Ecol Res (2006) 21:597–604
DOI 10.1007/s11284-006-0148-z

NOTE AND COMMENT

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Ecosystem services and their values: a case study in the Qinba mountains of China

Received: 11 March 2005 / Accepted: 14 December 2005 / Published online: 17 March 2006

Abstract Terrestrial ecosystem services can provide both direct and indirect economic benefits. In this case study, we estimated the annual economic value of some ecosystem services provided by terrestrial ecosystems in the Qinba mountains of Shaanxi Province of China, using both simulation models and a geographic information system that helps to analyze the effect of ecological factors on ecosystem functions. With respect to differences in vegetation types and their coverage, by combining the latest research, and using theory and methods for the value of terrestrial ecosystem services, we not only calculated goods produced by different types of vegetation but also estimated the value of various terrestrial ecosystem services. We also set up a database and an eco-account of a terrestrial ecosystem. The ecosystem services assessed relate to the following aspects: the vegetation's primary productivity, soil and fertility conservation, water conservation, carbon fixation and oxygen supply. The total economic value of terrestrial ecosystem services in the Qinba mountains was estimated to be 968.33 billion renminbi per year, and represents a part of the actual ecosystem services. In addition, we analyzed the spatial distribution of the vegetation based on the economic values of the terrestrial ecosystem services. Our findings can contribute to the conservation of these terrestrial ecosystems and the effective use of these ecosystem services.

Keywords Terrestrial ecosystem services · Ecological economic value · Qinba mountains · Green eco-account

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Introduction

The value of ecosystems has been an issue of environmental and ecological economics in recent years. There have some studies on ecosystems at various scales. Human lives and development depend on vegetation on land, and it is the main feedback and regulating system of regional and global environment change. Terrestrial vegetation not only provides resources but also has important ecological functions. Ecosystem services and natural capital stocks are critical to the functioning of the earth's life-supporting system. They contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet (Costanza et al. 1997). However, these services are not recognized fully by society. The economic evaluation of ecosystem services is becoming an effective way to understand their multiple benefits. A few studies in the past few decades have tried to estimate the values of a variety of ecosystem services. Peters et al. (1989) presented an assessment of the economic value of a tropical Amazon rainforest in Brazil, and proposed a strategy for the sustainable use of rainforests in the region. Tobias and Mendelsohn (1991), Bacilli and Mendelsohn (1992) and Chopra (1993) have also discussed the values of tropical forests. Pearce and Moran (1994) discussed methods of economic valuation of different biological resources and their interpretations. They listed the values of tropical forests, wetlands, rangelands and marine systems worldwide. McNeely (1993) analyzed economic incentives for biodiversity conservation in Africa. Cacha (1994), Lacy and Lockwood (1994) and Munasinghe (1994) discussed the economic evaluation of protected areas. Hyde and Kanel (1994), Kramer and Munasinghe (1994) and White et al. (1997) studied the economic value of endangered species management through some case studies. Gren et al. (1995) estimated the economic value of Danube floodplains. Costanza et al. (1997) assessed the value of the world's ecosystem services. Abramovitz (1998) pointed out that ecosystem services have extensive economic value but that they are not credited for their non-market value until they become depleted. While economic tools can be used to identify trade-offs between known ecological values, it remains challenging to link technical measures of ecosystem services to attributes that can be effectively evaluated by untrained individuals (Schaberg et al. 1999). Guo et al. (2000) reported an assessment of ecosystem services for water flow regulation and hydroelectric power production. There have been some studies on different ecosystems at various scales. These can provide ecosystem services for people's living needs and development, so they have a ecosystem services value. The ''green accountant'' system started in China this year. Work on the values of ecosystem and environmental loss is of great importance and is imminent. Because of the complexity of different ecosystems, the work described above remains at a primary stage and needs to be improved and perfected in both theory and practice.

In this study, the Qinba mountain area in Shaanxi Province, which has diverse vegetation types and obvious vertical change, was selected as a typical example for evaluation and analysis. When evaluating terrestrial ecosystem services, characteristics and coverage rate of different vegetation types should be considered. Based on a geographic information system (GIS), using methods of environmental ecology and ecological economics, the value of main ecosystem services can be calculated and a ''green eco-account'' established. What is a green eco-account? Currently, different definitions exist. Basically, it is a variant of traditional accounts, which determines resource and environmental costs in economic activities. All the work discussed can help the public realize the potential of vegetation and its great ecological value, in order to promote eco-environment construction and ensure regional eco-safety. In this study, the GIS is integrated with simulation and evaluation models.

