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ASSESSMENT OF INDIRECT USE VALUES OF FOREST BIODIVERSITY IN YAOLUOPING NATIONAL NATURE RESERVE, ANHUI PROVINCE

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ABSTRACT: Direct use values of forest ecosystem have been recognized apparently due to its easy and convenient assessment, while indirect use values are usually neglected because they are not easy to be recognized by the public. For a nature reserve with forest ecosystem, the most important economic values are the indirect use values, which provide human beings and other living things with beneficial services through ecological processes and functions. In this case study, a quantifying framework to estimate the annual indirect use values of forest ecosystem has been established in Yaoluoping National Nature Reserve based on alternative cost method and opportunity cost method. The ecological functions assessed in the study relate to six aspects: soil protection, water conservation, CO_2 fixation, nutrient cycling, pollutant decomposition and disease and pest control. These ecological functions provide an economic value of 86.1×10^6 yuan (RMB) per year (US$$10.37\times10^6$), which is 25 times higher than the opportunity cost for regular timber production. This study can contribute to the monetary assessment of indirect use values of forest biodiversity and to the conservation and sustainable use of nature reserves.

KEY WORDS: Yaoluoping National Nature Reserve; forest ecosystem; ecological functions; indirect use value

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1 INTRODUCTION

Forest biodiversity provides a wide range of indirect benefits to human being. While there may be little consensus on whether the various elements of forest biodiversity can be valued in economic terms, it is increasingly recognized that these values and the role of biodiversity in maintaining ecological services are essential to the humankind. The notion of indirect use value of biodiversity has been associated with a minimum level of ecosystem infrastructure, without which there would not be the goods and services provided by it (FARNWORTH *et al.*, 1981). EHRLICH and EHRLICH (1992) divided biodiversity values into four categories: ethical, aesthetic, direct and indirect, and considered that indirect value is the most important of these values of biodiversity. BARBIER (1994) described the indirect value of biodiversity as "support and protection provided to economic activity by regulatory environmental services". TURNER recently classified ecological functions into ecosystem life support functions, such as regulation of nature′s major cycles (e.g. water and carbon) and primary ecosystem processes, such as photosynthesis and biogeochemical cycling (TUENER *et al.*, 2000). In some literatures, there are terms such as "contributory value", "primary value", and "infrastructure value" of biodiversity, which all point at the same notion (NORTON, 1986; GREN *et al.*, 1994). Therefore, ecological functions are important part of economic value of forest biodiversity.

Indirect use values can not all be embodied in commodity market, or be quantified in the index of economic services and product capital, this makes it have little proportion in leaders decision-making, therefore brings about crisis to humanity sustainable development in biosphere. There are many difficulties and a lot

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of uncertainty in the assessment (CUI *et al*., 2000). So, to develop a system of valuing natural resources and to reform national accounting systems have now attracted more attention in the world (XUE and TISDELL, 2001；UNEP，1993). Generally, ecological benefits can′t be directly expressed in monetary form, but it can be quantified indirectly. Alternative cost method is considered as an effective methodology to value these indirect values of ecosystem′s functions. Many studies have been conducted worldwide. For example, in RUITENBEEK's valuation of the Korup Project in Cameroon, the benefits from watershed protection were estimated to be almost half of the direct conservation benefits (RUITENBEEK, 1989). ADGER *et al.* (995) made a study on indirect value of forests in Mexico. The results indicated an annual lower bound value of Mexico′s forests to be US$$4\times10^9$. Following the Western valuation methodologies, China Biodiversity Country Study estimated that the total annual indirect use value of biodiversity in China amounted to US$$1.69\times10^{12}$ per annum (SEPA,1998). Using alternative market and non-market methods, COSTANZA *et al*. (1997) estimated the current economic value of 17 ecosystem services for 16 biomes based on published studies and a few original calculations. And the value for the entire biosphere was estimated to be in the range of US$$16\times10^{12}$–$54\times10^{12}$ per year, with an average of US$$33\times10^{12}$ per year. The specific values in COSTANZA's study will not be applicable to the services provided by the protected areas (PAs) because they are based on broad averages that could not be expected to apply to specific situations. It must be noted that much valuatiotn work remains to be done; in other words, many of the values currently available are subject to confirmation.

