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Forest Ecosystem Services and Their Values in Beijing

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Abstract: As the most important ecosystem in Beijing, the forest supports a lot of ecosystem services to local and around communities, which plays a key role in the maintenance of urban ecological security. However, the valuation on the forest ecosystem services based on regional scale could not provide precise and reasonable values for forestry sector management. In this study, we estimated the magnitudes and economic values of the forest ecosystem services in Beijing at sublot level. The economic value of forest ecosystem services in Beijing was estimated to be 19 339.71×10^6 yuan (RMB) in 2004. Among all the ecosystem services indicators we estimated in this study, only fruit, timber and part of the recreation (which only include the tourism income from the forest parks and scenic areas, but not include that from other forest types) were measured in the social economic system. As estimated in this study, more than 82.19% of the economic value of forest ecosystem services could not be measured in the socio-economic statistical system. The importance of forest ecosystem services in Beijing to human welfare was underestimated by the socio-economic system. Therefore, the policies about the eco-compensation of forest ecosystem services should be established to maintain the sustainable supply of the forest ecosystem services in Beijing.
Keywords: forest; ecosystem service; economic value; Beijing

1 Introduction

Ecosystem services, such as climate regulation, soil formation, water regulation and water supply, provide a major contribution to human society without passing through the money economy (Costanza *et al.*, 1997). In the last 30 years, the valuation of environmental services and changes has become one of the most significant and fastest evolving areas of research in environmental and ecological economics (Turner *et al.*, 2003). To better recognize the multiple benefits of ecosystem services, a number of studies were conducted to assess the magnitudes and economic values of ecosystem services (Pearce and Moran, 1994; Gren *et al.*, 1995; Daily, 1997; van Beukering *et al.*, 2003). As the most important terrestrial ecosystem on the earth, forest provides fundamental services for human (Daisy *et al.*, 2006), and the quantification and valuation of forest ecosystem services have drawn considerable attention (Peters *et al.*, 1989; Chopra, 1993; Yaron, 2001). Since the end of the 1980s, many case studies on forest ecosystem services valuation in China have been conducted on regional scale (Xiao *et al.*, 2000; Yu *et al.*, 2002; Yu *et al.*, 2005; Wang *et al.*, 2007), which primarily developed the valuation framework of forest ecosystem services. However, few of the study cases on forest ecosystem services were at the sublot level.

In the last decade, extreme climate events and meteorological disasters frequently occurred, such as droughts, floods and high temperature (Zheng *et al.*, 2000). The forest ecosystem, which covers 35% of the administrative area of Beijing, provides important ecosystem services for the increasing population and rapid economic and social development, and ensures regional eco-environment security. The sustainable existence of these ecosystem services depends on the thorough realization and scientific management of Beijing′s forest resources. The ecosystem services valuation can be used as a tool to provide the scientific information for the forest ecosystem conservation and utilization in Beijing. This pa-

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per established the assessment indicator system on forest ecosystem services in Beijing, estimated their magnitudes and economic values at sublot level by the conventional valuation method. This study could present precise and reasonable values for forest sublots, and provide useful information for the forest resources conservation and management in Beijing.

2 Methodology

2.1 Study area

Beijing lies in 39º28′–41º05′N and 115º25′–117º30′E, on the northern edge of the North China Plain. The total area of Beijing is 16 807 km^2, and 62% of which is hills. It has a warm and semi-humid continental monsoon climate, with cold and dry winter and hot summer. Annual precipitation averages nearly 700 mm, most of which comes in July and August. The average annual temperature is 11.7ºC.

According to the Sixth Forest Resource Inventory of Beijing, the total forest area was 1.05×10^6 ha, with a forest coverage rate of 35% in 2004. There are seven types of forest resources in Beijing, which are forest land, open forest land, shrub land, newly established open forest land, nursery, unstocked forest land and suitable forest land. The forest land accounted for 58.7% of the total forest resources of Beijing, the shrub land 30.5%, and other six types 10.8%. There are 3 types of forest land in Beijing, which are coniferous forest, broadleaved forest and broadleaved-coniferous mixed forest, distributed in the northern and western mountainous area (Fig. 1). The dominant tree species in Beijing include *Quercus dentasa*, *Platycladus rientalis*, *Pinus tabulaeformis*, *Populus* spp., *Robinia pseudoacacia*, *Populus davidiana*, *Betula platyphylla*, and *Larix principis-rupprechtii*, which host a rich variety of other species of fauna and flora.