Materials and methods

Description of the Qinba mountains

The Qinba mountains are situated in the southern part of Shaanxi Province, China. (31°42′–34°45′N, 105°46′–111°15′E), and cover about 87.09×10^4 ha , accounting for 40% of the total land area of the province. The population is 10.2931 million people, and the population of agricultural workers is 9.1196 million, making up 88.6% of the region's total population. There are > 6,000 types of vegetation in this area, which have been termed the ''biological genetic pool'' and ''natural medical pool''. (Fig. 1)

The study area comprises three parts: Qinling mountains, Hanjiang Valley and Bashan mountains. The mean annual temperature is 12–15°C. The average temperature in July is 23.4–26.7°C, and in January is 0.0–3.6°C. The cumulative temperature (≥10°C) is 3,812–5,537.4°C. There is a high rainfall of 709.5–1,400 mm per year. Compared with other regions at the same latitude, this area has diverse vegetation types, a complex ecology, horizontal zone characteristics and a typical vertical zone.

We chose the Qinba mountains as the study site for the following reasons: (1) their plentiful vegetation constitutes part of various ecosystems and provides many ecosystem services; (2) they are located in the watershed of the Yellow, Han Jiang and Jia Ling rivers, where such ecosystem services as water and soil conservation are critical. So our work can contribute to the