2 STUDY SITE

Yaoluoping National Nature Reserve was chosen as study site to estimate the indirect use values of ecological functions of forest biodiversity in the study. The reserve is situated in the northwest of Yuexi County, Anhui Province, China (114°30′–117°05′E，30°02′–31°55′N), covers an area of about 123km^2 and is a part of Dabie Mountain. The reserve was established in 1991 and upgraded as a national reserve in 1994 and accepted by the web of Chinese Biological Cycle in 1999. The reserve is located in Duozhijian, which is 1721.2m a. s. l., and is the highest peak of Dabie Mountain. It is also a watershed of the Changjiang(Yangtze) River and the Huaihe River. The total area of forestland of the reserve is 10 996ha, accounting for 90% of the total land area. The reserve belongs to typical forest ecosystem of Dabie Mountain in northern sub-tropical climate zone, and is rich in biodiversity, with rare wild animals and plants. The forests are mostly secondary and have successive vegetation as the altitude changes. The climate here is northern sub-tropical monsoon climate, and temperature declines and precipitation increases as the altitude rises. Annual precipitation is about 1400 mm in the bottom and 1800mm in the peak. Soil types are yellow brown soil (≤800m a. s. l.)and brown soil (>800m a. s. l.). This paper estimates the economic values of forest ecological functions of soil protection, water conservancy, CO_2 fixation, nutrient cycling and pollutant decomposition and disease and pest control.

3 METHODS

All data came from the committee of Yaoluoping National Nature Reserve. Some data were from remote sensing and investigation, and some from the departments of forest, agriculture and hydrological stations.

In light of actual situation of Yaoluoping National Nature Reserve, the methods adopted related to establishing quantifying models for physical amount of ecological functions and services; and deciding shadow prices as pricing parameters of each services.

3.1 Soil Protection

Forest ecosystem helps in the formation and maintenance of soil structure and the retention of moisture and nutrient levels. Soil protection by maintenance of forest ecosystem can preserve the productive capacity of the soil, prevent landslides, safeguard riverbanks and coastlines, and prevent the degradation of coral reefs and riverine and coastal fisheries by siltation. The amount of soil conserved by forest ecosystem is estimated by the difference between potential erosion and actual erosion in the reserve according to the following equation:

$$Q_s=Q_p-Q_r \qquad (1)$$

where Q_s is the amount of soil erosion reduced by forests (t/a); Q_p is the potential amount of soil erosion (t/a); Q_r is the actual amount of soil erosion (t/a).

The total economic value of soil protection is estimated from three aspects including the value of reduced land, of protected soil nutrient and of reduction of siltation through alternative cost method. They are priced according to equations (2), (3) and (4) respectively :

$$V_1=Q_s/\rho/h\times P_1 \quad (2)$$

where V_1 is the value of reduced soil land (yuan/a); ρ is soil weight per unit volume (t/m^3); h is the thickness of topsoil (m); P_1 is the opportunity cost of land (yuan/ha).

$$V_2=\sum Q_s \times b_i\times P_f \quad (3)$$

where V_2 is the value of protected soil nutrient (yuan/a); b_i is the content of the ith nutrient element in soil (%); P_f is the price of chemical fertilizer (yuan/t); i denotes the type of nutrient element, which includes N, P and K in this study.

$$V_3= Q_s/\rho\times k_i\times P_s \quad (4)$$

where V_3 is the value of reduction of siltation in watercourses and dams(yuan/a); ρ is soil unit weight (t/m^3); k_i is the percent of solid flow into dams and rivers (%); P_s is clearing cost of siltation (yuan/m^3).

