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The net ecosystem services value in mainland China

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Abstract Protection of the ecological environment is an effective strategy for maintaining ecosystem health, improving provision of ecosystem services, and increasing human well-being. However, traditional calculations of the value of ecosystem services (VES) provide weak guidance because they ignore the costs of these services, leading to economically inefficient strategies. To understand the difference between VES and the net ecosystem services value (NES, after subtracting costs from VES) and to improve evaluations of ecosystem services, we estimated NES for mainland China (including farmland, grassland, forest, and wetland). NES totaled 10.0×10^3 RMB ha^{-1} yr^{-1} in 2014, which is only 35.1% of the corresponding VES. Grassland NES was -0.7×10^3 RMB ha^{-1} yr^{-1}, in contrast with a positive grassland VES. NES of farmland, grassland, forest, and wetland in 2014 totaled 7.2×10^{12} RMB, accounting for 27.0% of China's GNP. Recent Chinese planning based on VES emphasizes forest conservation and ignores the conservation of other important ecosystems, such as grassland, leading to a continuing loss of China's natural capital. Due to regional differences in economic conditions, resource endowments, and geographical characteristics, VES and NES differ among regions. To maximize the ecological benefits from conservation, it is necessary to account for these differences by comparing strategies based on NES, thereby choosing projects that maximize both economic and ecological benefits. To maintain the ecological balance, ecological restoration and socioeconomic activities should account for the costs of providing ecosystem services. This is essential to minimize the costs and maximize the benefits of projects.

Keywords Ecosystem services, Cost analysis, Environmental conservation, Land management, Ecological restoration

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1. Introduction

Ecosystems provide both direct production and living materials for mankind, and a variety of indirect services that are closely related to human well-being (Costanza et al., 1997; Dai et al., 2012; Xie et al., 2015). However, the human activities that occur during socioeconomic development can adversely affect the structure and function of ecosystems, thereby reducing the value of ecosystem services (VES) and threatening the sustainable development of human society (Dobson et al., 1997; Lamb et al., 2005). Previous research showed that the VES has declined by 63% worldwide since industrialization began (Birch et al., 2010). This reduction in VES will certainly affect future human benefits, particularly for the 1.1×10^9 people who live below the poverty line and rely on natural resources for their survival (Millennium Ecosystem Assessment, 2005). In recent years, people have become increasingly aware of the importance of ecological and environmental protection, and have actively implemented effective measures to increase biodiversity and to protect and restore the ecological environment (Pan et al., 2004; Bullock et al., 2011). However, the investment in these measures is much lower than the actual demand, and environmental degradation (especially pollution) has worsened (Liu et al., 2015; Wu et al., 2016).

The cost of ecological restoration is enormous. For ex-

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ample, the cost of a typical ecological restoration project ranges from $100 to $1000 per hectare (TEEB, 2009). At the same time, the benefits of restoration projects depend strongly on the type of ecosystem, the degree of ecosystem degradation, and the restoration method (Naidoo and Ricketts, 2006). Benayas et al. (2009) evaluated 89 eco-rehabilitation projects from around the world and found that biodiversity increased by an average of 44% after restoration of various types of ecosystems, and the value of services provided by the ecosystems increased by 25%, but that both parameters had lower values than those in comparable natural ecosystems that were not affected by humans. However, the relationships between the costs and benefits have not yet attracted enough attention from researchers. TEEB (2009) reviewed more than 2000 publications on ecological restoration, and found that none performed a detailed cost-benefit analysis of the projects.

Since Costanza et al. (1997) first calculated the value of global ecosystem services, VES calculations have become a hot topic in both ecology and economics (Bateman et al., 2013; He et al., 2013; Dai et al., 2016). However, most scholars have ignored the cost of ecosystem services when estimating VES (Cao et al., 2016a), or only accounted for part of the cost (Yang et al., 2007, 2014). Calculating VES while ignoring or inadequately calculating the associated costs will exaggerate the perceived benefits provided by an ecosystem, thereby misleading managers about the requirements for maintenance and restoration of the ecosystem to provide these benefits and reducing the likelihood that the land management will be successful (Nelson et al., 2009; Birch et al., 2010; Kareiva et al., 2011). It is important to account for costs in VES analyses so as to identify the true net benefits of projects (Goldstein et al., 2008). By improving their understanding of costs, managers will obtain a more holistic understanding of the land they manage, and will thereby have an opportunity to increase the effectiveness of their environmental protection projects (Chen et al., 2009).