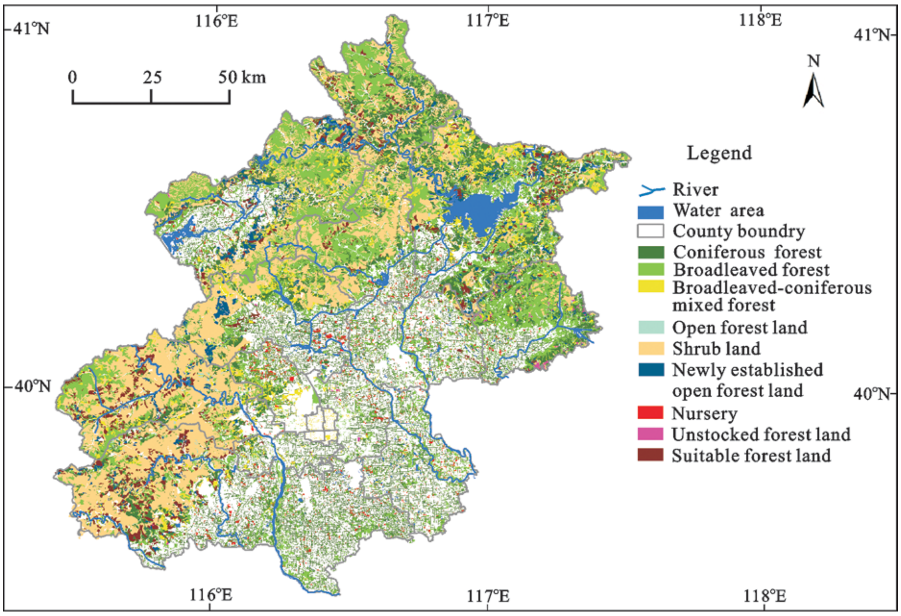

Fig. 1 Distribution of forest resources in Beijing

2.2 Data sources

Totally 131 532 forest data at sublot level from the Sixth Forest Resource Inventory of Beijing in 2004 were provided by Beijing Forestry Survey and Design Institute. The data described the spatial distribution of forest on the scale of 1∶10 000 and a series of attributes of all the forest sublots. The attributes included forest type, area, tree species, coverage, tree height, soil type and depth, litter depth, *etc*. We also adopted some data from other literatures to estimate the economic values of forest ecosystem services.

2.3 Methods

Due to the high complexity of the relation between ecosystem structure and function, the classification of ecosystem services is one of vigorous debates, and the random selection of evaluation indicators can be found in some case studies (Li *et al*., 2009). Based on the ecosystem services classification of Costanza *et al*. (1997), Millennium Ecosystem Assessment (MA) (WGMEA, 2003), "Specifications for Assessment of Forest Ecosystem Services in China" (State Forestry Administration, P. R. China, 2008), we presented a classification system with 4 types, 13 sub-types and 24 indicators of forest ecosystem services in Beijing in this study (Table 1). The methods to calculate the economic values of the ecosystem services included market value method, shadow price method, replacement engineering cost and benefit transfer according to the different characteristics of the indicators (Table 1).

3 Results and Analyses

3.1 Magnitude of forest ecosystem services

3.1.1 Provision service

The forest can supply fruit, timber and water to local people, which are essential for local community. In our study, the water supplied by forest in Beijing was 302×10^6 m^3 in 2004 (Table 2), which was significantly lower than that of 1.47×10^9 m^3/yr estimated by Zhou *et al*. (2000). They estimated the water supply by subtracting evaporation from rainfall, while in our study, the water supply was estimated according to the ratio of runoff to the total rainfall. The estimation by Zhou *et al*. might much higher than the real runoff, because besides the evaporation, part of the rainfall would be used by the plant or just stored in the soil porosity, which would not transformed into runoff.

