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ANALYSIS

Ecosystem functions, services and their values – a case study in Xingshan County of China

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Abstract

Forest ecosystem services can provide both direct and indirect economic benefits. In this case study, at county-level, we estimated the annual economic value of some ecosystem services by forest ecosystems in the Xingshan County of Hubei Province of China, using both simulation models and geographic information system (GIS) that helps to analyze the effect of ecological factors (vegetation, soil and slope) on ecosystem functions. Xingshan County is rich in forest resources, covering 50.64% of total land area in the county. In this study, we referred to ecosystem goods and services together as ecosystem services. The ecosystem goods include timber, other forest products and forest tour, and produce a direct economic value about 54.23 million RMB in 1997 (RMB: Chinese Currency, 8.3 RMB = US$1). The ecosystem services assessed relate to three aspects: water conservation, soil conservation and gas regulation. Water conservation includes hydrological flow regulation, and water retention and storage. Soil conservation relates to the reduction of land disuse, prevention of silt accretion, decrease of soil deposit, and protection of soil fertility. Gas regulation is by both carbon fixation and oxygen supply. These services provide an indirect economic value of 528.73 million RMB per year based on our estimation. Thus, the total economic value of forest ecosystem services in Xingshan County is estimated to be 582.96 million RMB per year, being a part of actual ecosystem services. In addition, we analyzed the spatial distribution of forest capital stock in the county based on the economic values of forest ecosystem service. Our work can contribute to the conservation of the forest ecosystems and effective use of the ecosystem services.

Keywords: Forest; Ecosystem service; Ecosystem function; Economic valuation; Spatial distribution

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1. Introduction

The ecosystem services and the natural capital stocks that produce them 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 human societies. The economic valuation of ecosystem service is becoming an effective way to understand the multiple benefits provided by them. 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 sustainable use of rainforest 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 valuation 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. Guo et al. (2000) reported an assessment of ecosystem service for water flow regulation and hydroelectric power production.

In this study, we conducted field investigations and mathematical simulations to evaluate the annual economic value produced by the services of forest ecosystems in Xingshan County, and synthesized previous studies based on some methods, noting the limitations and assumptions underlying each study. Here, we referred to ecosystem goods and services together as ecosystem services. A geographical information system was used in our work to analyze the characteristics of the forest ecosystems in question spatially, for it provides an aid for determining the relationship between the ecological functions and the types of habitats. And we used GIS to help to demarcate the spatial distribution of forest capital stock on the map of Xingshan County. The research benefits of a GIS approach have been illustrated by many ecological studies (Coleman et al., 1994; Carver et al., 1995; Mallawaarachchi et al., 1996; Bradshaw and Muller, 1998; Swetnam et al., 1998), but seldom for ecological economic valuation (Eade and Moran 1996). In this study, the GIS is integrated with simulation and evaluation models.

2. Description of Xingshan County

Xingshan County is situated in the west part of Hubei Province, China (110°25′–111°06′E, 31°03′–31°34′N), and covers about 2316 km^2. The area of forestland reaches 107 000 ha, accounting for 50.64% of the total land area of the county. We chose Xingshan County as the study site based on the specific situations of the county: (1) its plentiful forest resources are composed of various forest ecosystems and provide many ecosystem services; (2) it is located in the watershed of the Yangtze River, where such ecosystem services as water and soil conservation are critical; and (3) because of construction of the Three Gorges Project, the forest ecosystems in this region are undergoing a unprecedented disturbance. Our work can contribute to the conservation of the forest ecosystems and effective use of the ecosystem services.

In Xingshan County, forest ecosystems provide many services of great value besides various forest products and forest tour. Annual precipitation is about 1100 mm on the average. The Xiangxi River and the Liangtai River collect water from 62 major streams in the county and flow into the Yangtze River. Therefore, the ecosystem service for water conservation is very important in Xingshan. In this case, water conservation relates to hydrological flow regulation (e.g., provisioning of water for hydroelectric stations) and water retention and storage (e.g., provisioning of water by watersheds) (Costanza et al., 1997). We estimated the economic values of water conservation in these two aspects. The service of the forest ecosystems for soil conservation is critical because it prevents soil erosion into rivers, especially the Yangtze River, and protects farmlands. Erosion by water and wind can result in the degradation of the quality of farmlands, which may lead to land disuse. Silt by soil loss can be silted at some spots (marginal lands and river mouths) to hinder agriculture production. Soil deposit from eroded soil could enter into water bodies and decrease the capacities of water storage of lakes, rivers and reservoirs, which will shorten the time of effective utilization of water conservancy. Soil erosion can also result in a considerable loss of organic and inorganic material in surface soil, in other words a decrease of farmland fertility. Forest ecosystems can prevent those phenomena from occurring by retaining soil erosion. Accordingly, we assessed the service of forest ecosystems for soil conservation in these four aspects: a reduction of land disuse, prevention of silt accretion, a decrease of soil deposit, and protection of soil fertility. Moreover, forests can regulate gas by carbon fixation, contributing to a decrease in the greenhouse effect and hence global warming, and by oxygen supply that provides the base of existence for human beings. Global value arises from this service. Therefore, we assessed the economic values of carbon fixation and oxygen supply. Table 1 shows the forest ecosystem services focused on in this study.