Before implementing any restoration or protection project, a cost-benefit analysis must be performed to avoid wasting funds on activities that will provide high VES but that will also result in high costs due to environmental damage or other negative consequences associated with the activities. These consequences can threaten the project's success and the livelihood of the residents of a project area. To successfully protect the ecological environment, it is necessary to seek a win-win solution that can simultaneously protect the environment and promote regional socioeconomic development (Cao et al., 2016a). To demonstrate how to achieve this goal, we performed a study to compare the gross value (VES) and net value (NES, after subtracting costs from VES) of ecosystem services for China's farmland, forest, grassland, and wetland ecosystems (which cover a total area of 758.4×10^6 ha). We also evaluated the changes in these values between 1952 and 2014. We excluded Hong Kong, Macao, and Taiwan from the analysis because of their small size and the absence of sufficient long-term data. Our goal was to promote a fuller consideration of ecosystem services by including the costs associated with these services, thereby replacing potentially misleading VES estimates with more realistic NES estimates. Due to a lack of data, we did not calculate VES and NES for deserts, glaciers, permafrost regions, and cities. As this data becomes available, it should be included in future work to provide more comprehensive estimates.

2. Research methods

2.1 Study area

We divided China's 31 provinces into nine regions based on China's agricultural regional plan. These administrative divisions include provincial-scale municipalities and autonomous regions, but we will refer to them all as provinces for simplicity. The northwest region includes Xinjiang, Gansu, and Ningxia provinces; Inner Mongolia is the Inner Mongolia Autonomous Region; the Loess Plateau includes Shanxi and Shaanxi provinces; the north region includes Beijing, Tianjin, Hebei, Shandong, and Henan provinces; the northeastern region includes Liaoning, Jilin, and Heilongjiang provinces; the Qinghai-Tibet Plateau includes Tibet and Qinghai provinces; the southwest region includes Chongqing, Sichuan, Guizhou, and Yunnan provinces; the central region includes Hubei, Hunan, Jiangsu, Shanghai, Zhejiang, Anhui, and Jiangxi provinces; and the southern region includes Guangdong, Guangxi, Hainan, and Fujian provinces.

2.2 Data sources

We obtained our data from China's Forestry Statistics Yearbook (State Forestry Administration, 1953–2015), Agricultural Statistical Yearbook (Ministry of Agriculture, 1953–2015), Statistical Yearbook of Meteorological Disasters (Ministry of Agriculture, 2014), Statistical Yearbook (State Administration of Statistics, 1953–2015), and from Zhang et al. (2007). We obtained the areas of wetland, farmland, grassland, and forest; the costs of land and environmental management and maintenance (including the losses caused by natural disasters); ecological investments; and inputs in agricultural production. To account for gaps in early statistical data and the impact of inflation, we unified the cost accounting to use the annual average input intensity per unit area in the last five years. We validated the regional data using data from the 1998 and 2008 agricultural censuses (Ministry of Agriculture 1998, 2008) and the Forestry Census Bulletin (State Administration of Statistics, 1972–2015). To account for the fact that inputs varied among the nine regions, we averaged the values for each province within a region to produce a regional average.

