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An analysis of the spatial and temporal changes in Chinese terrestrial ecosystem service functions

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Since Westman (1977) and Ehrlich (1982) put forward the concepts of "the service of nature" and "ecosystem service functions", respectively, methods for conducting value accounting for them, and their practical application have become the subjects of intense study. Based on an overview of available research findings, we discuss three scientific hypotheses. First, the terrestrial ecosystem offers both positive and negative service functions. Second, changes in terrestrial ecosystem service functions lie not only in the number of ecosystem types and the coverage area of each type, but also in their quality. Third, the value of terrestrial ecosystem service functions should be assessed both in terms of the value stocked and the value added. We collected land use data from China during the period 1999–2008, and Normalized Difference Vegetation Index data based on remote sensing images from the Global Inventory Modeling and Mapping Studies for the same period. We then calculated and analyzed spatial and temporal changes in China's terrestrial ecosystem service values over the 10-year period. Considering temporal change, the total value (stocked) of China's terrestrial ecosystem service functions decreased from 6.82 trillion Yuan RMB in 1999 to 6.57 trillion Yuan RMB in 2008. During that period, the positive value decreased by 240.17 billion Yuan RMB and the negative value increased by 8.85 billion Yuan RMB. The decrease in total value lies mainly in the humidity control, soil formation, and waste recycling functions. The total value (added) of China's terrestrial ecosystem service functions increased by 4.31 billion Yuan RMB in 2000, but decreased by 0.13 billion Yuan RMB in 2008 (based on the constant price of China in 1999). The value (added) was a negative figure. From the perspective of spatial change, we can see that the supply of China's terrestrial ecosystem service functions fell slightly over the past 10 years, mainly in Northeast and Southern China. As a result of human activities on ecosystems, the loss of ecosystem service functions' value was relatively prominent in Shanxi and Gansu provinces, compared with an increase in value in Shaanxi Province. Terrestrial ecosystem service functions' value per unit area was relatively high in mid- and East China, showing a prominent spatial change over the 10-year period, but low in Western China. Some conclusions are drawn after an in-depth analysis of the factors causing the spatial and temporal changes in China's terrestrial ecosystem service functions, in the hope that our suggestions will be helpful for the management of China's terrestrial ecosystems.

China's terrestrial ecosystems, ecosystem service functions, positive and negative value accounting, analysis of spatial and temporal change

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As an important part of the biosphere, ecosystems play an irreplaceable role in balancing the life-support system and the environment, and their functions have been recognized worldwide [1]. Research on terrestrial ecosystem service functions has become a significant strategic need for ecosystem recovery, ecological function identification, the establishment of ecological compensation mechanisms, and protecting the ecological safety of countries [2]. Over the last 30 years, assessments of natural resource value based on different spatial and temporal measurement scales have

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*Corresponding authors (email: wangrs@rcees.ac.cn; jlhuang@rcees.ac.cn) been carried out from the perspectives of ecosystem services, natural capital, ecological assets, and biological diversity, among others [3]. These assessments have achieved unprecedented progress in terms of relevant theories, methods, and the breadth and depth of their application. Although opinions on accounting methodology differ, the framework and general idea of this research have come into being and are gradually becoming clearer. In recent years, more emphasis has been placed on the coupling research of "structure-process-service functions" of the ecosystem, as well as on human-influenced urban ecosystem service functions [4]. In turn, natural resource value assessments provide strong support for further research on terrestrial ecosystem service functions.

The International Environment Research Group was the first team to be engaged in probing ecosystem service functions for humans. They have identified that environmental deterioration (e.g. climate change, flooding) is related to decreasing ecosystem service functions [5]. Westman [6] first used the expression "natural services" with an attempt to assess the natural ecosystem's service value for humans. Ehrlich and Ehrlich [7] first proposed the concept of "ecosystem services", and conducted research on how both species extinction and the compensative efforts of humans can influence ecosystem service functions. Ehrlich and Ehrlich [7] have systematically studied whether biodiversity loss would influence ecosystem service functions. Vitousek and Hooper [8] have conducted research on how ecosystem service functions respond to changes in species composition by applying computer simulation. In addition, many ecologists and economists have jointly compiled a large number of quantitative descriptions concerning different types of ecosystem service functions provided to humans. They have also conducted a substantial amount of research on how to assess the service value of different types of ecosystems, which has accumulated a wealth of experimental research data [9–14].

Since the publication of "*Nature's Services: Societal Dependence on Natural Ecosystems*" [15] and the article "The value of the world's ecosystem services and natural capital" by Costanza et al. [16], many scholars worldwide have conducted systematic research on the methodologies for assessing natural ecosystem service functions and the value of their assets from different perspectives [17–19].

Over the past few years, Chinese researchers have been concentrating on scientific accounting of the quantity and quality of ecosystem services, and the value of ecosystem service functions. They have also focused on the study of human-influenced complex ecosystem service functions and ecological assets. Some Chinese researchers have conducted a series of comprehensive assessments of the quantity and quality of natural ecosystem service functions using remote sensing images [20–22]. Based on a balance of the relationship between the supply and consumption of ecosystem services, some studies have further probed into how artificial ecosystems, in particular construction land ecosystems, consume or affect ecosystem service value (ESV) [23,24]. Pioneering research on the positive and negative values of complex ecosystem service functions from the perspective of urban ecosystems has also been carried out [25,26].

Therefore, we can view the concept of "ecosystem service functions" in two ways: The first is based on natural ecosystem services whose corresponding carriers are natural ecological assets [15,16]; the second is based on a "society-economy-nature" complex ecosystem [26] and urban ecosystem service functions [25,26], whose corresponding carriers are complex ecological assets, including society, economy, and natural resources [27]. Natural ecosystem services are included in "society-economy-nature" complex ecosystems, while the latter is an expansion of the former. Natural ecosystem services are more mature in theoretical research but have not yet reached a consensus methodology, and "society-economy-nature" complex ecosystems are still in the initial stages of both theoretical and methodological research. We use the latter concept to conduct research on terrestrial ecosystem service functions.

Although the theoretical and methodological studies of ecosystem services are constantly updated, very few case studies integrate new theories and methods into in-depth research. Most research on China's terrestrial ecosystem service functions still fails to progress from research on the natural ecosystem's positive functions to research encompassing "society-economy-nature" complex ecosystems. Therefore, we consider three scientific hypotheses. First, the terrestrial ecosystem offers both positive and negative service functions. Second, changes in terrestrial ecosystem service functions not only lie in the number of ecosystem types and the coverage area of each type, but also in their quality. Third, the value of terrestrial ecosystem service functions should be assessed in terms of both the value stocked and the value added. Based on the above considerations, we conducted a comprehensive analysis of the spatial and temporal changes in China's terrestrial ecosystem (including urban ecosystems) from 1999 to 2008. Furthermore, we explain the ecological achievements made, and the ecological cost sacrificed by China's social and economic development over the 10-year period by accounting for positive and negative values, and the value stocked and value added. We also clearly describe how much value is provided by China's terrestrial ecosystem and how much value is added or removed by human activities.

1 Methodologies and data collection

1.1 Terrestrial ecosystem classification based on China's Land Use Classification Criteria

First, we divided terrestrial ecosystems into three categories: natural ecosystems, artificial ecosystems, and nature-alike ecosystems. According to China's Land Use Classification

Criteria (LUCC; National Agricultural Division Office, 1984), we subdivided them into eight categories: farmland ecosystem, garden ecosystem, forest ecosystem, grassland ecosystem, wetland ecosystem, urban ecosystem, road ecosystem, and non-used land ecosystems (Table 1). Urban and road ecosystems belong to artificial ecosystems, forest, grassland, and water ecosystems partially belonged to both natural ecosystems and nature-alike ecosystems, and farmland and garden ecosystems belonged to nature-alike ecosystems.