In order to characterize the impacts of internal heterogeneity on the ecosystems, a spatial database embodied within a geographic information system (GIS) was developed as the foundation 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 Xingshan County was organized at the scale of 1:50 000. The vegetation map was developed through visual interpretation of Landsat TM image on September 15, 1995, together with an extensive field survey in Xingshan County in 1997. Six vegetation types were used in this study, which are evergreen-deciduous and broadleaf mixed forest, conifer forest, shrub, grass, orchard and crop (Fig. 1). There are five types of soils: yellow brown soil, yellow soil, lime soil, purple soil and rice soil. The slope angle was divided into three categories according to its degree value: less than 15°, between 15° and 25° and more than 25°. Table 2 gives the abbreviations for these vegetations, soils and slopes. The whole county was divided into 90 type vegetation–soil–slope complexes by overlaying the maps of vegetation, soil and slope. Table 3 shows the 90 types of land cover complexes as well as their areas. In this study, the land cover complex with the vegetation type MIX or CON was considered as forestland.

Table 1
Forest ecosystem services assessed in this study

Type	Benefit	Services	Functions
Ecosystem goods	Direct economic value	Timber and other forest products	
		Taking forest tour	
Ecosystem services	Indirect economic value	Water conservation	Hydrological flow regulation
			Water retention and storage
		Soil conservation	Reduction of soil disuse
			Prevention of silt accretion
			Decrease of soil deposit
			Protection of soil fertility
		Gas regulation	Carbon fixation
			Oxygen supply

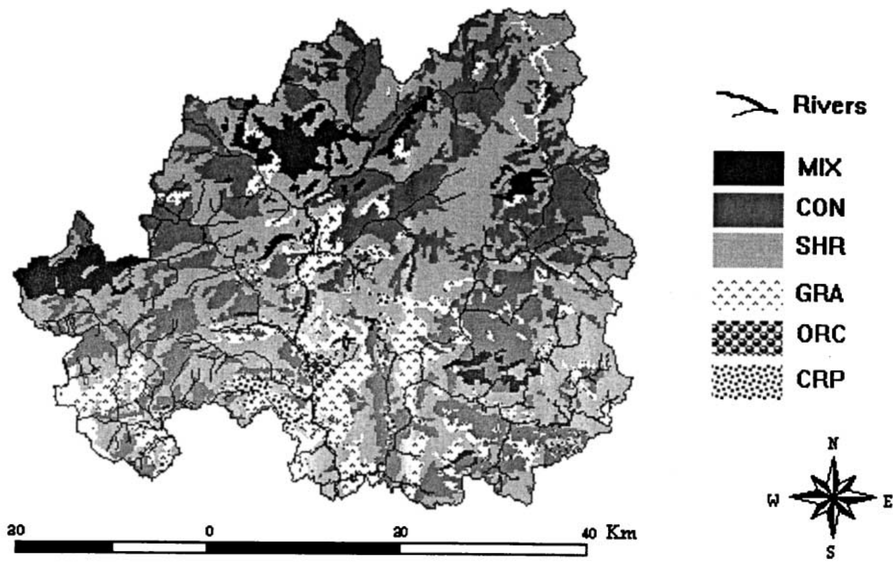

Fig. 1. Vegetation in Xingshan County.

3. 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; and (2) evaluating the ecosystem services derived from corresponding functions.

3.1. Taking forest tour

In the case study of Xingshan County, we adopted the travel cost method to estimate the economic value derived from taking forest tour. This method determines the demand for a recreational site, based on the number of visits per year to a park as a function of variables such as consumer income, price, and various socioeconomic characteristics (Munasinghe, 1994). The price is usually the sum of observed cost elements such as (1) entry price to the site; (2) costs of traveling to the site; and (3) foregone earnings or opportunity cost of time spent. The consumer surplus associated with the demand curve provides an estimate of the value of the recreational site in question. Thus, the economic value derived from forest tour, Vt, can be estimated by the following equation:

$$Vt = Cs + Tc, \quad (1)$$

where Cs is consumer surplus (in Chinese currency RMB, 8.3 RMB = US$1); Tc is the opportunity cost of time spent (RMB).

Table 2
A list of abbreviations for vegetations, soils and slopes

Type	Abbreviation
Evergreen-deciduous broadleaf mixed forests	MIX
Conifer forests	CON
Shrubs	SHR
Grasses	GRA
Orchard	ORC
Crop	CRP
Yellow brown soil	YBS
Yellow soil	YLS
Lime soil	LMS
Purple soil	PPS
Rice soil	RCS
Slope angle $<15°$	SA $<15°$
Slope angle between 15° and 25°	SA = 15°–25°
Slope angle more than 25°	SA $>25°$

Table 3
Ninety vegetation–soil–slope complexes and their areas (km^2) in Xingshan County