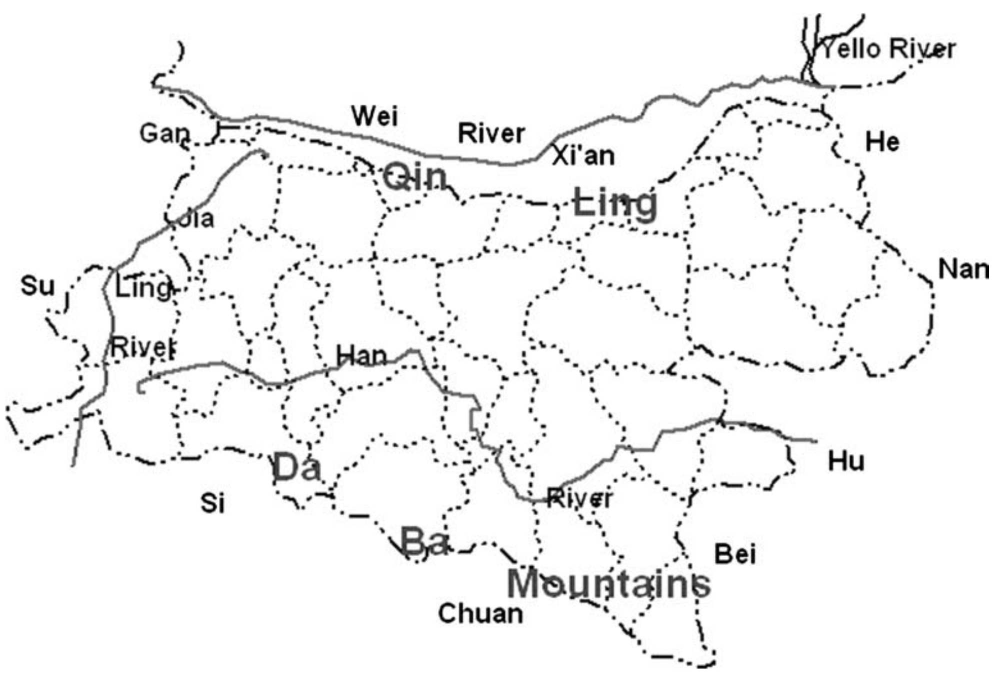

Fig. 1 Regional map of the Qinba mountains

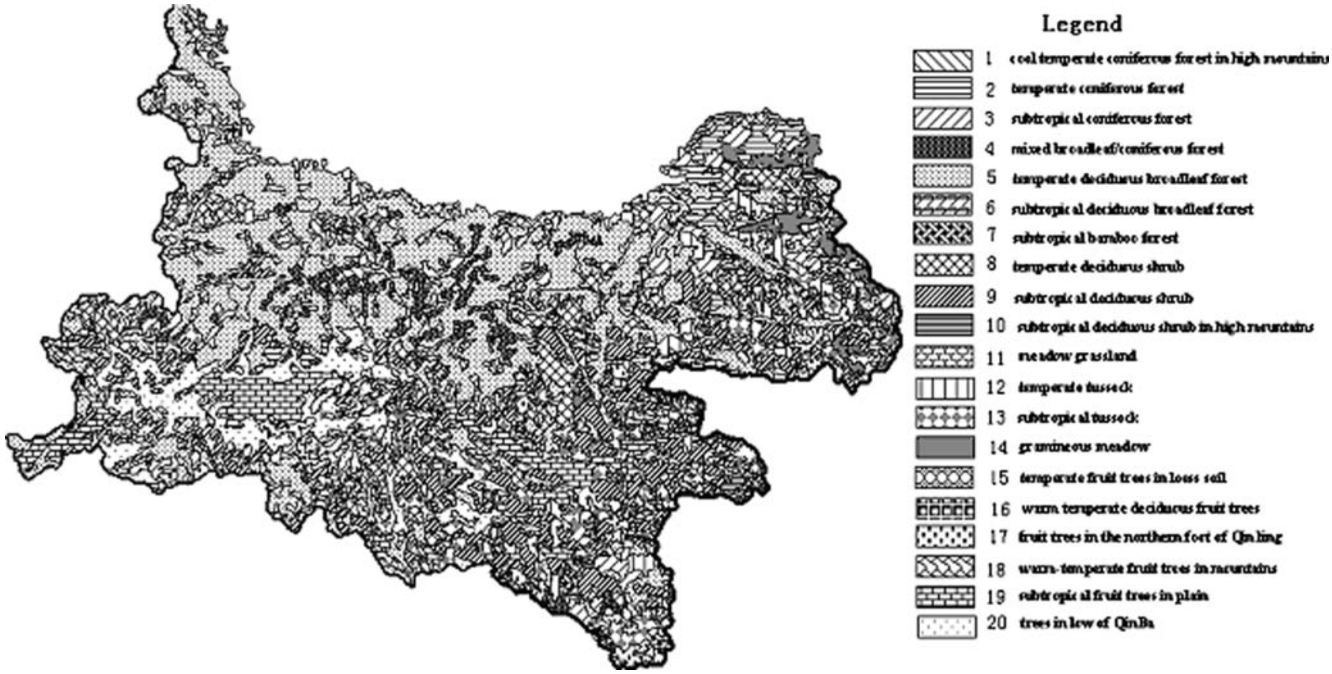

Fig. 2 Vegetation in the Qinba mountains

conservation of these ecosystems and effective use of their ecosystem services.

In order to characterize the impacts of internal heterogeneity on the ecosystems, a spatial database embodied within a GIS was developed as the basis for the economic valuation. An integrated spatial database was initially established using a workstation-based ARC/INFO system (ESRI 1994). The spatial database of vegetation, soil and topography for Qinba mountains was organized at the scale of 1:50,000. Twenty vegetation types were used in this study: (1) cool temperate coniferous forest in high mountains; (2) temperate coniferous forest; (3) subtropical coniferous forest; (4) mixed broadleaf/coniferous forest; (5) temperate deciduous broadleaf forest; (6) subtropical deciduous broadleaf forest; (7) subtropical bamboo forest; (8) temperate deciduous shrub; (9) subtropical deciduous shrub; (10) subtropical deciduous shrub in high mountains; (11) meadow grassland; (12) temperate tussock; (13) subtropical tussock; (14) gramineous meadow; (15) temperate fruit trees in loess soil; (16) warm temperate deciduous fruit trees; (17) fruit trees on the northern foot of Qin ling; (18) warm-temperate fruit trees in the mountains; (19) subtropical fruit trees on the plain; (20) trees in the lower regions of Qinba (Fig. 2).

Methods

In this study, the methods adopted relate to: (1) analyzing the functions of the forest ecosystems and determining their capacities under the conditions of different types of vegetation, soil and slope, as regards the natural environment of the Qinba mountains; and (2) evaluating the ecosystem services derived from corresponding functions.