1.2 Positive and negative values of China's terrestrial ecosystems per unit area

Currently, the majority of methods for ESV accounting only consider the value of natural ecosystems, and assume the value of artificial ecosystems (including construction land) to be zero. In fact, human ecological construction and ecosystem control can have positive or negative effects on ecosystem service functions and value [28]. Based on the "society-economy-nature" complex ecosystem concept, we considered the following functions provided by the natural ecosystem as positive: production resources, environmental regulation, material flow, and culture-cradling. Negative functions include various natural-disaster-caused losses to human social-economic development. An increase of the complex ecosystem's service value contributed by the artificial ecosystem as a result of human ecological construction is seen as a positive function. A loss of the complex ecosystem's service value caused by the artificial ecosystem as a result of human activities is seen as a negative function. Therefore, both the natural ecosystem and the artificial ecosystem have positive and negative function values, as shown in Figure 1.

Table 2 lists China's different terrestrial ecosystems and their corresponding service value parameters, which are parameters for the positive and negative values of the terrestrial ecosystem's service value per unit area [29–37]. Most of the parameters shown in Table 2 refer to natural ecosystems, and some parameters for negative values have not yet been assigned, as research on non-natural terrestrial

Table 1 The classification of terrestrial ecosystems in China[a)]

Ecosystem type	Land use and land cover type (the standard of 1984)
Grassland	Natural grassland (41), Improved grassland (42), Man-breed grassland (43), Rough grassland (81)
Garden land	Fruit garden (21), Mulberry plantation (22), Tea plantation (23), Rubber plantation (24), others (25)
Farmland	Irrigated farmland (11), Ordinary farmland (12), Dry farmland (14), Vegetable farmland (15)
Forest land	Woodland (31), Shrub (32), Low density forest land (33), Cultivated forest land (34), Nursery (35)
Wetland	River (71), Lake (72), Reservoir (73), Reed land (74), Beach (75), Pond (76), Channel (77), Marsh (83)
Urban land	City (50), Urban (51), Rural Residential (52), Industrial land (53), Salt land (54), Special land (55)
Road land	Railway (61), Highway (62), Village road (63), Airport (64)
Non-used land	Saline land (82), Sandy land and Desert (84)

a) Based on China's Land Use Classification Criteria (National Agricultural Division Office, 1984).

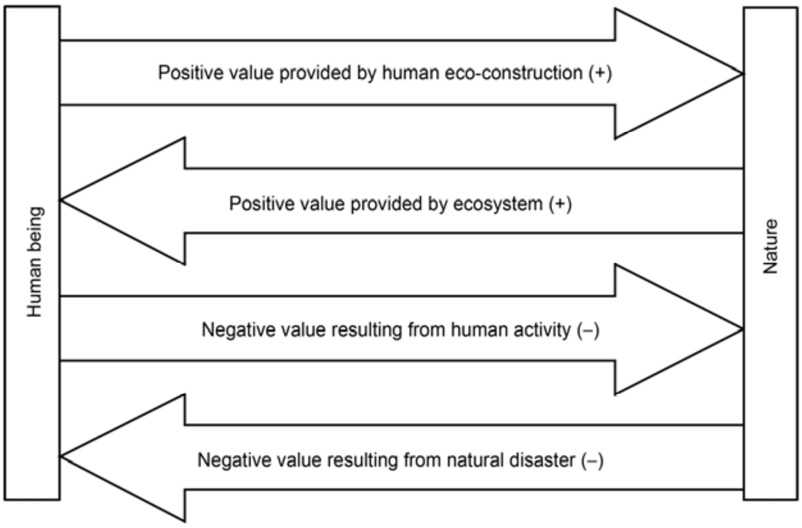

Figure 1 The connotation and composition of each positive and negative values of the ecosystem.

ecosystems, such as urban and road ecosystems has not been widely carried out.

1.3 GIMMS-NDVI-based modified value coefficients

Using the Normalized Difference Vegetation Index (NDVI) dataset compiled by the Global Inventory Modeling and Mapping Studies (GIMMS; collected annually each August) of the Western China Environmental and Ecological Scientific Data Centre (Figure 2) [38], we were able to modify the per unit area service-to-monetary value conversion rates for all functions provided by grassland, garden, and forest ecosystems. The λ function is the modified coefficient for the value, which reflects ecosystem quality change in different areas of China each year:

$$\lambda=\frac{\sum\left(\mathrm{NDVI}_i-\min(\mathrm{NDVI})\right)/\left(\max(\mathrm{NDVI})-\min(\mathrm{NDVI})\right)}{n}, \tag{1}$$

where NDVI_i is the NDVI's exponential value in grid i, min(NDVI) is the minimum value of the NDVI values in all grids, max(NDVI) is the maximum value of the NDVI values in all grids and n is the number of grids. The size of GIMMS image data is 8 km × 8 km.

1.4 Consumer price index-based modification of values in different periods

To conduct ESV accounting it is important to first choose a specific year as the price basis. By adopting these methods we can determine how much input is required to deal with pollution, conduct ecological constructions, and replace some distinguished species' value [39]. This study aims primarily at determining China's various terrestrial ecosystems' total service values (including natural ecosystems, nature-alike ecosystems, and artificial ecosystems) and focuses on the proportion of positive and negative values, total value (stocked), total value (added), and its spatial allocation in China. Therefore, we introduced the concept of comparable prices and comparable growth rates from economic sciences, and unified China's ESV in different periods to the constant price in 1999 (Table 3). Taking 1999 as

Table 2 The empirical parameters of China's terrestrial ecosystems' function values[a)]

Ecosystem type	Indirect value							Direct value			Total value per hm^2
	Climate regulation	Atmosphere regulation	Humidity regulation	Water & soil conservation	Soil formation	Waste recycling	Biological control	Food supply	Raw material	Culture & recreation	
Farmland[b)]	442.4	787.5	530.9	–	1291.9	1451.2	628.2	884.9	88.5	8.8	6114.3
Garden[c)]	1265.5	1170.3	41.5	796.8	1291.9	722.1	16.6	356.9	1145.4	547.8	7354.8
Forest[d)]	1902.5	1592.8	1769.7	796.8	2588.2	1159.2	1924.6	177	1172.4	584	13667.2
Grassland[e)]	707.9	796.4	707.9	102.9	1725.5	1159.2	964.5	265.5	44.2	35.4	6509.4
Wetland	–	407.0	18033.2	–	8.8	16086.6	2203.3	88.5	8.8	3840.2	40676.4
Urban[f)]	–	–	–6678	3480	–	–2174.1	–	–	–	–	–5372.1
Road[f)]	–	–	–	3480	–	–	–	–	–	–	3480
Unused	–	–	26.5	–	17.7	8.8	300.8	8.8	–	8.8	371.4
Total value	4318.3	4754	14431.7	8656.5	6924	18413	6038	1781.6	2459.3	5025	72801.4

a) Unit: Yuan RMB/hm^2; b) from [35], 2007; c) from [36], 2009; d) from [37]; e) from [34]; f) from [23].