Vegetation–soil–slope	MIX	CON	SHR	GRA	ORC	CRP
YBS–SA < 15°	2.406	58.165	44.527	8.193	0.390	0.266
YBS–SA = 15°–25°	16.35	275.59	347.21	73.39	8.260	6.989
YBS–SA > 25°	0.694	48.010	91.601	22.93	9.290	0.748
YLS–SA < 15°	0.282	6.140	8.395	2.768	0.187	0.719
YLS–SA = 15°–25°	0.917	24.355	35.395	15.47	3.460	3.845
YLS–SA > 25°	0.073	3.270	4.063	3.934	3.698	1.279
LMS–SA < 15°	9.487	122.83	80.802	23.54	0.400	0.769
LMS–SA = 15°–25°	16.48	247.28	220.38	55.49	3.405	4.090
LMS–SA > 25°	2.307	16.847	26.612	12.37	1.495	0.624
PPS–SA < 15°	0.890	9.860	12.376	5.345	0.703	0.907
PPS–SA = 15°–25°	0.211	20.703	51.541	22.32	2.700	5.071
PPS–SA > 25°	0	2.547	8.487	6.027	2.734	2.352
RCS–SA < 15°	0.090	1.926	30.097	1.316	0.063	0.124
RCS–SA = 15°–25°	0.328	14.139	19.822	8.245	2.896	2.309
RCS–SA > 25°	0.065	3.488	8.576	4.648	4.244	1.387

3.2. Water conservation

The function of water conservation by a forest ecosystem can be illustrated by the flow of rainwater in forests. Usually rainwater flow in a forest includes three stages: canopy interception L, litter containment U and soil containment S (Lee, 1980; Ma, 1993). Thus, the average amount of rainwater conserved by a forest ecosystem per year (mm), WR, can be shown as follows:

$$\mathrm{WR} = \mu(L + U + S), \quad (2)$$

where μ is an equivalent value of raining, which relates to the amount of rainfall and the times of raining in a rain season (Guo et al., 2000).

The capacity of water conservation by a forest ecosystem varies significantly due to differences in the types of vegetation, soil and slope. In comparison with the standard set of vegetation–soil–slope complex (i.e., 'MIX', 'YBS' and 'SA < 15°'), we used data from in situ surveys and field experiments to determine the relative efficiency of different types of vegetation, soil and slope in water conservation. Table 4 lists the coefficients of efficiency of water conservation for the other five vegetation types, three soil types and two slopes by considering the 'MIX', 'YBS' and 'SA < 15°' as the standard set. For example, lime soil (LMS) can conserve about 81% (0.81) of the amount of water conserved by yellowish brown soil (YBS) in a unit of area.

Then, the actual capacity of water conserved by each type of the 90 vegetation–soil–slope complexes in the county can be determined by the following equation:

$$\mathrm{WR}(p_i) = \varepsilon_l \delta_j \eta_k \mathrm{WR}(p_s), \quad (3)$$

where $\mathrm{WR}(p_i)$ is the annual amount of water conservation of the ith type of complex (mm/yr). Hence, for a type of complex, the model has ε_l ($l = 1,2,\ldots,6$), δ_j ($j = 1,2,\ldots,5$), and η_k ($k = 1,2,3$). $\mathrm{WR}(p_s)$ is the annual amount of water conserved by the standard vegetation–soil–slope complex based on Eq. (2).

Therefore, the total amount of water column conserved by all types of complex per year (m^3), AW, can be estimated by

$$\mathrm{AW} = \sum_{i}^{90} \mathrm{WR}(p_i) A(p_i), \quad (4)$$

where $A(p_i)$ is the area of the ith type of vegetation–soil–slope complex (m^2).

The contribution of forest to water conservation, CFW, can be determined by the equation as follows:

$$\mathrm{CFW} = (\mathrm{AW} - \mathrm{AW}_s)/\mathrm{AW}, \quad (5)$$

where AW_s is the amount of water conserved under the condition that forests are replaced by a mixture of shrub and grass in both current proportion in the region studied.

The valuation method of forest ecosystem services for water conservation can be described by the following equation:

$$\text{Ve} = \text{CFW Fe Ps}, \quad (6)$$

where Ve is an economic value of an ecosystem service (in RMB unit); Fe is an effect derived from an ecosystem service being determined according to specific case. Ps is the price of this economic effect per unit (in RMB unit).

3.3. Soil conservation

The amount of soil conserved by forest ecosystems can be estimated by the difference in soil erosion between forestlands and non-forestlands, using the following equation:

$$\text{St} = \text{Sr} - \text{Sf} = \text{MS}_\text{r}\,\text{Ar} - \text{MS}_\text{f}\,\text{Af}, \quad (7)$$

where St is the amount of soil erosion reduced by forests per year (m^3). Sr is the amount of soil erosion in non-forestlands per year (m^3) and Sf is the amount of soil erosion in forestlands per year (m^3). MS_r and MS_f are the modulus of soil erosion of non-forestland and forestland (ton/ha/yr), respectively. Ar and Af are the areas of non-forestlands and forestlands (ha).

The modulus of soil erosion for forest ecosystems also varies significantly with the differences in the types of vegetation, soil and slope. Based on the data from in situ surveys, the relative coefficients of different types of vegetation, soil and slope for soil erosion were determined. Table 4 lists these coefficients for the other five vegetation types, three soil types and two slope, using the moduli of soil erosion for 'MIX', 'YBS' and '$SA < 15°$' to be a standard set. Then, the actual modulus of soil erosion in each type of vegetation–soil–slope complex in the county can be determined by the equation

$$\text{MS}(p_i) = \beta_l \mu_j \sigma_k\, \text{MS}(p_s), \quad (8)$$

where $MS(p_i)$ is the modulus of soil erosion in the ith type of vegetation–soil–slope complex (ton/ha/yr). Hence, for a type of vegetation–soil–slope complex, the model has β_l ($l = 1$ or 2 … or 6), μ_j ($j = 1$ or 2 … or 5), and σ_k ($k = 1$ or 2 or 3). $MS(p_s)$ is the modulus of soil erosion in the standard vegetation–soil–slope complex.