We also performed a literature search to find relevant data using key words such as the names of the provinces, ecological water consumption, vegetation evapotranspiration, soil erosion, pollution, and negative effects of agriculture to obtain data on the water consumption of different vegetation types and negative environmental effects (soil erosion, environmental pollution, and greenhouse gas emissions) in the 31 provinces. When we found many papers, we selected the most recent papers that was published in the most influential journals and that described the calculation method sufficiently well that we understood how the authors determined their data. (That is, we ensured that the data would be comparable with our other data.) Finally, we obtained data on the water consumption of wetland (Guo and Li, 2007; Zeng et al., 2010; Niu et al., 2012; Peng et al., 2014; Liang et al., 2015; Liu et al., 2016), agricultural land (Yang et al., 2003; Wu, 2004; Li et al., 2008; Xu et al., 2009; Zhang, 2011; Yang et al., 2014; Lei et al., 2016), forest land (Cao et al., 2016b) and grassland (Geng, 2012; Chen et al., 2014), as well as data on other environmental negative effects from the published papers.

2.3 Cost calculations

Ecosystem management both provides valuable services (VES) and incurs costs. Thus, when VES is calculated under a given set of conditions, the total associated costs (C) cannot be ignored:

$$C = C_d + C_o + C_r, \tag{1}$$

where C_d is the direct cost for ecological protection and restoration, C_o is the opportunity cost of using an ecosystem to produce a given service instead of other services, and C_r is other external costs, which include the effects of plant pests (insects and diseases), fires, soil erosion, pollution, and greenhouse gas emission.

To simplify the calculation, the study defined the opportunity cost (C_o) of farmland, wetland, grassland, and forest ecosystems as the income or the value provided by using the land (C_i), water (C_w), and other natural resources (C_q) for other purposes:

$$C_o = C_i + C_w + C_q. \tag{2}$$

To account for the impact of different prices on inputs and outputs, we corrected all values to the 2014 value based on published data on inflation rates. The calculations are clearly incomplete, as they do not include data for several other land uses and costs such as the establishment of water treatment plants; this data can be added to future analyses when it becomes available.

2.4 Resource price calculation

Based on the economic principle of supply and demand, decreased availability of a resource will be accompanied by higher prices for that resource (Lu et al., 2016). This is also true for the prices of water, land, and other resources in a given area. We calculated the prices of water and land using the following resource-scarcity model (although this equation does not include an explicit demand parameter, we assumed that the price (V) reflected the consequences of the actual demand):

$$V_{it} = b - a P_{it}, \tag{3}$$

where V_{it} represents the price of available resources (water, land, etc.), P_{it} represents the per capita resource endowment of province i in year t, and a and b are the fitting coefficients. We performed the analysis separately for each of the nine regions.

To estimate the values of a and b, we used data (Wang et al., 2009) from China's South-to-North Water Diversion Project; the per capita water price (V_{it}) in 2014 was 1.2 RMB m^{-3} and the per capita water price in Tibet was 0.17 RMB m^{-3}. To account for land costs, we used the land resources network (http://www.tdzyw.com/) to obtain land rent prices; the maximum price in 2014 was 14520 RMB ha^{-1} in Beijing, and the lowest was 4320 RMB ha^{-1} in Tibet. For the provinces where we could not obtain comparable data, we estimated the value using data on per capita water and land resources as inputs for eq. (3).

2.5 Calculation of NES

We obtained cost data from Chinese and other databases on the value of different ecosystem services in the 31 provinces, and corrected the prices to 2014 values (as described in section 2.3). We obtained values for forest (Cao et al., 2016a; Xie et al., 2015), farmland (Chen and Gao, 2009; Xie et al., 2015), wetland (Guo et al., 2012; Pang et al., 2014; Yin et al., 2014; Xie et al., 2015), and grassland (Liu and Mu, 2012; Chi et al., 2015; Xie et al., 2015). We calculated NES by subtracting these costs from VES in the same year:

$$\text{NES} = \text{VES} - C. \tag{4}$$

3. Results

We found that the VES of wetland, grassland, farmland, and forest ecosystems in China in 2014 were 61.3×10^3, 4.8×10^3, 58.4×10^3 RMB ha^{-1}, and an area-weighted average of 44.2×10^3 RMB ha^{-1} (for plantations and natural forest combined), respectively (Table 1). After deducting the cost of water consumption, land rent, investments in ecological protection and agricultural production, and external costs, NES decreased to a weighted average (based on total land