The vegetation in the Qinba mountains is classified into 20 types according to distribution and characteristics. The study calculates the ecological economic value of systematic life-supporting functions, including organic matter production, soil conservation, water conservation, carbon fixation and oxygen supply.

Model of net primary productivity of natural vegetation

Vegetation uses energy from sunlight and converts inorganic compounds, such as CO_2 and H_2O, into organic compounds. This process is the primary and most important function of vegetation. It provides primary organic matter (and energy for human beings) so the production capacity of vegetation is called net primary productivity (NPP). NPP refers to various types of organic matter, including branches, leaves and roots, etc. produced by green plants per unit area and unit time. It reflects the production capacity of vegetation in a specific natural environment.

Under the conditions of the natural environment, the production capacity of the vegetation is limited by biological characteristics of the vegetation and soil, abiotic soil factors, and, mainly, by climate factors. So it is possible to estimate the NPP of vegetation from the correlations between plant production and climate factors, i.e. mainly solar radiation, temperature, precipitation. The original NPP model was designed for one country or the world, not a region. So for the case study of the Qinba mountains, an improved model of NPP of natural vegetation (Sun and 2000; Zhou and Zhang 1996; Zhu 1993) was devised by combining ecological characteristics of vegetation with energy balance, water balance and the model of regional evapotranspiration, and can be applied to different ecological regions. The model is as follows:

$$\mathrm{NPP} = \mathrm{RDI} \times \frac{r \times R_n(r^2 + r \times R_n + R_n^2)}{(R_n + r)(R_n^2 + r^2)} \times \mathrm{Exp}(-\sqrt{9.87 + 6.25 \times \mathrm{RDI}}) \lim_{x\to\infty} \quad (1)$$

$$\mathrm{RDI} = \frac{R_n}{L} \times r \quad (2)$$

$$R_n = R_a(1 - V') - I. \quad (3)$$

$$I = (0.39 \times T_a - 0.05 \times \delta \times e_a 0.5) \times \left(0.10 + 0.9 \times \frac{n}{N}\right) \times \left(s \times \frac{\delta}{4.18}\right) \quad (4)$$

where NPP is in t/ha per year; RDI is radiative dryness index; r is rainfall (mm); R_n is net radiant intensity (kcal/ha); L is latent heat of water evaporation; R_a is total radiation; I is effective long-wave radiation; V' is surface reflectivity, which generally equals 0.2; n/N is percent of sunlight; T_a is air temperature; e_a is the mean annual water vapor pressure; $\delta = 1{,}353.73\ \mathrm{W\ m^{-2}}$; $s = 0.567 \times 10^{-4}\ \mathrm{e\ cm^{-1}\ s^{-1}\ day^{-1}}$(Li 1999).

The natural vegetation NPP can be substituted by energy equal to goods. Natural energy, such as coal, oil and gas, transformed by organic matter, has its market value. So the value of goods produced by vegetation can be calculated by the price of energy. The formula is as follows:

$$V = \frac{AQ_1}{BQ_2} \times P_c \quad (5)$$

where V is the value of organic matter [in Chinese currency, renminbi (RMB), 8.3 RMB = 1$]; A is dry weight of organic matter; B is quality coefficient of coal, and equals 1 for standard coal; P_c is market price of standard coal; Q_1 is quantity of heat relative to dry weight of organic matter; and $Q_1 = 6.7$ kJ/g; Q_2 is quantity of heat relative to standard coal, and $Q_2 = 10$ kJ/g. (Li 1999).

Model of water conservation due to vegetation

Theoretical research on the function of vegetation in water conservation is currently improving both domestically and internationally. Water conservation through vegetation is studied in two ways: (1) the water-balance of regional vegetation; (2) the movement of water through the vegetation and soil of an area. In accordance with the actual conditions and special geographical position of the Qinling-Daba mountains, this study utilizes the second type. Water conservation through vegetation is made up of three components: canopy interception, litter containment, and soil containment (Lee 1980; Ma 1993). The goods model is as follows:

$$Q_t = W_1 + W_2 + W_3 \quad (6)$$

where W_1, W_2, W_3 are amount of water in the canopy, litter and soil, respectively. Q_t is the total amount of water conserved.