The average modulus of soil erosion of forestland, MS_f, and non-forestland, MS_r, can be calculated, respectively, using the equations showed as follows:

$$\text{MS}_\text{f} = \sum_i^k \text{MS}(p_i) A(p_i) \Big/ \sum_i^k A(p_i), \quad (9)$$

Table 4
The coefficients for water conservation and soil erosion of different types of vegetation, soil and slope

Type	Coefficient of water conservation	Symbol	Coefficient of soil erosion	Symbol
MIX	1.00	ε_1	0.013	β_1
CON	0.71	ε_2	0.022	β_2
SHR	0.57	ε_3	0.445	β_3
GRA	0.35	ε_4	0.680	β_4
ORC	0.11	ε_5	0.907	β_5
CRP	0.07	ε_6	1.000	β_6
YBS	1.00	δ_1	0.092	μ_1
YLS	0.98	δ_2	0.199	μ_2
LMS	0.81	δ_3	0.470	μ_3
PPS	0.78	δ_4	0.640	μ_4
RCS	0.05	δ_5	1.000	μ_5
$SA < 15°$	1.00	η_1	0.33	σ_1
$SA = 15°–25°$	0.57	η_2	0.54	σ_2
$SA > 25°$	0.31	η_3	1.00	σ_3

$$MS_r = \sum_j^h MS(p_j)A(p_j) \Big/ \sum_j^h A(p_j), \quad (10)$$

where $A(p_i)$ and $A(p_j)$ are the areas (ha) of the ith type of complex in forestland and the jth type of complex in non-forestland, respectively. k and h are the amounts of complex types for forestland and non-forestland, respectively.

We adopted the replacement cost technique to assess the economic values of the ecosystem services for soil conservation. This technique is based on the cost of replacing or restoring a damaged asset to its original state and uses this cost as a measure of the benefit of restoration (Pearce and Moran, 1994). Then the economic value of an ecosystem service can be expressed generally as follows:

$$\mathrm{Ve} = \mathrm{Fe}\ \mathrm{Co}, \quad (11)$$

where Co is the opportunity cost (RMB).

Economic values of several forest ecosystem services for soil conservation are presented not only in one year but also accumulated over time, for example, preventing the capacities of storing water of reservoirs from decrease by alluvial soil. Thus, for these ecosystem services a discount value should be added in the annual economic value. If the living time of forests is N years, the economic value is Ve (RMB) per year and the discount rate is R, then the annual economic value (RMB), Vp, can be shown as follows:

$$\mathrm{Vp} = \mathrm{Ve}[(1+R)^{N+1} - 1]/[R(1+R)^N]. \quad (12)$$

3.4. Gas regulation

There are three methods of assessing the economic value of forest ecosystem's fixing carbon and supplying oxygen, which are based on (1) the formula of photosynthesis and respiration; (2) the 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. First, we determined, when forests produce 1 ton of dry material, the amount of CO_2 absorbed and oxygen released by them based upon this formula. Next, according to the amount of local forestry production per year, we calculated the amount of carbon fixed and oxygen released by forests per year. The formula of photosynthesis and respiration is as follows:

$$CO_2\ (264\ \mathrm{g}) + H_2O\ (108\ \mathrm{g})$$
$$\rightarrow C_6H_{12}O_6\ (180\ \mathrm{g}) + O\ (193\ \mathrm{g})$$
$$\rightarrow \mathrm{Amylase}\ (162\ \mathrm{g}). \quad (13)$$

In this case, we assessed the economic value of forest ecosystem's fixing carbon or supplying oxygen based on its cost (Thomas, 1990; Titus, 1992). Then, this kind economic value can be estimated by the equation below:

$$\mathrm{Ve} = \mathrm{Fe}\ \mathrm{Pc}. \quad (14)$$

In the case of fixing carbon or supplying oxygen, Fe is the total amount of carbon fixed or oxygen supplied by forests (ton), and Pc is the cost of forests' fixing carbon or supplying oxygen (RMB/ton).

4. Results

4.1. Direct economic value

Direct economic values include the benefits derived from timber, other forest products, and forest tour, which can be considered as ecosystem goods. This type of economic value is usually figured as a part of the gross national product (GNP) in an administrative region. The data used in this section were extracted from an official statistics (BSXC, 1997).

4.1.1. Timber and other forest products

In Xingshan County, forests cover an area of 107 000 ha and there are more than 1000 kinds of woody plants. The total stock volume of stumpage is estimated to be about 4.87 million m^3. The county also produces many other forest products, such as raw lacquer, chestnut, mushroom, and some Chinese traditional medicinal materials, such as gallnut, palm fiber. The total value of timber and other forest products was 48.43 million RMB in 1997.