3.1.2 Regulation service

The gas regulation, which includes CO_2 fixation and O_2 emission, by the forest was necessary for local and around communities. The CO_2 emission of Beijing, the most developed area in North China, was about 29×10^6 t/yr in pure C (Xing *et al*., 2007). The CO_2 fixation by forest in Beijing was 10×10^6 t in 2004 (Table 2), that is, 2.73×10^6 t/yr in pure C, which could neutralize about 10% CO_2 emission (Xing *et al*., 2007). Therefore, CO_2 fixation by forest was important to mitigate the greenhouse effect.

The rainfall interception by the forest in Beijing was calculated to be 2×10^9 m^3 in 2004. Zhou *et al*. (2000) estimated that the forest in Beijing conserved about 1.47×10^9 m^3/yr of water, which was similar to the result of our study.

In 2004, the forest in Beijing absorbed 70×10^3 t of SO_2, 2×10^3 t of HF and 3×10^3 t of NO_x from atmosphere, eliminated 17×10^6 t of dust, and released 465×10^3 t of phytoncide and 27×10^{18} anions. As the noise reduction device, in 2004, the forest along road and protection forest in Beijing were calculated to be 3.51×10^6 m^2 (Table 2). All of the environment purification functions were beneficial to peoples′ health.

3.1.3 Support service

The vegetation nutrient accumulation held the nutrient in plant, and was the key link of the transformation of N, P and K from soil to plant. The forest in Beijing accumulated about 103×10^3 t of nutrients in 2004 (Table 2). The litter decomposition improved the soil structure and quality, which would facilitate plant growth. The magnitude of litter decomposition was estimated to be 857×10^3 t in 2004.

According to our calculation, the soil conserved by the forest in Beijing was 1.57×10^6 t in 2004, which would avoid 525 ha of abandoned land, 301×10^3 m^3 of sediment deposit and 52×10^3 t of nutrient loss (Table 2). According to the data from the Sixth Forest Resource Inventory of Beijing, there were 15×10^3 ha of cropland protection forest in Beijing in 2004, mostly distributed in the southeastern plain area. The cropland protection forest increased 103×10^3 t of wheat and maize in 2004 (Table 2). The forest of windbreak and sand fixation in Beijing was 9×10^3 ha in the same year (Table 2), mostly distributed in the wind routes in the northwestern, southern and eastern areas. There were 3 292 plant species and 2 430 animal species maintained by the forest in Beijing, which were essential for ensuring the environment safety.

3.1.4 Social service

The forestry in Beijing supplied 5 063 jobs in forestry sector in 2004 (Beijing Municipal Bureau of Statistics, 2005), and it also supplied other 15 189 jobs related to forestry to the local community, which was important to maintain and improve the lives of local people. In our study, we thought that all of the forest land in Beijing supplied beautiful scenery to local people and tourists with an area of 619×10^3 ha that include 24 forest parks and scenic areas in 2004. The test forest, seed production forest, environmental protection forest, scenery forest, commemoration forest and national defence forest with a total area of 53×10^3 ha supplied science and education opportunity to the public, schools, colleges and institutes in 2004.

Table 1 Methods to calculate magnitudes and economic values of forest ecosystem services in Beijing