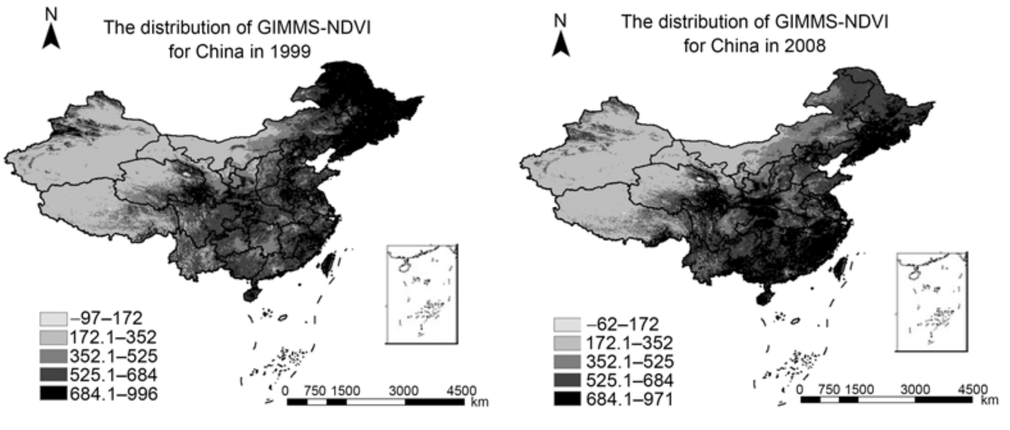

Figure 2 The spatial distribution of China's NDVI based on GIMMS data for the years 1999 (left) and 2008 (right).

Table 3 China's CPI values for 1999–2008

Year	CPI value	Inflation rate (%)	Year	CPI value	Inflation rate (%)
1999	−1.4	0	2004	3.9	3.79
2000	0.4	1.28	2005	1.8	2.29
2001	0.7	1.5	2006	1.5	2.07
2002	−0.8	0.43	2007	4.8	4.43
2003	1.2	1.86	2008	5.9	5.21

the base year,

Comparable growth rate of ESV in 2008 = ESV of 2008/(ESV of 2008 × (1 + Inflation rate)) − 1, (2)

where Inflation rate = (CPI of the current year − CPI of the base year)/CPI of the base year × 100%.

Therefore, the comparable ESV of the current year = the ESV of the base year × (Comparable growth rate +1) = the actual ESV of the current year/(1 + Inflation rate). (3)

1.5 Stocked, added, and intensity of ecosystem service value (ESV)

First, we used the value stocked to quantitatively describe the terrestrial ecosystems' inherent service value

$$\mathrm{ESV}_{\text{stock}} = \sum\sum \alpha_{ij}^{+} S_i + \sum\sum \alpha_{ij}^{-} S_i, \qquad (4)$$

where α_{ij} is the service-to-monetary value conversion rate when class i terrestrial ecosystem provides class j service function, namely the parameter for a terrestrial ecosystem's service value per unit area. We have $\alpha_{ij} = \alpha_{ij}^{+} + \alpha_{ij}^{-}$, if $\alpha_{ij} \geqslant 0$ then $\alpha_{ij} = \alpha_{ij}^{+}$, if $\alpha_{ij} \leqslant 0$ then $\alpha_{ij} = \alpha_{ij}^{-}$. S_i is the equivalent value of class i terrestrial ecosystem which can be substituted with the ecosystem's current coverage value.

The positive ecological constructions carried out by humans, such as the protection of farmland, forest and wetland ecosystems, lead to enhancements in regional ecosystem service functions and thereby increase its ecological value. Human destruction of natural ecosystems, such as occupying farmland, forest, and wetland ecosystems, as well as causing functional degradation of them, results in declines in regional ecosystem service functions and thus a loss in ecological value. Therefore, we can use the value (added) to quantitatively describe the influence of human activities on terrestrial ESV:

$$\mathrm{ESV}_{\text{added}} = \sum\sum\left(\lambda\alpha_{ij}^{+}C_i^{+} + \alpha_{ij}^{-}C_i^{-}\right) + \sum\sum\left(\lambda\alpha_{ij}^{+}C_i^{-} + \alpha_{ij}^{-}C_i^{+}\right), \qquad (5)$$

where λ is the modification coefficient for the GIMMS-NDVI value, a_{ij} is defined as above, and C_i stands for the equivalent value of class i terrestrial ecosystem type variation caused by human activities and is substituted with its coverage value. $C_i = C_i^{+} + C_i^{-}$, if $C_i \geqslant 0$, then $C_i = C_i^{+}$. If $C_i \leqslant 0$, then $C_i = C_i^{-}$.

Through spatial analysis, we found that the value (stocked) and the value (added) of regional ecosystems are relatively higher in some areas than in others. However, the per unit area service value and the per unit area value (added) of the ecosystem services in areas with higher value (stocked) and value (added) is relatively lower than those with lower values in other areas. Therefore, we used the ecosystem service intensity to compare an ecosystem's service function in one area with that of another area:

$$\mathrm{ESV}_{\delta\text{-intensity}} = \mathrm{ESV}_{\delta\text{-stock}} / S_{\delta}, \qquad (6)$$

$$\mathrm{ESV}_{\delta\text{-intensity}} = \mathrm{ESV}_{\delta\text{-added}} / S_{\delta}, \qquad (7)$$

where $\mathrm{ESV}_{\delta\text{-stock}}$ stands for the ecosystem service value (stocked) in area δ, $\mathrm{ESV}_{\delta\text{-added}}$ stands for the ESV (added) in area δ and S_δ is the coverage value of area δ.

1.6 Data collection

To meet our study objectives, we undertook the following steps for data collection:

(1) Searched ecosystem service function literature in China and abroad, with an emphasis on different types of ecosystems to provide different service function evaluations for Chinese ecosystems;

(2) Searched *China's Land Resources Yearbook* to collect land use area and change situation tables for 1999–2008, then referring to the classification of terrestrial ecosystems in China classified the different types of ecosystem areas and change situation tables;

(3) Collected long-term time-series GIMMS vegetation index data sets from the Western China Environmental and Ecological Scientific Data Center, then used Formula (1) to determine the ecosystem service function quality change of value correction factor;

(4) Unified the values of the Chinese ecosystem service functions to 1999 prices referring to Formulas (2) and (3), and the table of consumer price index (CPI) presented in the China Statistical Yearbook .

2 Results

2.1 Analysis of positive and negative values (stocked)

The positive values (stocked) provided by China's terrestrial ecosystems over the 10-year period were essentially stable, without any significant fluctuations in terms of total value, the values of different functions, or in terms of the values provided by different ecosystems (Figure 3). The total positive value provided by China's terrestrial ecosystem services decreased from 7.04 trillion Yuan RMB in 1999 to 6.8 trillion Yuan RMB in 2008 (based on the constant price of China in 1999).

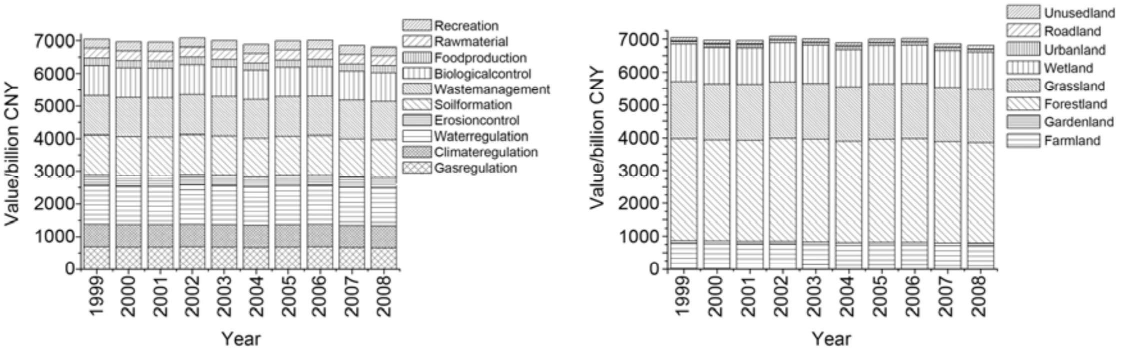

Figure 3 China's positive ecosystem service values in a recent 10-year period.