Another method used to calculate the water conservation of vegetation is employed in an alternative programme. This is a technological water storage programme which conserves the same amount of water as the vegetation. Because the investment value of the programme can be calculated easily, it is possible to use the price of this alternative programme to estimate the value of water conservation due to the vegetation. In addition, whether people would pay for this, and how, should be considered (Li 1999). To resolve the question of how much people are willing to pay, the equation is multiplied by the coefficient of development stage (l). l represents the relative level of people's willingness to pay on a certain scale. In this region and at this time, l is about 0.15. The method used to evaluate terrestrial ecosystem services for water conservation can be described by the following equation:

$$V = l \times \frac{Q_t}{Q_g} V_g \quad (7)$$

where V is the value of water conservation (in RMB), Q_t is the total amount of water conservation, Q_g is the water capacity of the alternative programme, V_g is the value of the alternative programme.

Model describing soil conservation due to vegetation

The amount of soil conserved by terrestrial ecosystems can be estimated by the difference between potential soil erosion and real soil erosion (Xiao and Ouyang 2000; Zhou and Li 2000). Real soil erosion refers to the amount of soil erosion at the current amount of surface covered. Potential soil erosion is the amount of soil erosion without surface cover and is influenced by land management. Up to now, the common soil erosion equation is the model used most extensively, based on the theory of soil erosion and a large number of statistical data derived from on the spot observations. The model is:

$$A_c = A_p - A_r \quad (8)$$

$$A_p = R \times K \times L \times S \times C \times P_s \quad (9)$$

$$A_r = R \times K \times L \times S \times C \times P_s \quad (10)$$

where A_c is the amount of soil conservation (t/ha per year); A_p is the amount of potential soil erosion (t/ha per year); A_r is the amount of real soil erosion (t/ha per year); R is erosion index by rainfall (foot t In/acre h); K is soil erosion factor; L is length of slope, S is slope; C is vegetation cover factor; P_s is soil conservation measure factor.

Once vegetation is destroyed, its function of conserving soil will weaken or disappear. Thus a series of serious consequences will ensue, mainly: deposition leading to sediment accumulation, shortened service life of irrigation works; increased desertification; soil nutrient loss and a drop in fertility. So, by using the market price, opportunity cost and alternative programme, the value of soil conservation due to vegetation is calculated from the role of vegetation in conserving soil fertility, and reducing land loss and sediment accumulation.

Soil erosion leads to a great deal of nutrient loss, especially loss of potassium, phosphorus and nitrogen. The contents of these vary greatly in different soil types. The mean values of potassium, phosphorus and nitrogen in various terrestrial ecosystems can be calculated using GIS. The model of soil fertility conserved by terrestrial ecosystems is as follows:

$$E_f = \sum A_c \times C_i \times P_i (i = N, P, K) \quad (11)$$

where E_f is the value of soil fertility conservation (in RMB); A_c is amount of soil conservation; C_I is pure content of potassium, phosphorus and nitrogen; P_I is the price of potassium, phosphorus and nitrogen (in RMB).

Land abandoned due to soil erosion can be calculated from the amount of soil conservation and the average thickness of surface soil (0.6 m). Using the opportunity cost, the value of the annual loss caused by land abandon can be calculated:

$$E_s = A_c \div \rho \div 0.6 \times \mathrm{B_r} \quad (12)$$

where E_s is the annual loss value caused by land abandon (in RMB), B_r is annual income from forestry (RMB/ha), ρ is soil bulk density (t/m^3).

According to the laws of mud and sand motion in major valleys in China, 24% of mud and sand accumulates in reservoirs, rivers and lakes. The cost of reducing sediment accumulation by terrestrial ecosystem can be calculated from water storage costs. The model is as follows:

$$\mathrm{E_n} = \mathrm{A_c} \div \rho \times 24\% \times \mathrm{C_r} \quad (13)$$

where E_n is the cost of reducing sediment accumulation (in RMB),and C_r is reservoir construction costs (RMB/m^3).

Model of carbon fixation and oxygen supply

There are three methods of assessing the economic value of a terrestrial ecosystem's ability to fix carbon and supplying oxygen; they are based on: (1) the formula of photosynthesis and respiration; (2) test and survey; and (3) a mathematical model (Thomas 1990; Ian 1991; Titus 1992; Robert 1993). In this study, we adopted the method based upon the formula of photosynthesis and respiration.