4.1.2. Taking forest tour

Forests form many natural beautiful scenes in Xingshan County, for example, the Longmenhe

National Forest Park and the Gaolan natural scenes. Here, three zones were defined by distance from the county: < 100 km, 100–200 km and > 200 km. The costs from the three zones (including the entry price to the site and the costs of traveling to the site) are 40, 60 and 80 RMB approximately. According to survey data, visitors from the three zones were approximately 43 000, 30 000 and 7000 in 1997. Thus, the consumer surplus for taking forest tour in Xingshan is 3.4 million RMB based on the approach of Common (1996). And the time cost is 2.4 million RMB. Using Eq. (1), the value derived from taking forest tour was estimated to be about 5.8 million RMB in this county.

4.2. Indirect economic value

Here, the indirect economic values include water conservation, soil conservation, and gas regulation. The economic values for these three aspects were estimated by the simulation and evaluation models described in the above, associated with the GIS-embodied spatial database. The data needed for the valuations were obtained either from in situ surveys and field experiments or extracted from the literature.

4.2.1. Water conservation

Xingshan County possesses two types of forest belts: central sub-tropic evergreen broadleaf forests and northern sub-tropic evergreen and deciduous broadleaf forests. According to the approach of Wen and Liu (1995), revised by field test, relevant data for the standard vegetation–soil–slope complex (i.e., MIX–YBS–SA < 15°) were obtained. In a typical rainfall event, the amount of rainwater intercepted by canopy is 0.87 mm, the amount of water held by litter is 5.97 mm and contained by soil is 101.6 mm. Therefore, the total amount of water conservation by the standard complex is estimated to be about 1326.23 mm/yr by Eq. (2) with $\mu = 61$ (Guo et al., 2000). Using the amount of water conservation by 'MIX–YBS–SA < 15°' complex as a standard and using Eq. (3) with the coefficients of water conservation in Table 4, we obtained the capacities of water conservation of each type of complex in Xingshan County (Fig. 2(a)). For example, the yearly-integrated capacity of water conservation by the twentieth complex type (CON–YLS–SA = 15°–25°) is: $WR(p_{20}) = 0.71 \times 0.98 \times 0.57 \times 1326.23 = 525.99$ (mm).

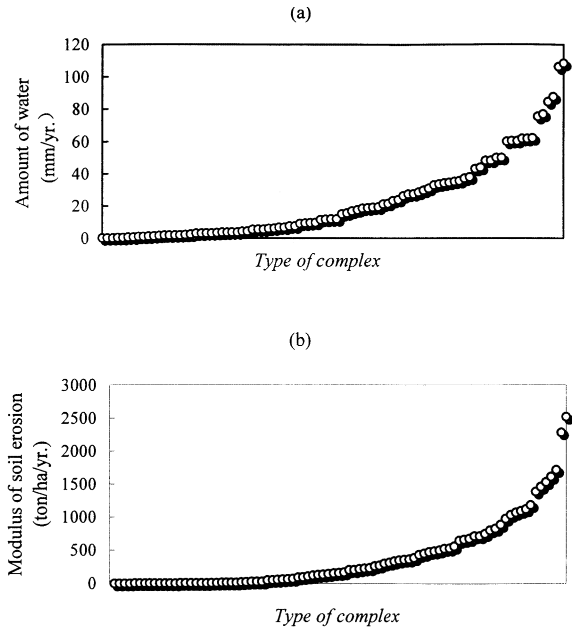

Fig. 2. (a) The capacities of water conservation of the complexes. Here, minimum is the complex of CRP–RCS–SA > 25°; maximum is the complex of MIX–YBS–SA < 15°. (b) The moduli of soil erosion of the complexes. Here, minimum is the complex of MIX–YBS–SA < 15°; maximum is the complex of CRP–RCS–SA > 25°.

Furthermore, using Eq. (4) and the above results, we estimated that the integrated capacity of water conservation of all vegetation–soil–slope complexes under the current condition is 25.1 million m^3/yr. Also, we simulated the capacity of water conservation of the entire region studied under the condition that forests are replaced by a mixture of shrub and grass in the proportion of 3.7:1, and the total amount of water conservation is estimated to be 14.4 million m^3/yr. Therefore, according to Eq. (5), the contribution of the forest ecosystems to water conservation is 0.42 in Xingshan.

4.2.1.1. Hydrological flow regulation. The benefit of regulating hydrological flows by forest ecosystems usually includes two aspects, i.e., reducing floodwater flow and regulating water flow into rivers. Because the floodwater does not happen every year, this kind of benefit cannot be obtained every year. Therefore, here, we just considered the benefit derived from water flow regulation (Guo et al., 2000). This kind of service is characterized by a decrease of water flow into rivers in wet season and an increase of water flow into rivers in dry season, resulting in an increase of available hydrological flows of rivers in a year.

According to Guo et al. (2000), the main beneficiaries for increasing the available amount of river flow are the hydroelectric stations for the region studied. Less available river flow in a year would result in less production of electricity in a hydroelectric station. Therefore, the effect derived from the ecosystem service for hydrological flow regulation could be assessed by the output of electricity generation. Using Eq. (6) with CFW = 0.42, Fe = 325.79 million kW h (the total output of electricity generation per year in Xingshan (BSXC, 1997)), and Ps = 0.4 RMB/kW h (the price of electricity in 1997), we estimated the economic value of hydrological flow regulation by the forest ecosystems as 54.7 million RMB per year in the county. In addition, since Xingshan County is located in the upper reach of the Yangtze River, forest ecosystems also contribute to river flows that allow the Gezhouba Hydroelectricity Plant to increase its output. According to the study of Guo et al. (1997), the value of this aspect is 5.08 million RMB per year. Thus, the total value of hydrological flow regulation by forest ecosystems in the county is 59.78 million RMB per year.