By considering the values contributed by different service functions (Figure 3), it can be seen that between 1999 and 2008 the gas regulation value decreased from 691.26 to 668.41 billion Yuan RMB; the climate regulation value decreased from 698.86 to 671.08 billion Yuan RMB; the water regulation value decreased from 1.17 to 1.14 trillion Yuan RMB; the water and soil conservation value decreased from 322.39 to 310.57 billion Yuan RMB; the soil formation value decreased from 1.23 to 1.18 trillion Yuan RMB; the waste recycling value decreased from 1.21 to 1.17 trillion Yuan RMB, and the biological control function value decreased from 917.90 to 882.93 billion Yuan RMB. The value jointly provided by water regulation, soil formation, waste recycling, and biological control functions accounted for nearly 63.2% of the total value in each year, whereas the climate regulation value only accounted for 10%.

Considering the values contributed by different types of ecosystems, it can be seen that between 1999 and 2008, the farmland ecosystem's service value dropped from 789.97 to 707.45 billion Yuan RMB; the garden ecosystem's service value increased from 73.55 to 82.49 billion Yuan RMB; the forest ecosystem's service value decreased from 3.12 to 3.07 trillion Yuan RMB; the grassland ecosystem's service value decreased from 1.72 to 1.62 trillion Yuan RMB; the wetland ecosystem's service value increased from 1.126 to 1.126 trillion Yuan RMB; the urban ecosystem's service value increased from 85.61 to 89.09 billion Yuan RMB, and the road ecosystem's service value dropped significantly from 19.72 to 8.16 billion Yuan RMB. The forest ecosystem's service value ranks highest with a contribution of almost 50% to the total value, followed by the grassland ecosystem and the wetland ecosystem, accounting for 25% and 17% respectively. A yearly service value drop in the farmland, grassland, forest land, and road ecosystems is apparent over the 10-year period. However, a yearly service value increase can be seen in other ecosystems. This shows that China's ecological problems lie mainly in the gradual reduction of arable land, the gradual degradation of grassland resources, and the ecological destruction caused by road construction. However, the urban ecosystem's service value has increased alongside the accelerated pace of China's ecological urban construction.

As the amount of research and available data are limited, we have only analyzed the negative value provided by the urban ecosystem and concentrated on two of its functions, the water regulation and the waste recycling functions (Figure 4). The negative value provided by China's terrestrial ecosystem's inherent services increased from –217.76 billion Yuan RMB in 1999 to –226.61 billion Yuan RMB in 2008, displaying slight yearly growth.

2.2 Analysis of the human-created ecosystem service value (ESV)

From changes in land use and NDVI in China over the past 10 years, it can be seen in Figure 5 that ESV created by human activities fluctuates wildly, showing a yearly downward trend from 2002. The ESV was 14.97 billion Yuan RMB in 2000, peaked at 83.03 billion Yuan RMB in 2002, and plunged to 3.46 billion Yuan RMB in 2008. Taking the peak of 2002 as an example, value was primarily added by water conservation and waste recycling, with values of 29.1

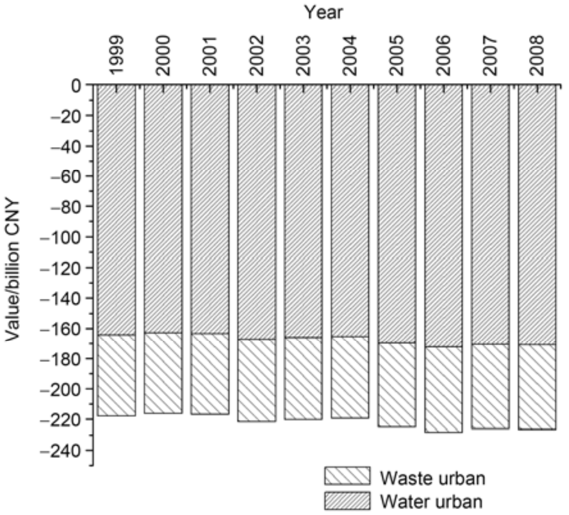

Figure 4 China's negative ecosystem service values in a recent 10 year period.

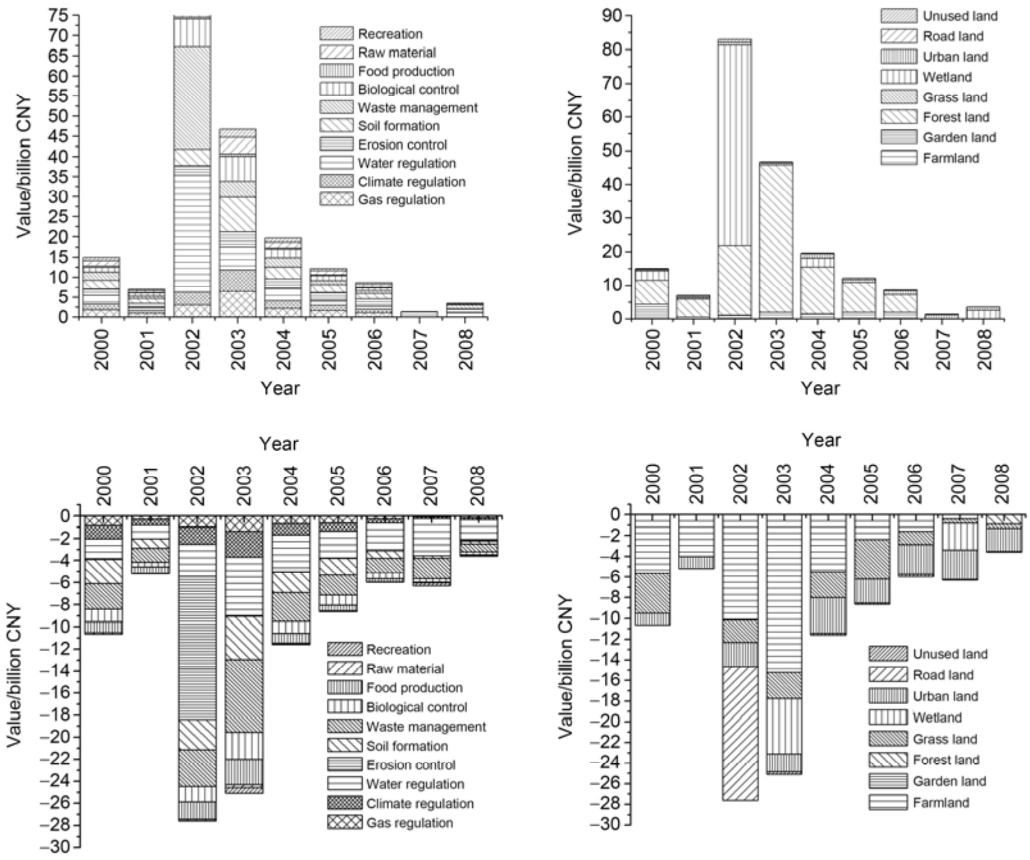

Figure 5 ESVs for ecological construction and degradation in a recent 10-year period in China.

and 25.38 billion Yuan RMB, respectively, primarily as a result of the construction of wetland and forest ecosystems, which added values of 59.4 and 20.87 billion Yuan RMB respectively. Taking 2008 as another example, value was also mainly created in water conservation and waste recycling, with values of 1.14 and 1.02 billion Yuan RMB, respectively, primarily as a result of the construction of wetland and urban ecosystems, which provided values of 2.58 and 0.88 billion Yuan RMB, respectively. Before 2007, the human-created ESV was primarily derived from forest ecosystem construction.