Type	Sub-type	Indicator	Method to calculate magnitude	Method to estimate economic value
Provision service	Primary product	Fruit	Actual production	Market price method of fruit*
		Timber	Annual increase ratio of timber (Wang *et al*., 2003)	Market price method of timber*
	Water supply	Water supply	Ratio of runoff to rainfall (Liu *et al*., 1996)	Replacement price method of water resource (Li *et al*., 1999)
Regulation service	Gas regulation	CO_2 fixation	Net CO_2 absorption (Fang *et al*., 2006)	Afforestation cost method (Li *et al*., 1999)
		O_2 emission	Based on CO_2 fixation and CO_2/O_2 ratios in respiration equation and photosynthesis equation	Afforestation cost method (Li *et al*., 1999)
	Hydrological regulation	Rainfall interception	Ratio of rainfall interception by canopy and litter to rainfall (Liu *et al*., 1996) and by soil porosity to rainfall (Gao, 2005)	Replacement cost method of reservoir engineering (Gao, 2005)
	Environmental purification	SO_2 absorption	Capacity of air pollutant reduction (Cheng *et al*., 2000)	Replacement cost method of air pollutant reduction (Cheng *et al*., 2000)
		HF absorption	Capacity of air pollutant reduction (Cheng *et al*., 2000)	Replacement cost method of air pollutant reduction (Cheng *et al*., 2000)
		NOx absorption	Capacity of air pollutant reduction (Cheng *et al*., 2000)	Replacement cost method of air pollutant reduction (Cheng *et al*., 2000)
		Dust retention	Capacity of air pollutant reduction (Cheng *et al*., 2000)	Replacement cost method of air pollutant reduction (Cheng *et al*., 2000)
		Phytoncide release	Capacity of phytoncide release	Replacement price method of garlic**
		Aero-anion release	Actual aero-anion released (State Forestry Administration, P. R. China, 2008)	Replacement cost method of aero-anion release machine (State Forestry Administration, P. R. China, 2008)
		Noise reduction	Description of forest with the function of noise reduction	Replacement price method of noise reduction device**
Support service	Soil formation	Accumulation of vegetation nutrient	Based on NPP and nutrient content (Cheng *et al*., 2000)	Replacement price method of fertilizer (Yu *et al*., 2002)
		Decomposition of litter	Based on litter biomass and decomposition ratio	Replacement price method of organic manure (Yu *et al*., 2002)
	Soil conservation	Soil conservation	Based on capacity of soil conservation (Yu *et al*., 2002)	—***
		Reduction of abandoned land	Based on soil conservation, soil bulk density and soil depth (Yu *et al*., 2002)	Replacement price method of forest land (Yu *et al*., 2002)
		Reduction of sediment deposition	Based on soil conservation, soil bulk density and ratio of sediment deposition (Yu *et al*., 2002)	Replacement cost method of sediment removal (Yu *et al*., 2002)
		Reduction of soil nutrient loss	Based on soil conservation and nutrient content in soil (Yu *et al*., 2002)	Replacement price method of fertilizer (Yu *et al*., 2002)
	Cropland protection	Cropland protection	Crop product improved by forest (Zhou *et al*., 2000)	Market price method of crop (Zhou *et al*., 2000)
	Wind protection and sand fixation	Wind protection and sand fixation	Actual area of wind protection and sand fixation forest	Market price method of forest land (Zhou *et al*., 2000)
	Biodiversity conservation	Biodiversity conservation	Description of the plant and animal species	Biodiversity conservation price method (State Forestry Administration, 2008)
Social service	Increasing employment	Increasing employment	Jobs in forest sector and coefficient of employment promotion (Gao, 2005)	Subsidy for each person of the lowest income family without job**
	Recreation	Recreation	Description of the forest with the function of recreation	Benefit transfer method based on tourism income of Beijing (State Forestry Administration, P. R. China, 2005)
	Science and education	Science and education	Description of the forest with the function of science and education	Benefit transfer method (Zhang, 2004)

Notes: * The methods were conventional. ** The methods were presented by the authors to valuate the economic values of forest ecosystem services in this article. *** The "soil conservation" in "indicator" column was just an intermediate parameter used to calculate the other three indicators of ecosystem sub-type of "soil conservation". Thus, there was not "method" to estimate economic value for it.

Table 2 Forest ecosystem services and their economic values in Beijing in 2004

Indicator	Magnitude	Economic value	
		Value ($\times10^6$ yuan)	Proportion (%)
Fruit	829×10^6 kg	2635.59	13.63
Timber	700×10^3 m^3	393.16	2.03
Water supply	302×10^6 m^3	331.92	1.72
CO_2 fixation	10×10^6 t	3532.49	18.27
O_2 emission	7×10^6 t	2540.59	13.14
Rainfall interception	2×10^9 m^3	2757.27	14.26
SO_2 absorption	70×10^3 t	44.38	0.23
HF absorption	2×10^3 t	0.31	0.002
NO_x absorption	3×10^3 t	2.12	0.01
Dust retention	17×10^6 t	2919.96	15.10
Phytoncide release	465×10^3 t	465.44	2.41
Aero-anion release	27×10^{18} anions	24.23	0.13
Noise reduction	3.51×10^6 m^2	118.67	0.61
Accumulation of vegetation nutrient	103×10^3 t	351.45	1.82
Decomposition of litter	857×10^3 t	728.67	3.77
Soil conservation	1.57×10^6 t	–	–
Reduction of abandoned land	525 ha	2.91	0.02
Reduction of sediment deposition	301×10^3 m^3	4.51	0.02
Reduction of soil nutrient loss	52×10^3 t	21.10	0.11
Cropland protection	103×10^3 t	103.32	0.53
Wind protection and sand fixation	9×10^3 ha	10.17	0.05
Biodiversity conservation	3292 of plant species 2430 of animal species	1227.32	6.35
Increasing employment	15189 jobs	596.99	3.09
Recreation	619×10^3 ha	415.72	2.15
Science and education	53×10^3 ha	111.61	0.58
Total	–	19339.71	100.00