Total value of soil protection V_s is the sum of V_1, V_2, and V_3, i.e.

$$V_s=V_1+V_2+V_3 \quad (5)$$

3.2 Water Conservancy

Forest vegetation in water catchments helps to maintain hydrological cycles, regulating and stabilising water runoff, and acting as a buffer zone against extreme events such as flood and drought, and purifying water. Vegetation also helps to regulate underground water tables. These services can be translated into substantial financial benefits. The amount of water conserved is nearly equal to annual runoff because of its high coverage of forests and lack in survey of plant respiration, and the shadow price is decided in accordance with building cost of per unit reservoir volume, i.e.

$$V_w=Q_w\times P_w=R_w\times S\times P_w \quad (6)$$

where V_w is the value of water conservancy yuan/a; Q_w is the amount of water conserved by the ecosystem (m^3/a); R_w is annual runoff (mm); S is the area of forest ecosystem (m^2); P_w is building cost of per unit reservoir volume (yuan/m^3).

3.3 CO_2 Fixation

Forest biodiversity of nature reserves provides a vast sink for CO_2 and a huge amount of CO_2 is deposited in their timber. In this study, the equation of photosynthesis and respiration is adopted. The economic value of CO_2 fixation is estimated by the total fixed CO_2 amount multiplied by a standard opportunity cost for per unit CO_2 fixation, based on afforestation cost (THOMAS, 1990).

The equation of photosynthesis and respiration is as follows:

CO_2(264g)+H_2O(108g)→$C_6H_{12}O_6$(180g)+ O_2 (193g) →Polysaccharide (162g)

The value of CO_2 fixation can be estimated by the following equation:

$$V_c=Q_c\times P_c=1.63\times 0.2729\sum r_i \times (+c)\times S_i\times P_c \quad (7)$$

where V_c is the value of CO_2 fixation(yuan/a); Q_c is CO_2 fixation amount(t/a); P_c is the cost of CO_2 fixation by afforestation (yuan/t). r_i is the net growth of the ith kind of tree(t/(ha·a)); c is the percentage of branches to timbers (dry weight %); S_i is the area of the ith forest (ha).

3.4 Nutrient Storage and Cycling

Nutrient cycling includes the elements moving in the atmosphere, soil and plant. Biodiversity is essential in this process. The value of nutrient accumulation can be evaluated by the total net nutrient amount yearly maintained in the standing forests multiplied by the market alternative price of nutrients (XUE and TISDELL, 2001), i.e.

$$V_n=\sum\sum S_i\times A_{ik}\times P_f \quad (8)$$

where V_n is the value of nutrient cycle yuan/a, S_i is the area of the ith forest (ha); A_i is net amount of maintained nutrients per area of the ith forest(t/ha), and k is the types of nutrients; P_f is the market price of fertilizer (N, P and K)(yuan/t).

3.5 Pollutant Breakdown and Absorption

Ecological processes play an important role in the breakdown and absorption of many pollutants created by human activities. These include wastes such as sewage, garbage and oil spills. The study estimates the value of SO_2 purification and powder dust absorption using the following equation.:

$$V_d=\sum\sum Q_i\times P_p =\sum\sum S_i\times A_{im}\times P_p \quad (9)$$

where V_d is the value of pollutant absorption (yuan/a); Q_i is absorption amount of the ith forest (t/ha·a); S_i is the area of the ith forest (ha); A_{im} is average absorption amount of m kinds of pollutants by the ith forest (t/ha); P_p is the cost of breaking down the pollutant (yuan/t).

3.6 Disease and Pest Control

Forest ecosystem provides animals and other species with a natural environment and ensures sound ecological processes in the ecosystem. The value of total disease and pest control is quantified by the following equation:

$$V_p = S \times P_c \quad (10)$$

where V_p is the value of disease and pest control (yuan/a); S is the area of the forestland (m^2); P_c is the cost of prevention based on the state statistical data (yuan/$m^2 \cdot a$).