The ESV loss reflected by land use change and NDVI over the past 10 years appears as a yearly downward trend, dropping from 10.66 billion Yuan RMB in 2000 to 3.59 billion Yuan RMB in 2008. Taking 2002 as an example, the loss was mainly in the value of water and soil conservation functions and the waste recycling function, reaching losses of 13.97 and 3.37 billion Yuan RMB, respectively. These losses were primarily caused by the disruption or quality degradation of farmland and road ecosystems, causing losses of 10.15 and 12.94 billion Yuan RMB, respectively. Taking 2008 as another example, the loss was mainly in the value of the humidity adjustment function (1.85 billion Yuan RMB), which was primarily caused by urbanization and land depletion, causing a loss of around 2.24 billion Yuan RMB. Finally, the ESV loss caused by land-use change before 2006 was most evident in farmland ESVs.

2.3 Analysis of the ecosystem's spatial intensity

Table 4 shows the total ESV of various regions in China in both 2000 and 2008, and Figure 6 displays changes in ESV for the regions identified in Table 4. The following six provinces (or autonomous regions) account for the highest proportions of terrestrial ecosystem value stocked (ESV_{stock}): Inner Mongolia Autonomous Region (Inner Mongolia for Short), Heilongjiang Province, Sichuan Province, Yunnan Province, and Tibet Autonomous Region and Xinjiang Uygur Autonomous Region (Xinjiang for Short), accounting for 11.82%, 6.68%, 6.3%, 5.4%, 10.62% and 8.1%, respectively, in 2000 and 11.54%, 6.42%, 7.2%, 6.3%, 8.91% and 7.6%, respectively, in 2008. China's terrestrial ESV declined mainly in Northeast and Southern China. For the change in total value over the past 10 years, the ESV increased significantly in Southwest China and declined prominently in Northwest China, while the tendency was unclear in mid-East China. In terms of the value added (ESV_{added}), some provinces or cities of Northern, East, Southern and Northwest China had negative growth in their ESV in 2000; that is, in those regions ESV loss was greater than the value created as a result

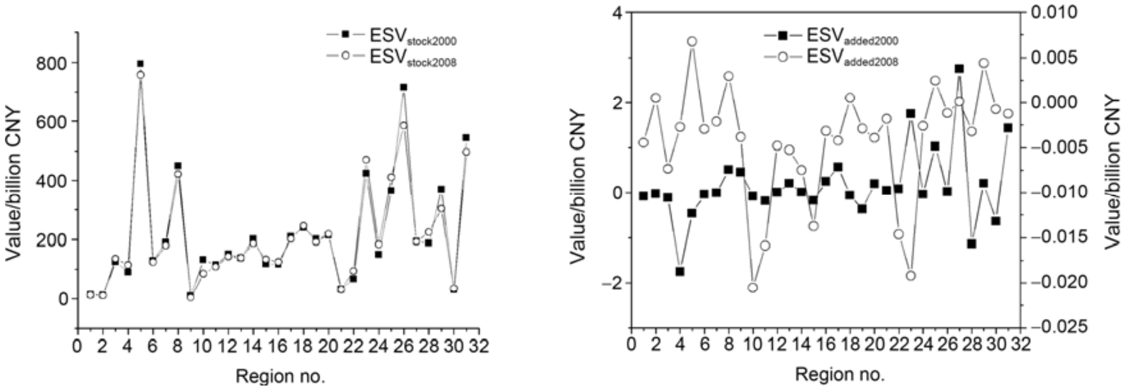

Figure 6 The change in ESV of each province in China from 2000 to 2008.

Table 4 The ESV of each province in China in 2000 and 2008[a)]

No.	Region	2000		2008		No.	Region	2000		2008	
		ESV$_{\text{stock}}$	ESV$_{\text{added}}$	ESV$_{\text{stock}}$	ESV$_{\text{added}}$			ESV$_{\text{stock}}$	ESV$_{\text{added}}$	ESV$_{\text{stock}}$	ESV$_{\text{added}}$
1	Beijing	133.39	−0.75	129.78	−0.04	17	Hubei	2099.56	5.67	2022.94	−0.04
2	Tianjin	126.97	−0.31	115.81	0.00	18	Hunan	2394.59	−0.56	2460.99	0.01
3	Hebei	1252.27	−1.05	1352.28	−0.07	19	Guangdong	2019.61	−3.72	1914.88	−0.03
4	Shaanxi	904.82	−17.51	1139.09	−0.03	20	Guangxi	2146.42	1.95	2184.60	−0.04
5	Neimeng	7956.46	−4.61	7573.73	0.07	21	Hainan	329.13	0.39	311.54	−0.02
6	Liaoning	1280.81	−0.41	1242.68	−0.03	22	Chongqing	663.48	0.77	943.45	−0.15
7	Jilin	1901.56	−0.10	1796.16	−0.02	23	Sichuan	4240.56	17.51	4696.93	−0.19
8	Heilongjiang	4494.37	5.10	4212.75	0.03	24	Guizhou	1497.56	−0.40	1833.97	−0.03
9	Shanghai	93.40	4.52	39.37	−0.04	25	Yunnan	3652.04	10.24	4105.33	0.02
10	Jiangsu	1316.65	−0.78	852.11	−0.21	26	Tibet	7149.53	0.17	5850.30	−0.01
11	Zhejiang	1144.16	−1.84	1084.97	−0.16	27	Shaanxi	1936.45	27.48	1922.78	0.00
12	Anhui	1515.31	0.00	1431.42	−0.05	28	Gansu	1878.88	−11.43	2243.62	−0.03
13	Fujian	1381.61	2.06	1383.10	−0.05	29	Qinghai	3696.25	2.08	3041.94	0.04
14	Jiangxi	2025.23	0.04	1863.10	−0.07	30	Ningxia	312.52	−6.42	345.22	−0.01
15	Shandong	1170.99	−1.76	1327.46	−0.14	31	Xinjiang	5433.61	14.31	4966.80	−0.01
16	Henan	1166.68	2.50	1250.95	−0.03		Total	67314.88	43.16	65640.1	−1.32

a) Unit: Billion Yuan RMB.

of human activities.

ESV loss was evident in Northern China (represented by Beijing, Hubei, Shanxi and Inner Mongolia), East China (represented by Jiangsu, Zhejiang and Shandong), Southern China (represented by Guangdong) and Northwest China (represented by Gansu and Ningxia Hui Autonomous Region (Ningxia for Short)). In Shanxi and Gansu, ESV loss reached 1.751 and 1.143 billion Yuan RMB in 2000, respectively, accounting for 34% and 22% of China's total ESV loss. However, ESV (added) was evident in other parts of China, in particular in Heilongjiang (Northeast China), Hubei (mid-China), Henan, Sichuan (Southwest China), Shaanxi, and Xinjiang (Northwest China), among which the ESV of Shaanxi experienced the largest increase of almost 3 billion Yuan RMB, accounting for 30.8% of China's total value (added). In 2008, however, all the provinces and cities in China suffered slight ESV loss except for Tianjin, Inner Mongolia, Heilongjiang, Hunan, Shaanxi and Qinghai.