Based on the NPP of natural vegetation, using the equation of photosynthesis, the dry matter per kilogram produced by a forest ecosystem can fix 1.63 kg carbon. Carbon fixed by various types of vegetation can be calculated by analogy. The value of carbon fixation can be estimated by using the reforestation cost. In this study, the reforestation cost adopted is 260.90 RMB/tC. (Chen and Zhang 2000; Li 1999; Ouyang 1999).

Using the equation of photosynthesis, dry matter per kilogram produced by a forest ecosystem can supply oxygen 1.2 kg. By analogy, oxygen supplied by various types of vegetation can be calculated. The value of oxygen supply can be estimated by using the reforestation cost and the cost of the industrial method of making oxygen. In this study, the reforestation cost and cost of making oxygen adopted are 260.90 RMB/tC, and 0.4 RMB/kg, respectively.

Results

Using the above estimations, we have examined the economic value of several services of forest ecosystems in Qinba mountains. Here, we determined the spatial distribution of vegetation based upon GIS. In general, capital is considered to be a stock of materials or information that exists at a point in time. Forests, as a type of natural capital stock, generate, either autonomously or in conjunction with services from other capital stocks, a flow of services that may be used to transform materials or the spatial configuration of materials to enhance the welfare of humans. According to the above results, we could determine the value of each type of vegetation in the forested areas (Fig. 3) and further, the spatial distribution of forest capital stock. Figure 3 shows their spatial distribution, expressed by economic value (RMB/ha). The more important economic values are for the Qinling mountains and DaBa mountains.

By valuing various terrestrial ecosystem goods and assets, the total value can be calculated (Table 1).

The annual value of the vegetation's primary productivity, soil and fertility conservation, water conservation, carbon fixation, and oxygen supply is 199.6 billion RMB, 22.64 billon RMB, 22.66 billon RMB, 352.24 billon RMB, and 374.19 billon RMB, respectively. The annual total value of ecosystem services is 968.33 billon RMB.

In this study, there are great differences in the relative contribution of the various terrestrial ecosystems. The temperate deciduous broadleaved forest has the highest contribution, at 184.20 billon RMB, accounting for 16.42% of the total. The contributions of the cool temperate coniferous forest in the high mountains, subtropical bamboo forest, subtropical deciduous shrub in the