Table 1 Benefits (value of ecosystem services, VES, without accounting for costs) and net benefits (net ecosystem services, NES, after subtracting costs) for China's four key ecosystem types in 2014

Ecosystem	Unit	VES	Cost				NES
			Water	Land rent	Investment	External costs	
Wetland	($\times10^3$ RMB ha^{-1} yr^{-1})	61.26	14.66	1.30	0.99	5.34	38.97
	($\times10^9$ RMB yr^{-1})	1301.86	311.61	27.66	21.07	113.39	828.13
Grassland	($\times10^3$ RMB ha^{-1} yr^{-1})	4.83	4.87	0.59	0.04	0.06	−0.72
	($\times10^9$ RMB yr^{-1})	1673.22	1687.10	159.80	13.19	19.26	−206.12
Farmland	($\times10^3$ RMB ha^{-1} yr^{-1})	58.45	15.56	8.12	0.08	7.02	27.67
	($\times10^9$ RMB yr^{-1})	7900.82	2103.16	1097.68	11.30	948.18	3740.50
Forest (plantation)	($\times10^3$ RMB ha^{-1} yr^{-1})	45.95	10.65	0.90	19.93	0.13	14.34
	($\times10^9$ RMB yr^{-1})	3190.17	739.09	62.56	1383.87	8.88	995.78
Forest (natural)	($\times10^3$ RMB ha^{-1} yr^{-1})	43.20	7.47	0.74	0.05	0.15	34.79
	($\times10^9$ RMB yr^{-1})	6386.86	1104.40	109.59	7.95	22.24	5144.33
Area-weighted mean	($\times10^3$ RMB ha^{-1} yr^{-1})	28.44	8.28	2.03	6.62	1.54	9.98
	($\times10^9$ RMB yr^{-1})	20482.01	5959.53	1458.56	4766.58	1111.34	7185.99

area) of 10.0×10^3 RMB ha^{-1}, which is 35.1% of VES. The NES of the wetland, grassland, farmland, and forest decreased to 39.0×10^3, -0.7×10^3, 27.7×10^3, and 28.3×10^3 RMB ha^{-1}, respectively. This represents decreases of 36.4, 114.9, 52.7, and an average of 35.8%, respectively.

In 2014, the overall mean VES and NES for the four major ecosystems were 20.5×10^{12} and 7.2×10^{12} RMB, respectively, which were equivalent to 32.6% and 28.1% of the total national income of 62.8×10^{12} RMB and national net income (the sum of disposable income of citizens and government revenues) of 25.6×10^{12} RMB, respectively.

NES differed significantly among the nine regions (Table 2). NES per unit area of land was highest in the northeast region, at 19.9×10^3 RMB ha^{-1}, and this was 99.5% higher than the national average. NES per unit area of land was lowest in the northwest, at 2.6×10^3 RMB ha^{-1}, which is 73.4% lower than the national average. NES in the northwest region was 238.6×10^9 RMB in 2014, accounting for 3.3% of the national mean value. NES in the southwest and northeast regions totaled 1863.6×10^9 RMB and 1647.0×10^9 RMB, respectively, accounting for 25.9% and 22.9% of the mean value in 2014.

Since 1952, the VES and NES of the main terrestrial ecosystems in China initially decreased, and then increased, with a similar overall trend for each region, but with large differences among the regions in the timing and values (Figure 1). In 1952, the national VES totaled 19.7×10^{12} RMB; subsequently, it decreased to a minimum of 17.4×10^{12} RMB in 1983, representing a decrease of 11.7%. In 2014, VES reached its maximum, at 21.1×10^{12} RMB. Although NES at a national scale showed a similar trend, it was much lower, at 7.74×10^{12} RMB in 1952 and 6.98×10^{12} RMB in 2014, representing a decrease 9.8%.

