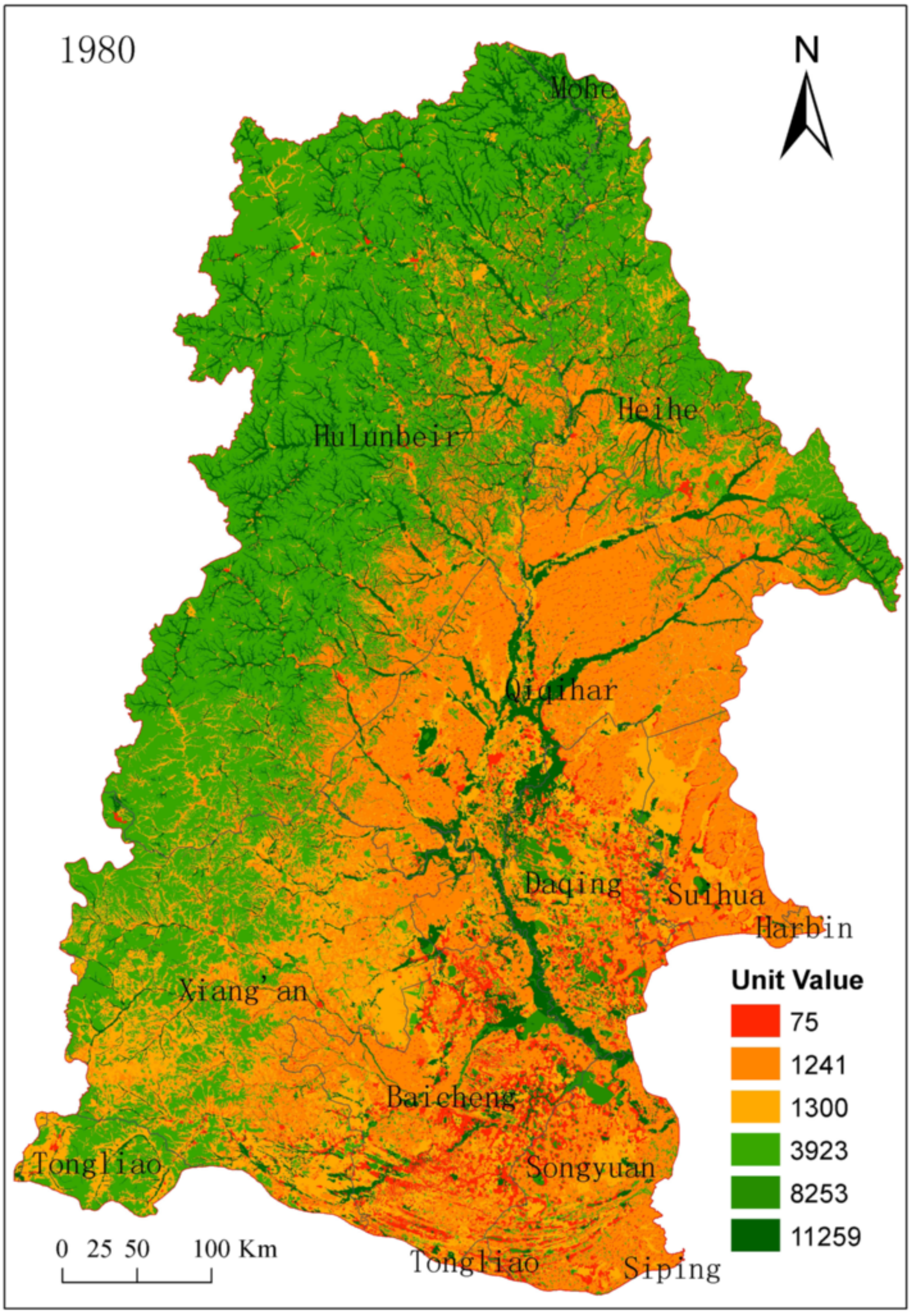

Fig. 3 Ecosystem service map of the Basin in 1980

The most important meadow soil has suffered substantial degradation after cultivation. If we took the soil C pool at the depth of 1 m in natural soil under the Steppified herbosa vegetation as control, the soil C pool under crops decreased by 7.76, 12.93, 14.66, 17.24, 20.26, and 23.71 % after 2, 8, 15, 30, 50, and 100 years cultivation, respectively (Fig. 5). Similarly, the soil N pool decreased by 6.5, 9.6, 11.3, 12.4, 12.5, and 13 %, respectively, in contrast to the increased trend of the soil N pool in the 0- to 50-cm-deep natural meadow soil.

For the same weather condition, in contrast to water storage in the 1-m-deep natural meadow soil, the water storage of soil after cultivation would decrease from 20.40 to 29.30 % in spring, 17.60 to 30.80 % in summer, and 19.70 to 29.90 % in Autumn (Fig. 6).

Deforestation and destruction of grassland has severely altered water distribution on land surface.