3.2 Economic values of forest ecosystem services

The economic value of forest ecosystem services in Beijing was estimated to be 19 339.71$\times10^6$ yuan in 2004 (Table 2). Zhou *et al*. (2000) estimated the economic value of the forest ecosystem services in Beijing to be 20.6$\times10^9$ yuan per year, not including aero-anion release, accumulation of vegetation nutrient, decomposition of litter and science and education. The values of phytoncide release and noise reduction by Zhou *et al*. were much higher than those estimated in our study. In Zhou *et al*.'s study, both the value of phytoncide release and noise reduction were calculated with the ratio (15%) to the total forest ecological value based on experts' knowledge, while they were estimated with their magnitudes and the replacement cost or price in our study. Yu *et al*. (2002) estimated that the economic value of the forest ecosystem services in mountain area of Beijing was 16.78$\times10^9$ yuan per year. As the ecosystem services by the forest in the plain area of Beijing were not accounted in the total economic value, the result by Yu *et al*. (2000) was lower than that from our study.

For ecosystem services indicators, the ratios of the economic values of CO_2 fixation, dust retention, rainfall interception, fruit production, O_2 emission to the total value were more than 10% (Table 2). Nowadays, among all the ecosystem services indicators we estimated in this study, only the incomes from fruit, timber and part of the recreation (which only include the tourism income from the forest parks and scenic areas, but not include that from other forest types) were measured in the social economic system. The economic values of these three indicators were only 17.81% of the total economic value, and rest 82.19% of the forest economic value was not measured. Actually, the gross output value of forestry in Beijing in 2004 was 1.27$\times10^9$ yuan (Beijing Municipal Bureau of Statistics, 2005), which was only about 6.57% of the economic value of ecosystem services. This indicated that most of the economic value was not accounted in the economic accounting system, meaning that the economic value of forest ecosystem services was underestimated. The importance of ecosystem services to human welfare was much more important than what we had thought.

Among the sub-types of the forest ecosystem services, the economic values of gas regulation accounted for nearly 31.41% of the total values, environment purification 18.49%, primary products 15.66%, hydrological regulation 14.26%, and other ecosystem services 20.18%. Among the ecosystem services types, the ratio of the economic values of regulation service to the total values was 64.14%, provision service 17.38%, support service 12.67%, and social service 5.81% (Table 2). Therefore, in Beijing, the regulation service was recognized much more important than others to local and around communities.

The average economic value of forest ecosystem services in Beijing was estimated to be about 9 548.77 yuan/(ha·yr) (Table 3). Li *et al*. (2003) estimated the economic value of ecosystem services by the rainforest in Hainan Province to be 7 000 yuan/(ha·yr), not including the timber and fruit production. Costanza *et al*. (1997) calculated the economic value of the ecosystem services by the world forest to be 969 USD/(yr·ha) (about 6 600 yuan/(ha·yr)). In this study the economic values of ecosystem services per hectare per year by forest land and shrub land were much higher than other types, and their proportions to the total value were also much higher than others (Table 3). That is to say, with more areas and higher capabilities, the forest land and the shrub land supported most of the ecosystem services.