The per unit area terrestrial ESV intensity shows different results (Figure 7). First, considering the intensity of the value stocked (ESV$_{\text{stock-intensity}}$), the per unit area terrestrial ESV appears relatively high in Mid- and East China, whereas it is relatively low in Western China. Taking 2000 as an example, the ESV$_{\text{stock-intensity}}$ was over 12 million Yuan RMB/km^2 in Jiangsu and Anhui, and over 9 million Yuan RMB/km^2 in Heilongjiang, Jilin, Henan, Hubei and Hunan, as well as in some provinces and cities in East and Southern China. In 2008, the regions with an ESV$_{\text{stock-intensity}}$ of over 12 million Yuan RMB/km^2 were Hunan and Chongqing, while other regions, for example, Sichuan, Guizhou and

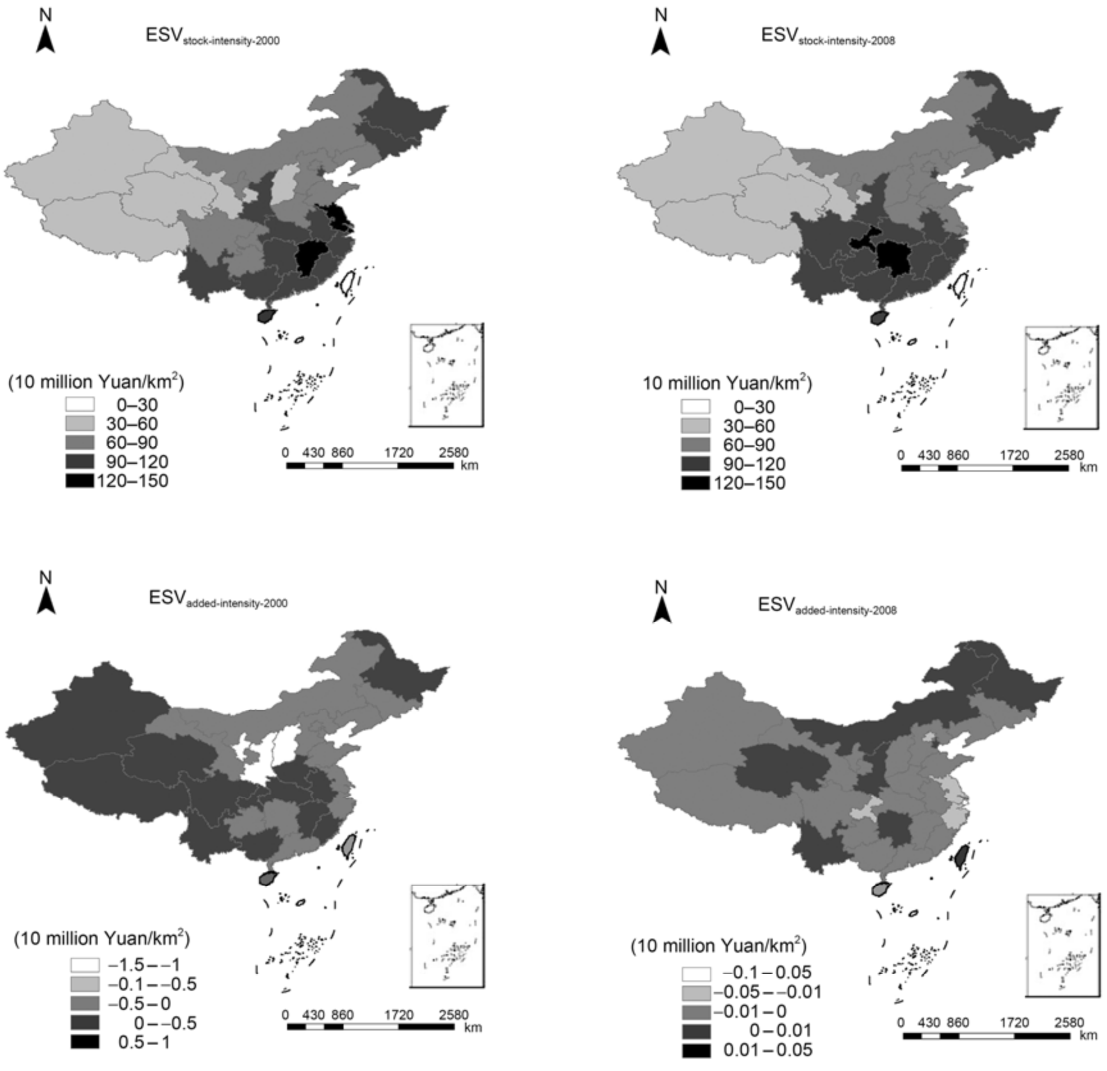

Figure 7 The spatial distribution of China's ESV intensity in 2000–2008.

Jiangxi had an ESV$_{\text{stock-intensity}}$ of over 9 million Yuan RMB/km^2. Second, considering the intensity of the value added (ESV$_{\text{added-intensity}}$) in 2000, the per unit area terrestrial ESV (added) appeared higher than the ESV loss in many places, for example, most parts of Western China, Heilongjiang (Northeast China), and some provinces in mid-East China (including Henan, Hubei, Zhejiang, Anhui and Fujian), and Hainan (Southern China). Whereas ESV loss was evident in Shanxi and Shaanxi, in 2008 the ESV$_{\text{added-intensity}}$ appeared as a negative figure in all regions of China with the exception of Inner Mongolia, Tianjin, Heilongjiang, Shaanxi, Qinghai, Guangxi and Hainan. However, the positive figures within these regions were low.

3 Discussion

3.1 Comparison with other relevant studies

Currently, most Chinese research on ESV change (following human activities) is restricted to certain areas or certain ecosystem types instead of including China as a whole to identify changes in total service value [39,40]. Our study is only comparable with others in terms of China's total stocked ecosytem value and the ecosystem's value intensity in different provinces or regions.

Having balanced all the positive and negative values, China's total terrestrial ESV was 6.82 trillion Yuan RMB in 1999 and 6.57 trillion Yuan RMB in 2008. The figures are similar to, but higher than, the figure of 6.44 trillion Yuan RMB obtained by Pan et al. [20], who analyzed remote measurements of ecological assets, and the figure of 5.61 trillion Yuan RMB obtained by Chen et al. [29]. There are three reasons for the differences. First, the data sources and accounting methods used are different. Our study is based mainly on LUCC, summarizing the coverage values of different terrestrial ecosystem types and taking into consideration the empirical parameters for different service function values (where the parameter is the per unit area of terrestrial

ESV), whereas Pan et al. [20] conducted value accounting based on remote sensing data of China's vegetation. The final accounting results are therefore bound to be different to some extent. Second, the time periods during which the data were collected are different. Pan et al. [20] obtained value accounting results based on remote sensing image datasets of China's vegetation in the 1980s and early 1990s, whereas we focused on data from 1999 to 2008, when China's ESV appeared to show an upward trend, which is in line with the Chinese government's yearly increased input into ecological construction [41]. Third, the most influential reason is that Pan et al. [20] calculated China's ESV by analyzing the spatial allocation of China's vegetation types without considering the possible positive values provided by artificial ecosystems, such as urban construction land and road ecosystems.