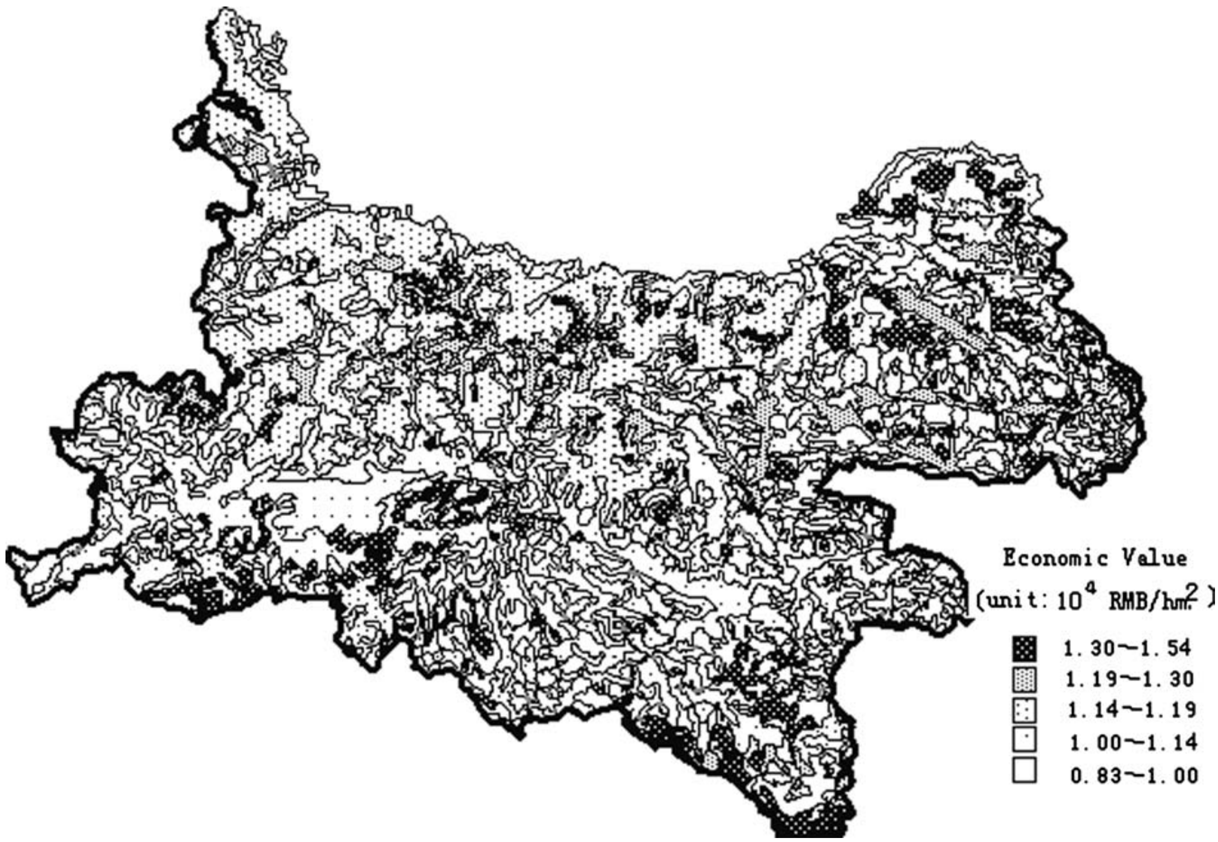

Fig. 3 The spatial distribution of economic values of terrestrial ecosystem services in Qinba mountains

high mountains, meadow grassland, gramineous meadow, temperate fruit trees in loess soil, warm temperate deciduous fruit trees and fruit trees on the northern foot of Qin ling are all $<1\%$. The contribution of the other types of vegetation rest varies between 1 and 10%.

Discussion

In this study, we have estimated that the annual value of the forest ecosystem services is 968.33 billon RMB for the Qinba mountains. However, because of the lack of ample data and efficient methods, we could not assess the economic value of every forest ecosystem service, such as air purification, noise dampening, protection of the ozone layer, etc. Despite these limitations, the economic value of this forest ecosystem is far more than what we had imagined.

When evaluating terrestrial ecosystem services, the characteristics and percentage of different vegetation types should be considered, in order to reflect the regional reality precisely.

In the Qinba mountains, the annual value of the vegetation's primary productivity is 196.6 billion RMB, that of soil and fertility conservation is 22.64 billon RMB, that of water conservation is 22.66 billon RMB, that of carbon fixation is 352.24 billon RMB, and that of the oxygen supply is 374.19 billon RMB.

Understanding the spatial distribution of natural capital stocks is as important as their value, and when ecosystems are being subjected to dramatic changes, it is of even more urgency. We demarcated the natural capital stock, delimitated on the map of Qinba mountains by means of GIS, providing a foundation for protecting and/or restoring forest capital stock.

The economic value of services of the forest ecosystems in Qinba mountains is huge. Though the local people obtain little or no profit from them directly, it cannot be doubted that the GNP of the county is based on these ecosystem services. In fact, the ecosystem services with an approximate value of 968.33 million RMB produce local benefits, such as a water supply, soil fertility protection, etc., which support annual economic development. It is impossible to imagine that the local population could make such a huge investment per year. In addition, many ecosystem services are literally irreplaceable, such as water conservation. In the Qinba mountains, some of the value of the ecosystem services is also an annual output from the county, as they are part of the support system of human welfare in larger regions, e.g. hydrological flow regulation, carbon fixation, oxygen supply, etc. With continuing economic development, forest ecosystem services will play a greater role than before and their values will also increase over time.