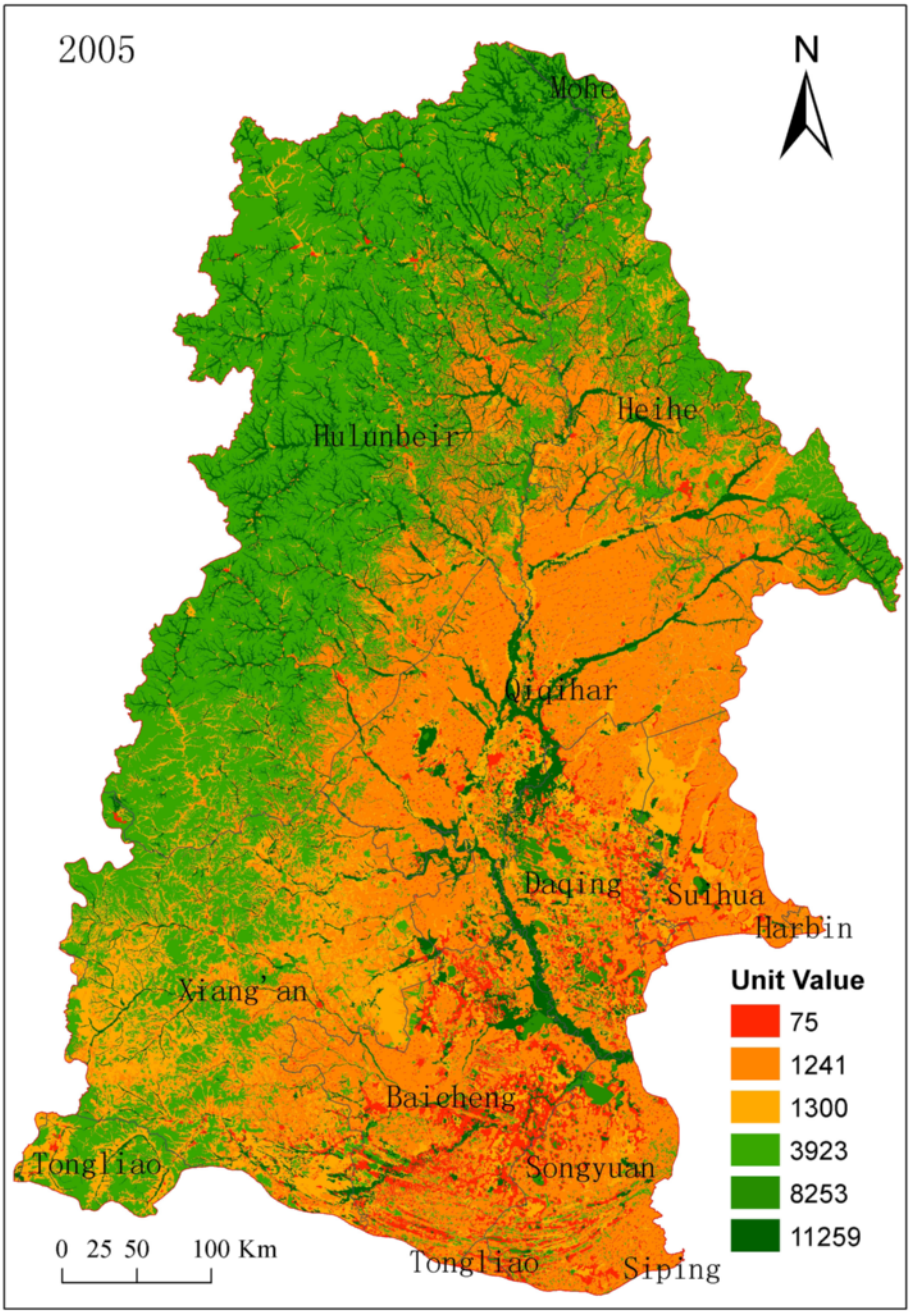

Fig. 4 Ecosystem service map of the Basin in 2005

Instead of infiltration and percolation, most of the surface runoff enters the channel directly during heavy rain, carrying soil from denuded farmland with it (Liu et al. 2005).

In short, it is land use/land cover changes that make tremendous influence on water and soil losses, but there is a little relationship of water and soil losses with the cultivation time. The effect of soil use/cover is bigger than the time effect (Han et al. 2005).

The effect of policy

Similar to the rest of China, policies of the central government put direct and important effects on land use/land cover changes in the Nenjiang River Basin. In the early 1980s, the decentralized decision-making in agricultural production of the household contract responsibility system afforded farmers more freedom in looking after their own interest. But, the central government attached great importance to food self-

Table 9 Total area and economic value of each city from 1980 to 2005 (USD · ha^{-1} · a^{-1})