4.2.1.2. Water retention and storage. Forests have a huge capacity for storing water, absorbing and reserving rainwater to decrease water draining, and thus can increase the amount of water storage. As abundant water is advantageous to spur the growth of the economy and to improve the living standard, this service of forest ecosystems can increase the economic effect of a region.

In this case, we assessed economic value of this ecosystem service by calculating the value of water increased by the forest ecosystems. The method of water balance is considered as an efficient way for the computation of amount of water storage increased by forests (Daniel, 1986). This method considers the difference between precipitation and evaporation as the amount of water retention and storage increased by forest ecosystems.

For Eq. (6), here, Fe is the amount of water retained and stored in the entire region studied (ton). Ps is the price of water (RMB/ton). In Xingshan County, the average annual precipitation is 1100 mm and the area of the county is 231 600 ha, thus, the total amount of precipitation per year is 25.47 million ton. It was reported that the proportion of evaporation to precipitation is 72% in the region (Wang, 1985). Thus, the amount of water retained and stored in the entire region is 7.13 million ton/yr. The price of water is 1.20 RMB/ton. The value of water retention and storage by forest ecosystems in Xingshan County is 3.59 million RMB per year, by using Eq. (6) with CFW = 0.42.

4.2.2. Soil conservation

According to the field surveys, the modulus of soil erosion for the standard vegetation–soil–slope complex ‘MIX–YBS–SA < 15°’ is 1.09 ton/ha/yr. We obtained the modulus of soil erosion for each type of complex in Xingshan County using Eq. (8) with the coefficients of soil erosion in Table 4 (Fig. 2(b)). By Eqs. (9) and (10), we obtained the moduli of soil erosion for forestland and non-forestland of the county, and they are 9.44 and 268.28 ton/ha/yr, respectively. Therefore, according to Eq. (7), the amount of soil erosion reduced by forests is 258.84 ton/ha or 199.38 m^3/ha/yr. The total amount of soil erosion reduced by all forests of 107 000 ha in the county is thus estimated to be 42.2 million ton or 32.5 million m^3/yr.

It was reported that, in the watershed of the Yangtze River, the amounts of silt accretion and soil deposit are 53% and 21% of the total amount of soil erosion, respectively (ECCWCA, 1996). We thought that the amounts of silt accretion and soil deposit reduced by forests are in same proportions, too.

4.2.2.1. Reduction of land disuse. Soil erosion can result in a loss of surface soil of farmlands and may eventually cause land disuse. Based on the amount of soil erosion reduced by forest ecosystems (St) and the average thickness of surface soil for planting (h), we calculated the area of disused land reduced by forest ecosystems. In this study, we assumed that disused land reduced by the forest ecosystems is just forestland itself in Xingshan County; then forestry economic profit of the county was considered as the opportunity cost.

Here, for Eq. (11), Fe is the area of disused land reduced by forest ecosystems (ha), or $Fe = St/h$, here, h being the thickness of surface soil for farming (m). According to data provided by CAFS (1994), the thickness of surface soil for planting in China is 0.5 m. Thus, the area of disused land reduced by forest ecosystems is 6500 ha/yr in the county. The forestry economic profit of Xingshan in 1997 is 452.62 RMB/ha in accordance with the statistical data (BSXC, 1997), which was considered as the opportunity cost of forest ecosystem's reducing land disuse. Using Eq. (11), the value of disused land reduced by forest ecosystems is estimated as 2.94 million RMB per year in the county.

4.2.2.2. Prevention of silt accretion. Forest ecosystems can prevent silt accretion by retaining soil loss. In this study, we assumed that if this service of forest ecosystem was replaced by labor power, then the cost of labor power was considered as the opportunity cost of this ecosystem service. We defined Fe as the amount of forest's reducing silt accretion (m^3).

If the amount of silt reduced by forest ecosystems is about 53% of the total amount of soil erosion reduced by them, then, in Xingshan County, about 16.6 million m^3 of silt is prevented per year. According to a local situation, we assumed that a labor could clear away silt about 2.6 m^3 with the transporting of 20 m per workday, which can produce economic value about 12.3 RMB. The cost of clearing away one cubic meter of silt should be 4.7 RMB/m^3. Therefore, according to Eq. (11), the value of forest ecosystems for the prevention of silt accretion is 78.02 million RMB per year in Xingshan County.

4.2.2.3. Decrease of soil deposit. Deposited soil can decrease the capacity of water storage of a reservoir and shorten its time of effective utilization. In this case, we considered the cost of reservoir construction as the opportunity cost, Co, in assessing the value of forest ecosystem's decreasing soil deposit and the amount of deposited soil decreased by forest ecosystem (m^3) as Fe.