Due to differences in the socioeconomic conditions and the resource endowments among regions, VES and NES differed greatly between regions. VES and NES in Tibet changed the most, with VES decreasing from 1.18×10^{12} RMB in 1952 to 0.73×10^{12} RMB in 1993, a decrease of 38.1%; after 1993, it gradually increased, reaching 0.87×10^{12} RMB in 2014. Tibet's NES decreased from 0.85×10^{12} RMB in 1952 to 0.41×10^{12} RMB in 2005, a decrease of 50.0%; after 2005, it began to increase, reaching 0.44×10^{12} RMB in 2014. VES and NES changed least in the north region, where VES and NES increased by 2% and 7%, respectively, from 1952 to 2014 (Figure 1).

4. Discussion

Ecosystem services (including soil and water conservation, biodiversity conservation, gas regulation, and water conservation) are essential to sustain human life and an acceptable standard of living (Pearce, 1997; Ouyang et al., 2016). Human activities have drastically changed land use around the world, thereby changing the natural environment and its ability to supply ecosystem services (Cao et al., 2016b). Although land-use decisions and investments in land management can increase the flow of these services, these interventions are accompanied by both direct and indirect costs that must also be considered; analyzing only VES provides an inadequate basis for choosing among potential interventions because it does not account for these costs (Joppa, 2012). For example, in the present study, we found that VES of the grassland ecosystem was 4.8×10^3 RMB ha^{-1} yr^{-1} in 2014, whereas the net value after deducting the costs that we analyzed was negative (Table 1); this was mainly because years of overgrazing have decreased the grassland carrying capacity (China Agricultural Statistical Yearbook, Ministry

Table 2 Benefits (value of ecosystem services, VES, without accounting for costs) and net benefits (net ecosystem services, NES, after subtracting costs) for China's four key ecosystem types in 2014

Area	Unit	VES	Cost					NES
			Water	Rent	Investment	Others	Total	
Northwest	($\times10^3$ RMB ha^{-1})	13.54	7.69	1.55	0.86	0.79	10.89	2.65
	($\times10^9$ RMB)	1218.65	692.18	139.31	77.29	71.28	980.06	238.59
Inner Mongolia	($\times10^3$ RMB ha^{-1})	16.51	6.71	1.11	1.06	0.79	9.67	6.84
	($\times10^9$ RMB)	1639.63	666.50	109.97	105.73	78.44	960.64	679.00
Loess Plateau	($\times10^3$ RMB ha^{-1})	29.97	10.67	2.37	4.24	2.42	19.71	10.26
	($\times10^9$ RMB)	899.55	320.31	71.28	127.41	72.62	591.63	307.92
North	($\times10^3$ RMB ha^{-1})	39.41	8.69	4.69	12.80	4.65	30.82	8.59
	($\times10^9$ RMB)	1873.43	412.99	223.03	608.26	220.98	1465.25	408.17
Northeast	($\times10^3$ RMB ha^{-1})	42.68	10.88	2.75	7.26	1.87	22.77	19.91
	($\times10^9$ RMB)	3530.52	900.19	227.58	600.72	155.01	1883.49	1647.03
Tibet	($\times10^3$ RMB ha^{-1})	7.16	2.31	0.34	0.14	0.04	2.83	4.33
	($\times10^9$ RMB)	863.92	278.42	40.78	16.94	5.41	341.55	522.37
Southwest	($\times10^3$ RMB ha^{-1})	37.06	9.81	1.95	5.87	1.33	18.96	18.10
	($\times10^9$ RMB)	3815.27	1010.22	200.83	604.09	136.52	1951.66	1863.61
Central	($\times10^3$ RMB ha^{-1})	42.94	10.78	3.36	15.33	3.12	32.58	10.35
	($\times10^9$ RMB)	3873.26	972.44	302.70	1382.41	281.66	2939.21	934.05
South	($\times10^3$ RMB ha^{-1})	48.87	12.47	2.53	21.96	1.58	38.54	10.33
	($\times10^9$ RMB)	2767.79	706.28	143.09	1243.74	89.43	2182.54	585.25
Area-weighted mean	($\times10^3$ RMB ha^{-1})	28.44	8.28	2.03	6.62	1.54	18.47	9.98
	($\times10^9$ RMB)	20482.01	5959.53	1458.56	4766.58	1111.34	13296.02	7185.99