City[a]	Area (ha)	1980	Rank	2005	Rank	Change	Rank	Trend
Mohe	150,119	58.85	1	59.54	1	0.68	7	↑
Hulunbeier	10,017,875	45.84	2	45.78	2	−0.06	10	↓
Heihe	3,228,976	38.74	3	37.07	3	−1.67	2	↓
Tongliao	565,079	30.71	4	30.96	4	0.25	8	↑
Daqing	1,705,401	30.28	5	28.73	5	−1.55	3	↓
Xiang'an	4,396,439	27.53	6	26.75	6	−0.77	6	↓
Qiqihar	4,134,101	25.96	7	24.13	7	−1.82	1	↓
Baicheng	2,453,927	23.14	8	22.12	8	−1.02	5	↓
Songyuan	1,387,153	18.70	9	17.23	9	−1.47	4	↓
Suihua	1,026,414	16.40	10	16.22	10	−0.18	9	↓

[a] Cities of small area belonging to the Nenjiang River Basin were not included, such as Siping, Changchun, and Harbin

sufficiency; as users of the land (but not its owners), farmers still had to honor grain production quotas imposed by the government (Wang et al. 2009). Due to the inconsistency between decision-making at the macro-level and the objective of agricultural production at the micro-level, cultivated land was increased through zealous reclamation of grassland, marginal woodland, and even fallow land (Liu et al. 2005).

By the late 1990s, after market-oriented reforms introduced to the agrarian sector, northeast-grown maize and soybean were not as profitable as rice in the market. Thus, large-scale farms were transformed into paddy fields; such changes have caused a severe shortage of water resources and the shrinkage of lakes/rivers along with climate change. These years, although the ecological functions of woodland, grassland, and wetlands were recognized widely and ecological projects such as "Grain for Green" and "Construction of Ecological Province" were adopted, driven by the short-term economic interests, in the less developed county, the reclamation of reserve resources still caused a substantial increase of farmland, and the amount of agricultural labor grew steadily (Liu and Li 2010).

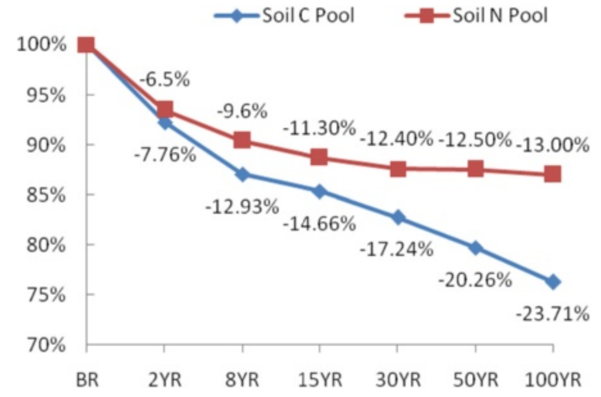

Fig. 5 Time variation of soil C pool and N pool in meadow soil after cultivation. *BR* before cultivation; *2YR*, *8YR*, *15YR*, *30YR*, *50YR*, *100YR* years after cultivation

Conclusions

According to the above calculation and analysis, in the Nenjiang River Basin, the two most valuable land use types were forest (40.00 billion USD, about 40.03 % of the total value in 1980; 38.71 billion USD, about 39.70 % of the total value in 2005) and wetland (38.14 billion USD, about 38.16 % of the total value in 1980; 37.90 billion USD, about 37.90 % of the total value in 2005), which are mainly located in the upstream Da and Xiao Xing'anling mountainous area, such as Mohe, Hulunbeier, and Heihe city. The economic value of land use types decreased obviously from 1980 to 2005, especially in the grassland of the downstream plain, such as Qiqihar and Daqing city, where large-scale grassland and wetland were reclaimed as farms in the past.

As for individual ecosystem service, besides the food production, all of the ecosystem service values declined from 1980 to 2005, of which water regulation and supply decreased the most for the human-induced cultivation and the warming and drying trend in the Nenjiang River Basin.

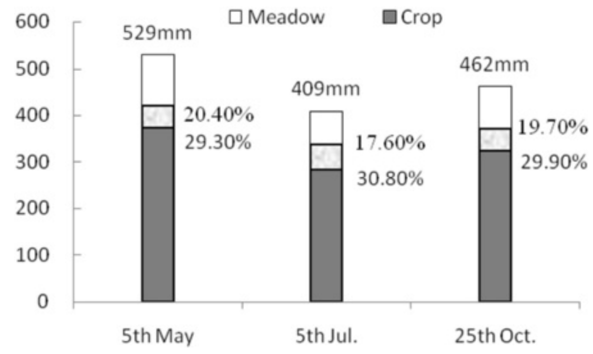

Fig. 6 Time variation of water storage in 1-m-deep meadow soil after cultivation

In a word, the economic value of ecosystem services in the Nenjiang River Basin decreased 2.43 billion USD, about 97.2 million USD per year from 1980 to 2005, due to tremendous land use/land cover changes under the encouragement policy during the past decade. So, the policies of Grain for Green and Construction of Ecological Province projects should be well-implemented to optimize land use/land cover.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
ZLW, ZW, and BZ designed the research; ZLW, CL, and CR conducted the research and analyzed the data; ZLW drafted the manuscript; ZW, BZ, and CR revised the manuscript. All authors read and approved the final manuscript.

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