The same issue of different methodologies applies to the accounting of the Total Service Value Stocked of China's various terrestrial ecosystems and to the accounting of the Total Service Value Stocked of different types of service functions. In this paper, the forest ecosystem's service value ranks at the top, accounting for almost 50% of the total value, although its value dropped from 3.12 trillion Yuan RMB in 1999 to 3.07 trillion Yuan RMB in 2008. Ranking in the second and third places, the shrub-grassland ecosystem's and wetland ecosystem's service values account for 25% and 17% of the total value, respectively. However, according to the results presented by Pan and other scholars [20], the forest ecosystem's service value, which mainly comprised tropical and sub-tropical forest ecosystems (88.92%), accounted for 24.76% of the total value, while the wetland ecosystem accounted for 41.02%. According to that study, these two types of ecosystems jointly accounted for 65% (24.76% plus 41.02%) of China's terrestrial ecosystem's service value. The differences between the two groups of data resulted from having used different ecosystem classification criteria. In this paper, forest ecosystems include woodlands, coppice woodlands, open forest lands, in-forestation lands, and nursery gardens; whereas in Pan's research, forest ecosystems only covered tropical and sub-tropical forests and temperate forests. If we added the shrub-grassland ecosystem's service value to the corresponding result in Pan's research, then Pan's research results would be in accordance with ours.

From the perspective of China's total terrestrial ecosystem service value for each year in the period 1999–2008, we find that China's total terrestrial ecosystem's service value (stocked) increased by 1.32%. During this period, the water regulation function's value increased the most rapidly (2.96%), which was primarily because of the enhancement of the forest, grassland, and wetland ecosystems' service functions. The results presented by Ran et al. [41] in 2006, are similar to our own. According to their analysis, China's ecosystem service value increased by 0.91% in the period 1996–2004. During those years, the climate regulation function's value increased the most rapidly (3.43%), which was primarily the result of an increase in the coverage area of water, forest, and garden ecosystems. The difference in the ecosystem's Service Value Increase between our research results and Ran's (ours is 1.32% while theirs is 0.91%) resulted from using different time periods for the analysis. For a given ecosystem's function value, our estimated value increase is different to theirs. This is because we have used different ecosystem service function classification criteria. In this paper, ecosystem service functions are divided into gas regulation, climate regulation, water regulation, water and soil conservation, and so on. In Ran's research, the gas regulation, climate regulation, and water regulation functions are all classified into the climate regulation function.

We found that in terms of the ESV intensity in different regions of China, China's terrestrial ESV falls mainly in Northeast and Southern China. In terms of per unit area ESV intensity, mid- and East China enjoy a relatively higher intensity, whereas Western China has a lower intensity. Our findings are in accordance with results of Bi et al. [21] and He et al. [22]. In terms of the value added ($\mathrm{ESV}_{\mathrm{added}}$), some provinces or cities in Northern, East, Southern, and Northwest China have experienced negative growth in their ESV, while growth was evident in Heilongjiang (Northeast China), Hubei and Henan (mid-China), Sichuan (Southwest China), and Shaanxi and Xinjiang (Northwest China), which is in accordance with the results of Ran et al. [41].

3.2 Explanation of findings

The dynamics of the positive and negative valued stock of China's land ecosystem service functions changed over time. Although the total amount did not significantly change, the various service functions provided by different ecological systems changed significantly.

For example, in China, farmlands, forests, and grasslands ESVs have been falling each year, while the urban ecosystem service function increased. This shows that ecological problems such as the reduction of arable land resources, and degradation of forest and grassland resources are still serious, and that as the pace of ecological urban construction increases gradually, the terrestrial ecosystem service function supply will play an increasingly important role. The changing negative value of urban ecosystems also demonstrates this point.

With regards to human activities, China's land ecosystem service function value dynamic changes according to human influence. Overall, it decreases each year. However, the decreasing trend for lost value is much more obvious than the decreasing trend for created value. This means that the relationship between China's social and economic activities and the natural ecological environment is sustainable, and in general, heading in the right direction.

From 1999 to 2002, the increase in ecosystem services in China is mainly because remarkable achievements in the construction of wetland and forest ecosystems had been made. However, since 2003, although forest and wetland ecosystems are still the main focus of socio economic activities that have a positive influence on the value of the natural eco-environment, the construction of urban ecosystems has gradually become a prominent reason behind the rising value. From the negative value perspective, the blind expansion of cities and disorderly land development are still the largest causes of a reduction in the ecosystem services of China.

Therefore, according to the above conclusions, the pace of China's urban ecological construction is still behind the pace of its ecological destruction. China has a long way to go to achieve its urban ecological construction goals.

With regards to the spatial distribution of China's land ecosystem service function and the changes in its strength, we offer the following explanations. First, China's regional ecological systems differentiation is the cause of such different distributions of unit value and total value. Second, it is the regional differentiation of China's socio economic system that caused the observed differences in the increase of total value and unit value among different areas. For example, Western China has much more natural ecological resources than the east, and can provide much more ecological service. However, it requires much more advanced ecological repair work and ecological construction ideas to maintain its resource services.

3.3 Analysis of uncertainty

Ecosystems feature multiple strata, and the current assessment method and practice fail to conduct strictly comprehensive assessments for all of the service functions, let alone conduct comprehensive assessments of different ecosystems' various service functions based on different scales [28]. Therefore, this study provides a modest verification and analysis of three hypotheses based on previously published results, and fails to propose perfect methods for value accounting practice. There are two main issues.

The first issue relates to ensuring the precision of data used for ESV accounting. Generally, when LUCC image data are used for ESV accounting, there are two problems to deal with, namely, scale and classification criteria. Land cover could be miss-classified as a result of various image definitions, or different classification criteria [21]. If an image involves more than one type of land cover, the image will only be classified into the land type that accounts for the majority of the image unit; other land cover types in the image will be neglected. For example, if an image depicts wetland and forest areas, and the forest is much bigger than the wetland, then this image will be classified into the forest ecosystem image database. However, the wetland ESV is higher than that of a forest ecosystem of the same size, so the actual service value of the land cover that the image represents is higher than we believe. This research did not use the remote sensing image data of LUCC directly, as we used the GIMMS Vegetation Index Data to scientifically modify the image data. However, the potential error introduced by the definition of images still cannot be avoided. Therefore in the future, we should enhance the image definition to reduce the error in ESV accounting and thereby increase the accounting precision regardless of whether we use the remote sensing image data directly or use it after modification.

The second issue relates to the scientific methods for accounting for an ecosystem's negative service value. In contrast to the theory that holds that the natural ecosystem has only positive service values, we believe the terrestrial ecosystem's service value includes both positive and negative values provided by natural ecosystems, as well as positive and negative values provided by artificial ecosystems (including construction land) [28,39]. The service value (added) should be the sum of the positive value (added) and the negative value (added). Therefore, if the positive value decreases and the negative value increases, then the service value has negative growth. Similarly, if the positive value (added) is less than the negative value (added), then the service value has negative growth. Although this study has proposed the scientific rationale of, and the accounting frames for the positive and negative values of ecosystem services, when it comes to accounting practice, it fails to offer the methods to account for the natural ecosystem's negative service value. In addition, this study fails to offer perfect methods to account for the positive and negative values of artificial ecosystems, such as urban ecosystems. This is because good methods for conducting quantitative research on urban ecosystems' service values have yet to be found. Therefore, regarding the future of ESV research, not only should the scientific accounting methods for ecosystems' various service values be refined, but more research on positive and negative values should be undertaken. In particular, we should pay more attention to the changes in urban and infrastructure constructions' ecological service values, as they are special terrestrial ecosystems. As research on urban ecosystems' service values is conducted worldwide, research on urban ecosystem structures, functions, and construction processes will draw increasingly more attention.

4 Conclusions

When considering temporal change, it can be seen that the total value (stocked) of China's terrestrial ecosystem service functions decreased from 6.82 trillion Yuan RMB in 1999 to 6.57 trillion Yuan RMB in 2008. During that period, the positive value decreased by 240.17 billion Yuan RMB and the negative value increased by 8.85 billion Yuan RMB. The decreased positive value lies mainly in the humidity control, soil formation, and waste recycling functions, while the increase in negative value lies in the functions of water and soil conservation. The total value (added) of China's terrestrial ecosystem service functions increased by 4.31 billion Yuan RMB in 2000, but decreased by 0.13 billion Yuan RMB in 2008, and thus the value (added) was a negative figure.