of Agriculture, 1978–2015; China Animal Husbandry and Veterinary Yearbook, Ministry of Agriculture, 2015), leading to a decline in grassland provision of ecosystem services and an increase in the cost of maintaining the normal state of the grassland ecosystems. This result contradicts the original goal of grassland management, which was based on VES rather than NES. This result clearly demonstrates that ecological protection and restoration inputs have been lower than the actual needs of China's grassland ecosystems. For a different example, consider China's forest ecosystem. Since 2000, China has implemented a number of forest protection and restoration projectsbecause of the high VES of plantation forest (Table 1), but the large decrease in the magnitude of these benefits when NES is calculated suggests that this is not the optimal strategy, and that more attention must be paid to the grassland and other terrestrial ecosystems. The currently unbalanced ecosystem protection policy, with an excessive focus on forests, will further exacerbate the current shortage of resources in China. Therefore, in future ecological restoration planning, managers should include estimates of the project cost using a method similar to that described in the present study, but should also learn from the grassland example and reconsider the balance of their investments between ecosystems to achieve more effective land use planning (Wang et al., 2013).

Climate change and human activities affect the provision of ecosystem services (Jack et al., 2008). In areas with abundant rainfall and moderate temperatures, VES is generally higher than in less favorable areas, but after deducting the associated costs, NES is much lower than VES. In contrast, although the endowment of natural resources is small in some areas, their NES can be higher because of lower costs. For example, in the central region of China, NES accounted for only 24.1% of VES in 2014 (Table 2). However, the natural conditions are worse in Inner Mongolia; although its NES was only 679×10^9 RMB in 2014, which is much lower than the central region's NES (934×10^9 RMB), this NES accounts for a much higher proportion of VES (41.4%). With the traditional VES-based assessment method, it seems that the environmental protection projects should focus more on areas with favorable resource conditions, but this is contradicted by the NES assessment results; in the example of ecologically fragile Tibet, the rate of environmental protection is higher. Considering the actual environmental situation in China, the difference in the insights obtained using the VES and NES assessments is large and very important. By accounting for costs, the NES assessment method lets managers select projects with the highest net income. This method can help managers to account for regional characteristics in their land use planning, thereby balancing the