According to the proportion of 21%, in Xingshan County, the amount of deposited soil reduced by forest ecosystems would be 6.83 million m^3/yr. Then, the water body at the lower reach of Xingshan can avoid the loss of same volume of the capacity of water storage. In China, the cost of one cube meter of capacity of reservoir is 0.67 RMB (ECCWCA, 1996). Then, the economic value of forest ecosystems in reducing soil deposit would be 4.58 million RMB per year in the county, based on Eq. (11).

In fact, if the lakes, reservoirs and rivers were filled up, their capacities would be lost not only in same year when eroded soil enters them and also over time. Thus, the value of forest ecosystems in reducing soil deposit should add a 'discount value'. According to Eq. (12), if a reservoir is available for 50 years and the discount rate is 0.1, the total value of forest ecosystems for a decrease of soil deposit in Xingshan County could be 50.38 million RMB per year.

4.2.2.4. Protection of soil fertility. Because a large amount of organic and inorganic material contained by surface soil can be lost with eroded soil, soil erosion results in a decrease in the fertility of farmland. Forests can protect soil fertility by reducing soil erosion. In Xingshan County, stalks and straw are usually used as fertilizer to complement the organic material in farmland; however, they are also fuel staples for people in the county. If a great deal of stalks and straw are used as fertilizers, the locals will increase the consumption of firewood. Thus, in this study, the cost of firewood was considered as an opportunity cost to assess the economic value of forest ecosystems in protection of soil organic fertility. In addition, soil erosion also causes losses of nitrogen, phosphorus and potassium, and results in the increased demand for more use of chemical fertilizers. Therefore, the economic value of forest ecosystems in reducing inorganic nutrient loss can be assessed by the price of chemical fertilizers. Here, Fe is defined as the amount of soil fertility protected by forest ecosystem (ton).

According to the survey data in Xingshan County, the proportions of organic material and inorganic nutrients (including nitrogen, phosphorus and potassium) in surface soil are 1.1% and 0.18%, respectively. Because the total amount of soil erosion reduced by forests is 42.2 million ton/yr in the county, the organic material and inorganic nutrients contained should be 464 200 and 75 960 ton, respectively.

The data from the CAFS (1994) show that the rate of firewood turning into organic material is 0.5, and thus the opportunity cost of firewood in China is 51.3 RMB/ton. In addition, the average price of inorganic chemical fertilizers in China is 2549 RMB/ton. Using Eq. (11), we estimated that the values of the forest ecosystems for the protection of soil fertility are 47.6 million RMB and 193.7 million RMB per year in Xingshan County.

4.2.3. Gas regulation

According to Eq. (13), forest absorbs 264 g CO_2 for producing 162 g dry material, in other words, it needs 1.63 g CO_2 and releases 1.2 g oxygen to form 1 g dry material. It was reported that the weight of branch and root of a tree is 25% of its trunk weight, and the average specific gravity of the timber is 0.45 ton/m^3 (CAFS, 1994). The growth amount of trees in Xingshan County is 181 500 m^3/yr (Fang, 1991). Then, by the formula $(181\,500 \times 0.45)(1+0.25)$, the growth amount of dry material is about 102 094 ton/yr in the county.

4.2.3.1. Carbon fixation. According to Eq. (13), while producing 162 g dry material, forests absorb 264 g carbon. Thus, 1.63 ton carbon will be absorbed when one ton dry material is formed, and the carbon fixed by forests (Fe) is 166 413 ton/yr in Xingshan. Then, the value of carbon fixation by forest ecosystems is 46.45 million RMB per year in the county, based on Eq. (14) with an average cost of forests carbon fixation Pc = 279.14 RMB/ton (CAFS, 1994).

4.2.3.2. Oxygen supply. While producing 162 g dry material, forests can supply 193 g oxygen, based on Eq. (13). Thus, 1.2 ton oxygen will be discharged when one ton dry material is formed. Therefore, the oxygen supplied by forests (Fe) is 122 513 ton/yr in Xingshan County. According to Eq. (14), with the average cost of forests' supplying oxygen Pc = 377.64 RMB/ton (CAFS, 1994), the value of the forest ecosystems' supplying oxygen is 46.27 million RMB per year in the county.

4.3. Spatial distribution of the forest capital stock

According to the above estimations, we have understood the economic value of the several services of forest ecosystems in Xingshan County. Here, we determined the spatial distribution of forest capital stock 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 form 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. The ecosystems in Xingshan County were divided into 90 types vegetation–soil–slope complex, 30 of them are forestlands. Forests generate the flows of services in the 30 complexes in conjunction with the services from soil and topography, which can also be considered as two types of natural capital stock. According to the above results of valuation, we could determine the value of each vegetation–soil–slope complex in the forestlands (Fig. 3) and further, the spatial distribution of forest capital stock in the county. Fig. 4 shows the situation of spatial distribution of them, expressed by economic value (RMB/ha).