Ecological functions, valuation methods, indicators, and pricing parameters adopted in the study are summarized in Table 1.

4 RESULTS

4.1 Value of Soil Protection

According to the on-site survey by the management committee of the reserve, the actual amount of soil erosion in the reserve is 231×10^3t/a, and the erosion module of wilderness is 148.0 t/(ha·a), so the potential amount of soil erosion is 1.67×10^6t, and the total amount of soil erosion reduced by the reserve is 1.44×10^6t/a on the basis of Equation (1). The total value of soil protection is composed of value of abandoned land, value of reduced soil fertility loss and value of reducing silt accretion and soil deposit.

Table 1 The indicators, parameters, methods and counting model of indirect use values of forest biodiversity of Yaoluoping Nature Reserve

Function category	Pricing indicators	Pricing parameters	Quantifying models	Valuation methods
Soil protection	Reduction of soil erosion (t), depth of topsoil (m), the content of soil N, P and K (%)	Opportunity cost of land, average price of fertilizer, clearing cost of silt in reservoir	$V_s=V_1+V_2+V_3=Q_s/\rho/h \times P_1+\sum Q_s \times b_i \times P_f + Q_s/\rho \times k_i \times P_s$	Alternative cost method, market price method
Water conservancy	Forest area (ha), annual runoff (mm)	Shadow price of water	$V_w=R_w \times S \times P_w$	Opportunity cost method
CO_2 fixation	Area of different kind of forest (ha), net annual growing amount of plants (t/ha·a)	Cost of CO_2 fixation through afforestation	$V_c=1.63 \times 0.2729 \sum r_i \times (1+c) S_i \times P_c$	Alternative cost method
Nutrient cycling	Area of different kind of forest (ha), annual accumulation and fixation amount of N, P, K (t)	Prices of fertilizer N, P, K	$V_n=\sum\sum S_i \times A_{ik} \times P_f$	Alternative cost method
Pollutant decomposition	Area of different kind of forest (ha), absorption amount of SO_2 and powder dust (kg/ha·a)	Cutting cost of SO_2 and powder dust	$V_d=\sum\sum S_i \times A_{im} \times P_p$	Alternative cost method
Disease and pest control	Area of primary and secondary forest (ha)	Prevention cost per unit area	$V_p=S \times P_c$	Alternative cost method

4.1.1 Value of abandoned land

Provided that the average topsoil thickness of forestland is assumed to be 0.5m, so the abandoned land area is 480ha. The average net profit of per unit forestland for timber production per year is adopted as opportunity cost, which is 282.17 yuan/(ha·a) (appraising at the rate of 1990) according to the state′s official statistics (HOU, 1995), thus the value of avoided soil erosion is 135×10^3 yuan.

4.1.2 Value of reduced soil fertility loss

The amount of reduced soil organic matter, N, P, and K is 38 955t, 1728t, 720t and 4176t respectively according to the soil fertility status in the reserve. By taking the current average price of chemical fertilizer, which is 2549 yuan/t as the shadow price of soil fertility (synthetic N, P and K) (SEPA, 1998), the value of soil fertility loss reduced by forest of the reserve is 16.9×10^6 yuan according to Equation (3).

4.1.3 Value of reducing silt accretion and soil deposit

According to the rule of sand movement of major valleys in China, the amounts of silt accumulation, deposit and entering the sea are 24%, 33% and 37% respectively (China Water Conservancy Ministry,1992). The amount of reduced silt accumulation and deposit in reservoirs, rivers and lakes is 3.24×10^5t, equivalent to volume $5.40 \times 10^5 m^3$. In light of the costs for reservoir construction in China during 1988–1991, the average price for $1m^3$ of water storage capacity is estimated to be 0.67 yuan, based on whole year′s costs of new investment for reservoirs′ construction divided by whole newly increased storage capacity (SEPA, 1998). By adjusting the price according to the GDP of 1990 and 2000, the alternative cost can be estimated at 3.2 yuan for $1m^3$. Since reservoir is a long-run project and the longevity of reservoir is assumed to be 20 years, the average price for $1m^3$ of water capacity is 0.16 yuan. So, the economic value of silt accumulation reduction is 86×10^3 yuan according to Equation (4).