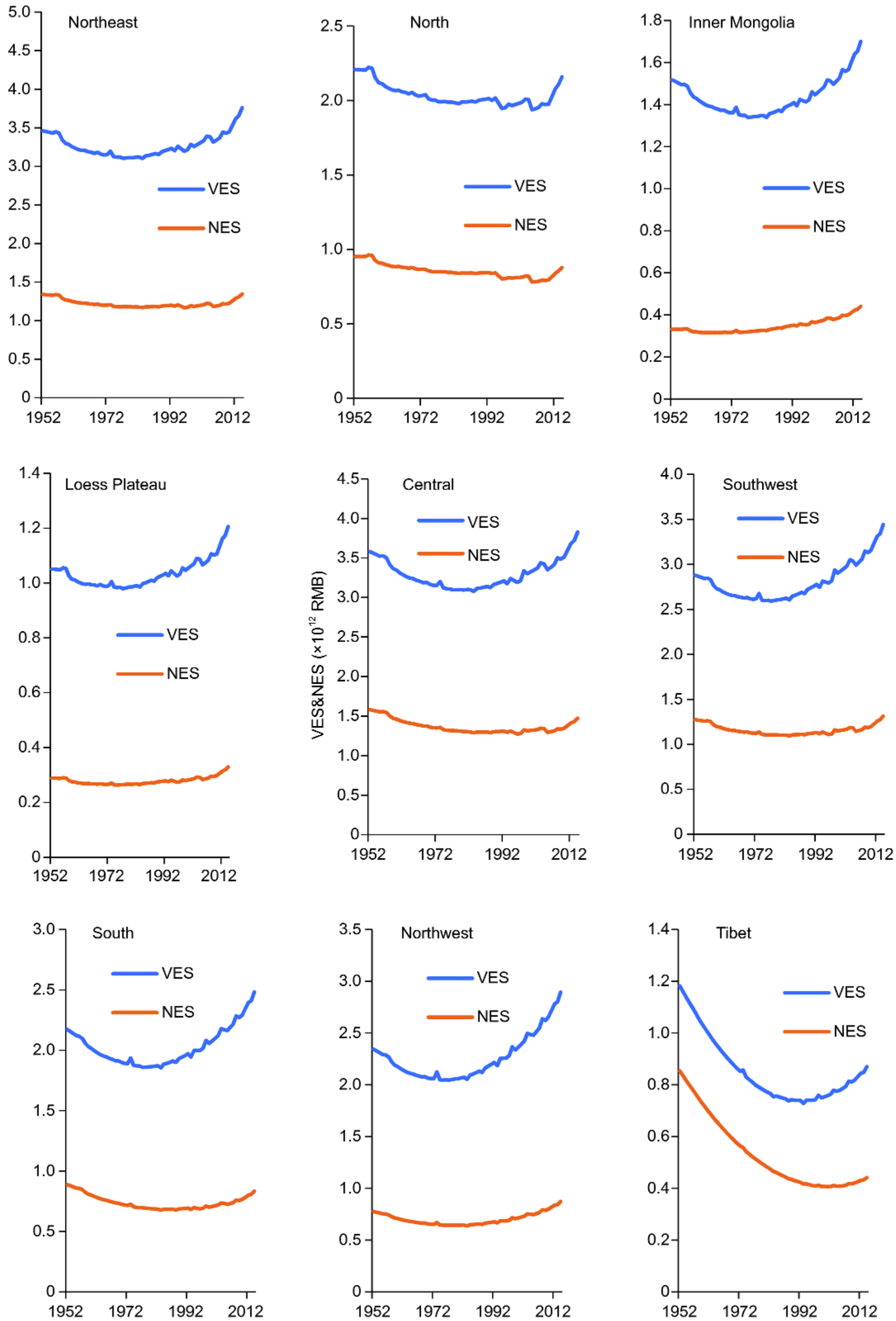

Figure 1 Changes in the value of ecosystem services (VES) and net value of ecosystem services (NES) in China's nine regions from 1952 to 2014. The *y*-axis scale differs greatly among the graphs.

allocation of resources among a range of ecological restoration projects; as a result, it increases the likelihood of a win-win strategy that will achieve both environmental protection and socioeconomic development (Mittermeier et al., 2003; Kinzig et al., 2011; Cao, 2012; Costanza et al., 2014).

Anthropogenic land use change is one of the main drivers of changes in the natural environment and in the supply of ecosystem services as a whole. Wetland, grassland, farmland, and forest ecosystems are most frequently affected by human activities (Goldstein et al., 2008). The transformation of natural grassland, forest, and wetland into farmland, plantations, and cities has greatly increased the supply of food, wood, housing and other products required by humans, but has also reduced biodiversity and the provision of many ecosystem services (Lawler et al., 2014). Before the 1980s, China's government blindly pursued a policy that focused on socioeconomic growth and that ignored environmental protection, leading to the destruction or degradation of natural ecosystems and a decline in the provision of terrestrial ecosystem services. After the 1980s, the national government gradually realized the importance of environmental protection and implemented a series of environmental protection projects, such as returning degraded farmland to forest, protection of natural forest (Cai et al., 2015), and wetland protection (Zheng et al., 2013). As a result of these programs, the service functions of wetland, forest, and other ecosystem have gradually recovered, and VES has shown an upward trend (Figure 1). Although NES has shown a similar pattern, our assessment of NES showed that NES remains much lower than VES in all areas of China and that excessive attention has been paid to projects with high VES (e.g., plantation forest) at the expense of ecologically fragile areas such as grassland that require more attention. This demonstrates how assessing NES and its changes over time provides more profound insights into the merits and drawbacks of a proposed policy and into its impacts on the environment.