Considering spatial change, the supply of China's terrestrial ecosystem service functions decreased mainly in Northeast China and Southern China, emerging as a very slight change over the 10-year period. As a result of human activities on ecosystems, the loss of ecosystem service functions' value was relatively prominent in Shanxi and Gansu provinces, compared with an increase in value in Shaanxi Province. The terrestrial ecosystem service functions' value per unit area was relatively high in mid- and East China, but low in Western China, emerging as a prominent change during the 10-year period.

The reduction of cultivated land resources, the degradation of forest grassland resources, and a series of other ecological problems are still severe ecological problems in China. Although eco-city construction is increasing each year, relative to ecological destruction, the pace of China's urban ecological construction still has a long way to go.

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1 Li W H, Zhang B, Xie G D. Research on ecosystem services in China: Progress and perspectives. J Nat Resour, 2009, 24: 1–10

2 Fu B J, Zhou G Y, Bai Y F, et al. The main terrestrial ecosystem services and ecological security in China. Adv Earth Sci, 2009, 24: 571–576

3 Zhao J, Yang K. Valuation of ecosystem services: Characteristics, issues and prospects. Acta Ecol Sin, 2007, 27: 346–356

4 Wang R S, Hu D, Wang X R, et al. Urban Ecosystem Service. Beijing: China Meteorological Press, 2004

5 SCEP(Study of Critical Environmental Problems). Man's Impact on the Global Environment. Cambridge: MIT Press, 1970

6 Westman V E. How much are nature's services worth? Science, 1977, 197: 960–964

7 Ehrlich P R, Ehrlich A. Extinction: The Cause and Consequences of The Disappearance of Species. New York: Random House, 1981

8 Vitousek P M, Hooper D U. Biological diversity and terrestrial ecosystem biogeochemistry. In: Schulze E D, Mooney H A, eds. Biodiversity and Ecosystem Function. Berlin: Springer-Verlag, 1993

9 Chapin F S III, Korner C. Arctic and Alpine Biodiversity: Patterns, Causes and Ecosystem Consequences. Ecological Studies, Vol. 113. Berlin: Springer-Verlag, 1995

10 Hobbs R J. Biodiversity in Mediterranean Ecosystems in Australia. Chipping Norton: Surrey Beatty & Sons, 1992

11 Davis G W, Richardson D M. Mediterrean-Type Ecosystem: The Function of Biodiversity. Heidelberg: Springer-Verlag, 1995

12 Solbrig O T, Meidna E, Silva J F. Biodiversity and Savanna Ecosystem Process: A global perspective. Berlin: Springer-Verlag, 1996

13 Orians G H, Dirzo R, Cushman J H. Biodiversity and Ecosystem Process in Tropical Forests. Berlin: Springer-Verlag, 1996

14 Vitousek P M, Loope L L, Adsersen H. Islands: Biological Diversity and Ecosystem Function. Vol. 115. Berlin: Springer-Verlag, 1995

15 Daily G C. Natures Services: Societal Dependence on Natural Ecosystems. Washington D C: Island Press, 1997

16 Costanza R, Arge R, Groot R, et al. The value of the world's ecosystem services and natural capital. Nature, 1997, 387: 253–260

17 Bolund P, Hunhammar S. Ecosystem services in urban areas. Ecol Economics, 1999, 29: 293–301

18 Bjorklund J, Limburg K, Rydberg T. Impact of production intensity on the ability of the agricultural landscape to generate eco-system services: An example from Sweden. Ecol Economics, 1999, 29: 269–291

19 Holmund C, Hammer M. Ecosystem services generated by fish populations. Ecol Economics, 1999, 29: 253–268

20 Pan Y Z, Shi P J, Zhu W Q, et al. Mesuring the eco-capital of terrestrial ecosystems in China by RS. Sci China Ser D Earth Sci, 2004, 34: 375–384

21 Bi X L, Ge J P. Evaluating ecosystem service valuation in China based on the IGBP land cover datasets. J Mount Sci, 2004, 22: 48–53

22 He H, PanY Z, Zhu W Q, et al. Measurement of terrestrial ecosystem service value in China. Chin J Appl Ecol, 2005, 16: 1122–1127

23 Dong J H, Bao C K, Shu T F. Analysis on the balance between supply and consumption of ecosystem services. Acta Ecol Sin, 2006, 26: 2001–2010

24 Xie G D, Zhen L , Lu C X, et al. Supply, consumption and valuation of ecosystem services in China. Resour Sci, 2008, 30: 93–99

25 Zong Y G, Chen H C, Guo R H. The systematic analysis on value of regional ecosystem services—A case study of Lingwu City. Geograph Res, 2000 ,19: 148–155

26 Wang R S. Efficiency and Harmony: The Principal and Method to Ecologically Control the City. Changsha: Hunan Education Press, 1988

27 Zhou T, Wang R S. A review of ecoasset management. Ecol Economy, 2009, (10): 65–68

28 Li W H. The Theory, Method and Practice of the Ecosystem Service Value. Beijing: China Renmin University Press, 2008

29 Chen Z X, Zhang X S. The ecosystem service value in China. Chin Sci Bull, 2000, 45: 17–22

30 Xie G D, Zhang Y L, Lu C X, et al. Study on valuation of rangeland ecosystem services of China. J Nat Resour, 2001, 16: 47–53

31 Ouyang Z Y, Wang R S, Zhao J Z. Ecosystem service function and the evaluation of it's ecological economic value. Chin J Appl Ecol, 1999, 10: 635–640

32 Ouyang Z Y, Wang X K, Miao H. A primary study on Chinese terrestrial ecosystem services and their ecological-economic values. Acta Ecol Sin, 1999, 19: 607–613

33 Zhao T Q, Ouyang Z Y, Zheng H, et al. Forest ecosystem services and their valuation in China. J Nat Resour, 2004, 19: 480–491

34 Zhao T Q, Ouyang Z Y, Jia L Q, et al. Ecosystem services and their valuation of China grassland. Acta Ecol Sin, 2004, 24: 1101–1110

35 Sun X Z, Zhou H L, Xie G D. Ecological services and their values of chinese agro-ecosystem. China Popul Resour Environ, 2007, 17: 55–60

36 Wang B, Lu S W. Evaluation of economic forest ecosystem services in China. Chin J Appl Ecol, 2009, 20: 417–425

37 Yu X X, Lu S W, Jin F, et al. The assessment of the forest ecosystem services evaluation in China. Acta Ecol Sin, 2005, 25: 2096–2102

38 Tucker C J, Pinzon J E, Brown M E. Global Inventory Modelingand Mapping Studies (GIMMS) Satellite Drift Corrected and NOAA-16 Incorporated Normalized Difference Vegetation Index (NDVI), Monthly 1981–2003. Maryland: University of Maryland, 2004

39 Dong J H, Shu T F, Xie H, et al. Calculative method for ecosystem services values of urban constructive lands and its application. J Tongji Univ (Nat Sci), 2007, 35: 636–640

40 Wan X, Chen W Q. Negative ecological impacts caused by sea reclamation and selection of economic evaluation approaches. Ecol Econ, 2009: 48–51, 55

41 Ran S H, Lu C H, Jia K J, et al. Environmental impact assessment of the land use change in China based on ecosystem service value. Environ Sci, 2006, 27: 2139–2144