Table 3 Economic values of ecosystem services of different forest types

Forest type	Area ($\times10^3$ ha)	Economic value		
		Annual value per unit area (yuan/(ha·yr))	Annual value ($\times10^6$ yuan/yr)	Proportion (%)
Forest land	619	23059.44	13060.76	67.53
Open forest land	5	10109.12	49.41	0.26
Shrub land	321	17643.57	5658.59	29.26
Newly established open forest land	33	5868.03	211.47	1.09
Nursery	20	5354.84	104.83	0.54
Unstocked forest land	4	2124.83	20.65	0.11
Suitable forest land	52	2681.55	234.00	1.21
Total	1054	9548.77	19339.71	100.00

The economic values of forest ecosystem services in the northwest, southwest and northeast of Beijing were much higher than those in other areas. Although the economic value per hectare per year of ecosystem services by the protection forest in the southeastern plain was relatively higher, it contributed a little to the total value of forest ecosystem services in Beijing as its area was less. Therefore, the forest in the northwestern, southwestern and northeastern mountainous areas of Beijing supported most of the ecosystem services.

4 Conclusions and Discussion

As the most important ecosystem in Beijing, forest supported a lot of ecosystem services to local and around communities, including primary products, water supply, gas regulation, hydrological regulation, environmental purification, soil formation, soil conservation, cropland protection, wind protection and sand fixation, biodiversity conservation, increasing employment, recreation and science and education. The economic value of ecosystem services by the forest in Beijing was estimated to be 19 339.71$\times10^6$ yuan in 2004. Among all the ecosystem services indicators we estimated in this study, only fruit, timber and part of the recreation (which only include the tourism income from the forest parks and scenic areas, but not include that from other forest types) were measured in the social economic system. Thus, more than 82.19% of the economic value of forest ecosystem services would not be measured in the social economic statistical system. The importance of forest ecosystem services in Beijing to human welfare was underestimated by the social economic system.

According to the statistical data, the GDP of Beijing was 428×10^9 yuan in 2004 (Beijing Municipal Bureau of Statistics, 2005). Although the economic value of the forest ecosystem services in Beijing was only 4% of GDP, these forest ecosystem services were the direct and indirect guarantees of the accomplishment of GDP. Therefore, the policies about the eco-compensation of forest ecosystem services should be established to maintain the sustainable supply of the forest ecosystem services in Beijing.

The studies on ecosystem services have been paid much attention to since the 1990s, but there are still many controversies on valuation indicators, valuation methods, parameter values, and so on. This study was based on synthesis of existing research efforts and expert knowledge. It was very difficult to find rational methods suitable to estimate the forest ecosystem services at sublot scale. In previous studies, the valuation cases mainly focused on the middle scale (province) or large scale (nation), such as the studies on the Changbaishan Mountains (Xue *et al*., 1999; Wu *et al*., 2001), Hainan Island (Xiao *et al*., 2000) and the forest in China (Jiang and Zhou, 1999; Zhao *et al*., 2004). However, in this study, we paid special attention to the forest ecosystem services at sublot level, and the maximum area of the sublot was larger than 1 000 ha and the minimum area smaller than 1 ha. There was obviously difference between former studies and this study. Although the data from the Sixth Forest Resource Inventory of Beijing provided important data source for the valuation of forest ecosystem services, simultaneously, they increased difficulties in the study. For instance, during the valuation of hydrological regulation, it was easy to calculate the amount of conserved water at the watershed level, but very hard at the forest sublot scale. On the basis of a wealth of research achievements, we proposed that the hydrological regulation services of forest mainly included rainfall interception and soil water storage, thus the service of rainfall interception could be calculated by means of the amount of rainfall intercepted by forest canopy, litter and soil, and the amount of soil water stored could be estimated by the soil non-capillary pore. Besides, due to the indivisibility of forest ecosystem services, it is very hard or not realistic to segment some forest ecosystem services, such as biodiversity maintenance, increasing employment and recreation, into different forest land sublots.

This study comprehensively considered all the forest ecosystem services that have been realized presently, however, more and more forest ecosystem services will be realized and understood by human in the future. With the development of science and technology and deeper insight to the relationship between human beings and forest ecosystems, the forest ecosystem services would play a more important role in human life. In this study, the price of ecosystem service was more reasonable and conservative, thus the actual economic value of forest ecosystem services in Beijing might be higher than the result of $19\ 339.71\times10^6$ yuan in fact. The importance of ecosystem services to human welfare was much more important than what we had thought.

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