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Valuing ecological functions of biodiversity in Changbaishan Mountain Biosphere Reserve in Northeast China

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Abstract. Conservation of biodiversity can generate considerable indirect economic value and this is being increasingly recognized in China. For a forest ecosystem type of a nature reserve, the most important of its values are its ecological functions which provide human beings and other living things with beneficial environmental services. These services include water conservancy, soil protection, CO_2 fixation and O_2 release, nutrient cycling, pollutant decomposition, and disease and pest control. Based on a case study in Changbaishan Mountain Biosphere Reserve in Northeast China, this paper provides a monetary valuation of these services by using opportunity cost and alternative cost methods. Using such an approach, this reserve is valued at 510.11 million yuan (USD 61.68 mill.) per year, 10 times higher than the opportunity cost (51.78 mill. yuan/ha.a) for regular timber production. While China has heeded United Nations Environmental Program (UNEP)'s call for economic evaluation of ecological functions, the assessment techniques used need to be improved in China and in the West for reasons mentioned.

Key words: biodiversity, biosphere reserve, Changbaishan, China, ecological function, economic valuation

Introduction

Valuation of environmental goods has become an important issue in the fields of environmental protection and sustainable development. The values of natural resources have not been incorporated into the national economic accounting systems in many countries, and many of the environmental benefits of natural resources are not marketed and therefore do not command a market price. This encourages over exploitation of natural resources, results in the irreversible depletion of some resources, and increases the risk of malfunctioning of ecological systems. An under valuation problem exists. To reform national accounting systems and to develop a system of valuing natural resources has now attracted worldwide attention. UNEP called for all the Parties to the Convention on Biological Diversity to conduct country studies with emphasis on economic valuation of biodiversity (UNEP 1993), in order to show policy-makers and public the significance of biodiversity conservation and ecosystem functions.

China has a particular need to develop a sound national accounting system involving in natural resources valuation because of major environmental pressures in the country, its large population and relatively limited natural resources (cf. Tisdell 1999, Ch. 9). Chinese government has given increasing attention to valuation policy research since 1990s. They established some small study projects, which introduced many methodologies currently used in Western countries, such as the alternative cost method, opportunity cost method and travel cost method (SSTC 1995). China's Agenda 21, in its chapter four, specially proposed to establish a comprehensive national accounting system inclusive of environment and natural resources (SPC 1994). In addition, a country study on China's biodiversity was conducted during 1995–1997, funded by GEF/UNEP, with a focus on biodiversity valuation (SEPA 1998). However, this was only a 'pilot' research project in China and more detailed case studies and improved analysis are needed to develop a sound valuation system for natural resources in China. This paper uses valuation methods similar to those used in SEPA (1998, Ch. 5) to estimate the ecological functions of Changbaishan Mountain Biosphere Reserve (CMBR) and notes some limitations of those methods.

Ecological services generated by conservation of preserved natural environments are beneficial to human beings and society. From an anthropocentric perspective, biodiversity helps to supply human beings with an array of free ecosystem services, without which civilization could not survive. Ehrlich divides biodiversity values into four categories: ethical, aesthetic, direct and indirect, and considers that indirect value is the most important of these values of biodiversity (Ehrlich and Ehrlich 1992). Pearce and Moran defines biodiversity values as direct, indirect, option, bequest and existence (Pearce and Moran 1994). McNeely describe the indirect values as involving three aspects: (1) ensuring ecosystem succession and bio-evolution; (2) maintaining ecosystem structures and functions; (3) providing the ecological services of ecosystems (McNeely et al. 1990). So ecological services are an important component of biodiversity's indirect values.

Generally, ecological benefits can not 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, though it had better be valued at a base of willingness to pay of the community in some cases. Many studies have been conducted, especially in western countries. For example, Adger et al. (1995) made a study on indirect value of forests in Mexico. Using alternative cost method, the study estimated the indirect values of the forests in carbon storage and watershed protection. The results indicated an annual lower bound value of Mexico's forests to be in the order of USD 4 billion (Adger et al. 1995). Costanza et al. (1997) using alternative market and non-market ways, 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 is estimated to be in the range of USD 16–54 trillion (10^{12}) per year, with an average of USD 33 trillion per year (Costanza et al. 1997). Based on alternative cost approaches, case studies to value opportunity costs were conducted worldwide, such as opportunity cost of protected areas in Uganda, opportunity costs of alternative forestry practices in Nepal, opportunity cost of a Fijian mangrove (WCPA/IUCN 1998). By using alternative cost method, Gupta and Foster measured the wetland's benefits of four groups in wildlife production, visual-cultural benefits (i.e., recreational, educational and aesthetic benefits), water supply and flood control potential (Gupta and Foster 1975). Following the western valuation methodologies, China biodiversity country study estimated the total annual ecological values of biodiversity in the country amounts to USD 1.69 trillion per annum (SEPA 1998). The country study report was officially launched by Chinese government in 1998, and some methodologies and parameters in this country study are used in this paper.