5. Discussion

In this study, we have estimated that the annual value of the forest ecosystem services is 582.96

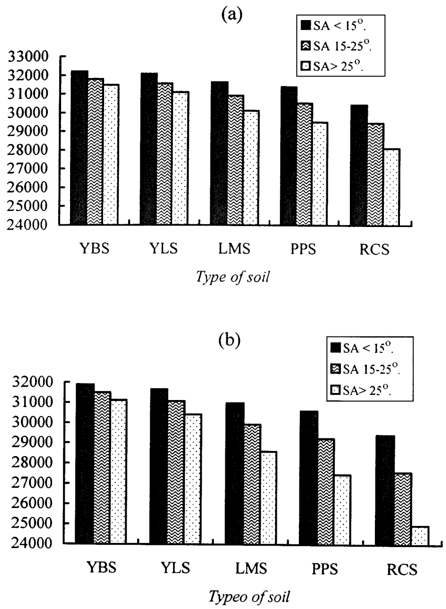

Fig. 3. The economic values of every complex with (a) MIX and (b) CON.

million RMB in Xingshan County (Table 5). However, because of the lack of ample data and efficient methods, we could not assess every aspect of economic values of forest ecosystem services, such as air purification, decreasing noise, protecting ozonosphere, etc. Despite this limitation the economic value of forest ecosystem is far more than what we had imaged.

In Xingshan County, the direct value of forest ecosystem, including forestry products and forest tour, was 54.23 million RMB in 1997; while the total value of agriculture and husbandry were 108.71 million RMB and 44.19 million RMB in the same year, respectively. Compared with the value of 582.96 million RMB provided by forest ecosystem services, the GNP of Xingshan County in 1997 was about 629.95 million RMB.

Understanding the spatial distribution of natural capital stock is as important as the value of it, especially when the ecosystems are being faced with dramatic changes, it is more urgent. We demarcated the natural capital stock, expressed as vegetation–soil–slope complex on the map of Xingshan County by the means of GIS, providing a foundation for protecting and/or restoring forest capital stock.

The economic value of services of the forest ecosystems in Xingshan County is huge. Though the local people obtain little or no profits from it directly, it cannot be doubted that the GNP of the county is produced based on these ecosystem services. In fact, the value of the ecosystem services of approximate 417.04 million RMB produce local benefits, such as water supply, soil

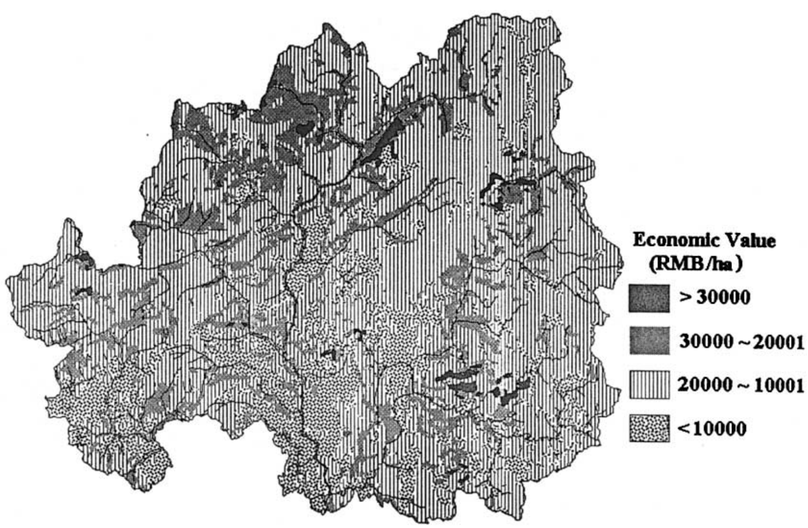

Fig. 4. The spatial distribution of economic values of forest ecosystem services in Xingshan County.

Table 5
Economic values of the forest ecosystem services in Xingshan County

Type	Ecosystem service	Value (million RMB)
Direct value		54.23
	Timber and other forest products	48.43
	Taking forest tour	5.8
Indirect value		528.73
	Water conservation:	
	Hydrological flow regulation	59.78
	Water retention and storage	3.59
	Soil conservation:	
	Reduction of land disuse	2.94
	Prevention of silt accretion	78.02
	Decrease of soil deposit	50.38
	Protection of soil fertility	241.3
	Gas regulation:	
	Carbon fixation	46.45
	Oxygen supply	46.27
Total value		582.96

fertility protection, etc., to support economic development per year. It cannot be imagined that the local people are able to make such huge quantity of investment per year. Taking the service of soil conservation as an example, the opportunity cost of the forestlands for agriculture is 310.85 RMB/ha, while forests in one hectare can reduce silt accretion by 155 m^3, soil deposit by 64 m^3 and use of soil fertilizers by 4.9 ton. Without the forests, in order to yield the same effects, 1784.3 RMB/ha has to be spent. In addition, many ecosystem services are literally irreplaceable, such as water conservation. In Xingshan County, the value of ecosystem services (approximate 111.51 million RMB) is an output from the county per year, being a part of support system of human welfare in larger regions, such as hydrological flow regulation, carbon fixation, oxygen supply, etc. With economic development continuing, forest ecosystem services will play a greater role than before and their values will also increase over time.

Through this case study in Xingshan County, it is clearly shown that ecosystem services contribute substantially to human welfare on this planet. In the decision-making process, we should give adequate weight to natural capital stock that produces these services and build up the mechanisms of economic compensation for the people who conserve ecosystem services. We should also pay specific attention to conservation of natural capital stock and find ways for its sustainable use. As natural capital and ecosystem services become more stressed and more ‘scarce’ in the future, we must determine how to use and protect them. The economic valuation of ecosystem services is just a useful starting point.

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