Consequently, total economic value of soil protection in Yaoluoping National Nature Reserve is 17.1×10^6 yuan/a by summing up the above three kinds of values.

4.2 Value of Water Conservancy

According to the surveying records of Yaoluoping National Nature Reserve of the past 10 years, average annual runoff is 1004mm in the reserve. So, there are about $1.24\times10^8 m^3$ of water conserved by the forest per annum. Taking 0.16 yuan/m^3 as the shadow price of water, the value of water conservancy in the reserve is 19.8×10^6 yuan/a according to Equation (6).

4.3 Value of CO_2 Fixation

The price of CO_2 storage in this study is decided by alternative cost of afforestation cost. Chinese afforestation cost of carbon is 273.3 yuan/t (ZHOU and LI, 2000). Annual average stock volume growth per unit area of different kinds of forest is shown in Table 2. The data are acquired by the management committee of the reserve through sampling investigation in the 1990s. According to Equation (7), the value of CO_2 storage by the reserve is 1.91×10^6 yuan/a.

4.4 Value of Nutrient Cycling

The total net nutrient amount yearly maintained in the standing wildwood forests is 49.6kg/(ha·a) according to the study of CHEN Bu-feng *et al.* of in Jianfengling of Hainan Province(CHEN *et al.*, 1997), and the total net nutrient amount yearly maintained in the standing broad-leaved forests and coniferous forests is 49.6 kg/(ha·a) and 155.47kg/(ha·a) respectively according to the study of XU Guang-shan *et al.* in the Changbaishan Mountains (XU *et al.*, 1995). Due to lack of on-site study of nutrient maintenance and recycling in Yaoluoping, we take the average outcome of the above two studies as the total net nutrient amount yearly maintained in the standing forests in the reserve, so the total amount of maintained nutrient (N, P and K) of broad-leaved forests and coniferous forests is 247.16t/a and 455.08 t/a respectively according to the data from the reserve′s research work. By multiplied an alternative synthetic price(2549 yuan/t) of fertilizer, the total value amounts to 1.79×10^7 yuan/a.

4.5 Value of Pollutant Decomposition

The study estimates the values of forest absorption of pollutant SO_2 and powder dust. On the basis of China Biodiversity Country Study (SEPA, 1998), absorption capacity to SO_2 is 88.65kg/(ha·a) for broad-leaved forests and 215.60kg/(ha·a) for coniferous forests. The alternative price is 600 yuan/t (SO_2), which is based on the cost of engineering control to SO_2 in China (SEPA, 1998). The area of broad-leaved and coniferous forests is 6032ha and 5472ha respectively, so the value of SO_2 absorption is 1.79×10^6 yuan/a.

Table 2 Average annual stock volume increment of all species in Yaoluoping Nature Reserve

	Evergreen broad-leaved forest	Evergreen and deciduous broad-leaved forest	Deciduous broad-leaved forest	Broad-leaved forest mixed with coniferous forest	Coniferous forest
Average stock growth(m^3/ha·a)	1.9	1.7	1.8	2.5	2.7
Forest area(ha)	8.3	335	4284	3220	2812

Absorption capacity to powder dust is 10.11t/ha for broad-leaved forests and 33.2t/ha for coniferous forests on the basis of China Biodiversity Country Study (SEPA,1998). By multiplying the forest area, total amount of dust decomposition is 210 624.7t. The alternative price is 170 yuan/t (powder dust) based on the cost of engineering control to powder dust in China (SEPA, 1998). So, the value of dust decomposition is 43.4×10^6 yuan/a.

Consequently, value of pollutant decomposition is 4.52×10^7 yuan/a by summing up the above two kinds of values.