Based on the terrestrial ecosystem services, using energy substitution, the alternative programme, market

Table 1 The eco-account of terrestrial ecosystem services in Qinba mountains (renminbi)

Vegetation type	Area (ha)	NPP (×10^4)	Water conservation (×10^4)	Soil conservation (×10^4)	Carbon fixation (×10^4)	Oxygen supply (×10^4)	Total value (×10^4)
1	77,649.30	19,785.16	2,535.03	3,224.28	35,432.27	37,639.44	98,616.18
2	201,082.00	41,309.74	6,592.85	11,584.57	77,560.78	82,392.24	219,440.18
3	516,386.00	157,891.11	18,870.09	12,273.76	282,627.68	300,233.30	771,895.94
4	226,319.00	58,503.60	5,851.97	8,537.98	104,715.65	111,238.66	288,847.86
5	249,5999.28	558,800.82	82,961.98	138,022.63	999,901.09	106,2187.56	284,1874.08
6	270,067.00	71,193.47	13,769.27	9,090.62	127,484.15	135,425.47	356,962.98
7	49,081.10	15,270.63	2,728.34	1,092.31	27,343.07	29,046.34	75,480.69
8	918,535.00	189,953.50	23,318.45	5,684.83	340,232.31	361,426.27	920,615.36
9	105,1846.00	236,625.17	34,895.04	5,663.14	423,607.68	449,995.31	115,0786.34
10	11,581.80	2,654.40	168.44	265.63	4,752.97	5,049.04	12,890.48
11	12,205.80	2,100.19	152.78	82.50	3,763.27	3,997.70	10,096.44
12	517,376.00	91,500.27	4,829.90	4,270.42	163,697.07	173,894.19	438,191.85
13	677,530.00	132,684.16	6,519.02	3,133.00	237,420.07	252,209.59	631,965.84
14	39,033.16	7,208.91	244.52	365.81	12,897.82	13,701.26	34,418.32
15	7,575.19	1,843.44	94.27	139.96	3,298.79	3,504.28	8,880.74
16	10,284.00	2,508.47	134.23	164.87	4,491.53	4,771.32	12,070.42
17	637.52	159.80	8.32	10.31	286.03	303.85	768.31
18	355,648.00	88,811.07	4,723.49	5,285.35	158,958.87	168,860.84	426,639.62
19	599,854.00	134,191.84	8,643.47	10,116.45	240,047.32	255,000.50	647,999.58
20	670,281.00	153,038.76	9,526.69	7,349.21	273,931.50	290,995.42	734,841.58
total	870,8971.15	1,966,034.51	226,568.15	226,357.62	3,522,449.91	374,1872.59	968,3282.78

1 Cool temperate coniferous forest in high mountains, *2* temperate coniferous forest, *3* subtropical coniferous forest, *4* mixed broadleaf/coniferous forest, *5* temperate deciduous broadleaf forest, *6* subtropical deciduous broadleaf forest, *7* subtropical bamboo forest, *8* temperate deciduous shrub, *9* subtropical deciduous shrub, *10* subtropical deciduous shrub in high mountains, *11* meadow grassland, *12* temperate tussock, *13* subtropical tussock, *14* gramineous meadow, *15* temperate fruit trees on loess soil, *16* warm temperate deciduous fruit trees, *17* fruit trees on the northern foot of Qin ling, *18* warm-temperate fruit trees in mountains, *19* subtropical fruit trees on the plain, *20* trees in low-lying areas of Qinba

prices and reforestation cost, 20 vegetation types have been evaluated. The vertical change in vegetation type is very clear. Terrestrial ecosystem services and their values similarly show spatial change.

This study evaluated several major functions of terrestrial ecosystem services; other functions, such as species shelter, rest and recreation, etc., will be evaluated subsequently in order to improve the eco-account of terrestrial ecosystem services in the Qinba mountains. The study has examined ecosystem services from the perspective of human existence. It will help further understanding of the ecological value of this region, the protection and construction of the environment, enhance people's understanding of ecological services, and be of value in the setting up an economic managerial system of eco-environment.

It has been clearly shown that ecosystem services contribute substantially to human welfare. In decision-making processes, we should give adequate weight to the natural capital stock that produces these services and increase mechanisms of economic compensation for the people who conserve ecosystem services. We should also pay specific attention to the conservation of natural capital stock and find ways for its sustainable use. In the future, as ecosystem services become more stressed and both these and natural capital scarcer, we must determine how to use and protect them. The economic evaluation of ecosystem services is just a useful starting point for this.

Acknowledgements The research was supported by the National Natural Science Foundation of China (no. 40371003), the State Education Department of China (no. 01158) and the Doctor Originality Programme of Shaanxi Normal University.

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