Scientific and rational land use planning must be based on an integrated analysis such as that described in the present study to ensure maximization of the long-term net benefit (i.e., NES) rather than focusing on a single indicator (such as forest cover). Differences in endowments of natural resources among regions leads to different resource prices, which will lead to increased costs where these resources are in short supply; during the implementation of a project, the price of resources will also change, which will lead to additional differences in NES among regions. During project planning, managers should therefore seek ways to predict such changes in resource prices, and thus in the project costs. During the development of a wide range of ecological restoration policies and land use plans, it's necessary to fully consider the effects of regional differences in resource prices. Thus, this problem must be solved in future research. Policy makers, scientists, and land managers should fully account for the impacts of market factors such as changes in supply of and demand for resources, regional differences, and climate change on the costs and benefits of any option, and should actively identify and quantify the key factors responsible for these effects. Only by carefully weighing both the economic and ecological benefits will it be possible to correctly grasp the relationship between short- and long-term benefits. The NES assessment method described in this paper can help them perform this analysis and choose programs that maximize the environmental and socioeconomic benefits. At the same time, wetland, grassland, farmland, and forest ecosystems should be considered with equal attention to ensure that problems such as the negative NES of grassland that we identified can be detected and solved. This is especially true for farmland and grassland ecosystems based on the present results, which suggest that these ecosystems are the weak link in China's current environmental protection plans.

Calculations based on VES (Costanza et al., 1997, 2014) ignore the cost-effectiveness of a plan and therefore do not accurately reflect its real benefits. This can lead to the choice of suboptimal or ineffective plans. For example, traditional assessments of the negative effects of agriculture account the negative effects of water consumption and environmental hazards such as pollution and soil erosion (Yang et al., 2007, 2014), but ignore the opportunity costs (Geng, 2012), the direct costs of environmental protection and agricultural production investment, and other costs such as those caused by natural disasters (e.g., insects and diseases). There is a big gap between the calculated VES and the NES calculated by means of cost–benefit analysis. Compared with previous assessment methods, NES calculation does a better job of balancing the needs for ecosystem protection and socioeconomic development because it provides a more complete picture of the consequences of any plan. Although research on the services provided by terrestrial ecosystems in China is still in its early stages, the present results demonstrate an urgent need to incorporate NES calculations in such research. A particular problem relates to the assessment of NES based on published results for regions outside of a study area. As Table 2 shows, regions differ greatly in their benefits and costs even within a country such as China. Therefore, in the future research, assessments should be based on the actual situation in a management area, using local data, to reflect differences among the regions affected by a proposed project.

Because data availability in China is currently limited, it was necessary to restrict our analysis to four major types of terrestrial ecosystem (wetland, grassland, farmland, and forest). This neglected the NES of important ecosystems such as deserts, glaciers, and cities. Future research should attempt to obtain enough data to include these and other ecosystems in the analysis. Because the approaches used for ecological engineering and the characteristics of each region differ, this variation should also be accounted for in future research; for example, the analysis could be expanded to account for variation among the provinces within a region. An additional problem is that the present study only accounted for some of the opportunity costs (i.e., those for water consumption and land rent); this approach does not account for all potentially important costs (which may vary among regions), and may not represent the optimal choice of parameters for quantifying costs. The cost analysis must therefore be improved in future research. The problem of regional variation and the need to obtain data on regional characteristics will be difficult to solve for large countries such as China because of the high costs of acquiring this data; thus, the implementation of more advanced techniques to provide this data, such as satellite remote sensing or automated field monitoring stations, should be investigated.

Land managers must find ways to balance the needs for environmental protection and socioeconomic development. Our results show that the NES assessment method can provide more data to help them achieve this balance. The results of such analyses provide a more complete picture of the ecosystems that must be managed, therefore providing an improved basis for protecting the environment during socioeconomic development. As this method matures, based on new data sources and new technologies, it will profoundly affect the sustainability of China's socioeconomic development.

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