4.6 Value of Disease and Pest Control

The control cost of diseases and pests is 3.57 yuan/ha on the basis of the whole cost to control 70% of forest diseases, pests and mice by chemical application in 1995 in China (ZHOU and LI, 2000), so this kind of value is 39.3×10^3 yuan/a by Equation (10).

4.7 Total Indirect Use Value of Forest Ecosystem

Total indirect use value is the sum of aforementioned six kinds of values of ecological functions and services provided by the reserve, namely 85.8×10^6yuan/a (Table 3).

Table 3 The indirect use values of forest biodiversity of Yaoluoping National Nature Reserve

	Value (×10^6yuan/a)
Soil protection	17.10
Water conservancy	19.80
CO_2 fixation	1.91
Nutrient cycling	1.79
Pollutant decomposition	45.20
Disease and pest control	39.30
Total	85.80

5 DISCUSSION

Monetary form is the best way to evaluate the ecological functions of forest biodiversity and to facilitate comparison among different kinds of ecosystems. By using the alternative cost method, we can lay a price on the ecological functions of forest ecosystem. The unit price of ecological functions of Yaoluoping Nature Reserve is valued at 0.78×10^6 yuan/(ha·a), which is less than that of Changbaishan Mountains Reserve (1.04×10^6 yuan/(ha·a)), according to the study of XUE *et al.* in Changbaishan Mountains Biosphere Reserve in Northeast China (XUE and TISDELL, 2001). The result shows that the value of ecological functions of coniferous forest is higher than that of broad-leaved forest excluding the difference from the process of data collection.

As to valuing methods, the alternative cost method and the opportunity cost method used in this study display some limitations. For example, to use alternative′s price as shadow price of ecological functions is subject to underestimating the value because the market price is lower than willingness to pay (WTP). Furthermore, WTP is inclined to being less than the real indirect use value of biodiversity depending on the stages of social economic development and the public′s understanding of ecological functions and services. Anyway the alternative cost method is a relatively proper one, though much improvement in economic assessment methods for biodiversity and protected areas is required. For instance, how to choose quantifying and pricing indexes to make the valuation more appropriate on condition that ecological functions are dynamic and uncertain. Apart from the six ecological functions involved in the study, forest biodiversity provides many other ecological functions and services. These functions include soil organic matter for animals, plants and micro-organisms; climate regulation function; flood regulation; water quality improvement and pollination etc. However, it is quite difficult to quantify all the ecological functions and services in monetary form, their values are ignored in this study. All such kind of factors tends to underestimate the indirect use values of forest. On the other hand, there are some factors subject to overestimating the values. For instance, land used for timber production will still continue to supply some of the ecological functions of protected areas even if in diminished measure, e.g. water conservancy, control of soil erosion etc.(TISDELL 1999), but the former outbalances the latter to some extent, so the result of the study is only a lower number of the real one.

In a word, though ecological functions are very diverse and very difficult to be valued sometimes because of lack of suitable available methodologies and data, the valuation in monetary terms of ecological functions which is abstract to the public can help them to recognize and understand the significance of indirect use values of biodiversity and facilitate them to participate in the conservation and sustainable use of forest biodiversity. Also though it still remains many issues to be resolved, the method proves to be effective and practicable.

6 CONCLUSION

The result of the study indicates that the economic value of ecological functions and services provided by forest ecosystem of Yaoluoping National Nature Reserve amounts to at least 85.8×10^6yuan/a and make significant economic contribution to the well-being of the people and society, while the opportunity cost for normal timber production in the reserve is 3.47×10^6yuan if the average net profit of 282.17 yuan/(ha·a) for timber production in China is used for this estimation. Thus, the indirect economic value of the forest is 25 times higher than its value for regular timber production, excluding other kinds of values of forest biodiversity such as non-use values and justifying public financial support for conservation of biodiversity in the reserve. We attempt to establish evaluating models on the basis of alternative cost method and opportunity cost method to simplify and standardize the valuation framework to some extent in this study.

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