This paper assesses the value of the ecological services of a forest ecosystem, namely that of CMBR located in Northeast China, a border area to North Korea. Changbaishan Reserve, established in 1960, was one of the first group reserves in China, and it was accepted into the World Biosphere Reserve Network in 1980 for its outstanding forest ecosystem of international significance for scientific research, cultural heritage and recreational values. It is a strict reserve in terms of IUCN categories, and is rich in biodiversity, with a rare forest ecosystem, uncommon wild animals and plants. The whole area of the reserve is 1 96 465 ha, of which 1 67 081 ha is forested. The forests are mostly primary and have obvious diverse vegetation as the altitude changes. As a forest ecosystem, the ecological functions of the reserve are mainly displayed in: water conservancy; soil-erosion prevention; wild animals and plants conservation; CO_2 fixation and O_2 release; pollutant decomposition; disease and pest control; nutrient cycle and maintenance; climate regulation (Figure 1).

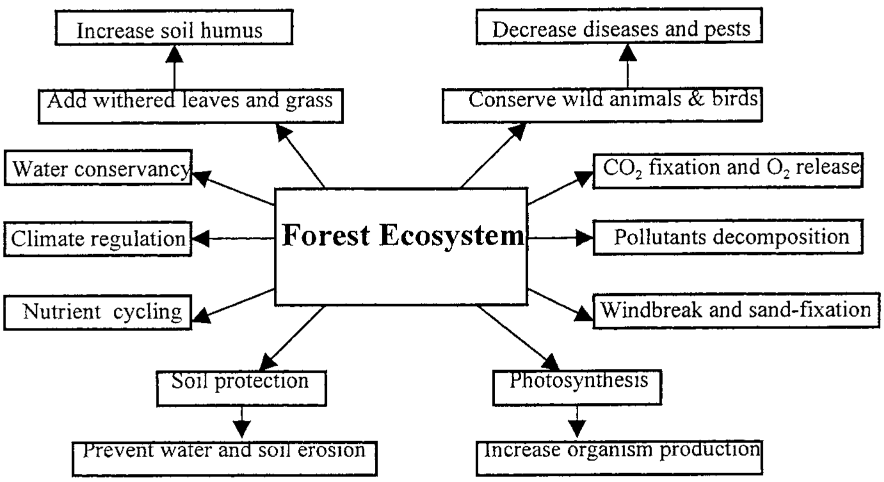

Figure 1. Diagram indicating the ecological benefits of forest ecosystem.

Valuation methods for the ecological services in CMBR

In light of actual situation in CMBR and using available methodology, five ecological services are considered in this paper. The definitions of each service and the method of estimating the economic value of each are as follows:

Water conservancy

Forest canopy and grass under trees can slow down runoff of precipitation, and forest soil, because of its good permeability, can foster infiltration of rainwater to groundwater. This function of water conservancy is displayed in three ways: increasing the quantity of effective water available, improving water quality and reducing water runoff. Due to the forests, 86% of water precipitation percolates as groundwater and only 14% flows away as surface runoff in the reserve area (Pei 1995). The value for the water conservancy of forest can be estimated by the total annual amount of conserved water multiplied by the altered price of per unit water. The former is roughly equal to the difference between the total precipitation and total evaporation, i.e.

$$P = R + E \Rightarrow R = P - E$$

where P is the annual average precipitation in the area, R the annual average runoff water from the area (water conservancy of forest) and E the annual average evaporation of the area.

Soil protection

The ecological function of soil protection is reflected in a decrease in soil erosion. Soil conservation results in a reduction of silt in rivers, lakes and reservoirs and a reduction of fertility loss that accompanies soil erosion. In this paper, the functional value of soil protection is estimated by the economic loss arising from soil loss and fertility loss if erosion occurs.

The total amount of soil loss can be estimated by the erosion difference between woody land and non-woody land. Based on experiments, Japanese researcher find that the erosion difference in volcanic rocky soil is 0.01:10.0 mm/a between woody land and non-woody land and in volcanic ash soil is 0.10:50 mm/a (Chen 1994). As Changbaishan Mountain has both volcanic rocky and volcanic ash soil and has a similar latitude with Japan, an average difference of 30 mm/a is taken as the parameter in this study. The total amount of soil loss equals to the parameter multiplied by the total forest area of the reserve. In other words, this amount is a reduction of erosion because the forest exists in the reserve. It is a benefit of the forest ecosystem.

Furthermore, the abandoned land area can be deduced from the soil loss amount and land area, and then the monetary loss for abandoned land can be calculated by taking account of the opportunity production cost.

CO_2 fixation

The main chemical flow between forest and atmosphere is the exchange of CO_2 and O_2 by a process of photosynthesis. Forests provide a vast bank for CO_2 and a huge amount of CO_2 is deposited in its timber. This cuts down the CO_2 concentration in atmosphere and plays an essential role in maintaining a dynamic balance between CO_2 and O_2 in atmosphere. Reducing CO_2 is an obligation for the Parties to implement the UN Climate Change Framework Convention. So CO_2 fixation has an obvious indirect economic value that can be estimated by taking account alternative methods of fixing CO_2.

At first, the CO_2 amount absorbed to produce 1 g dry organism matter can be calculated on the basis of the photosynthesis equation. Then the total annual amount of the dry organic matter of the reserve's forests can be estimated in line with the annual net production amounts of various standing forests. It provides a foundation for reckoning the total amount of CO_2 fixation by the forests in the reserve. Further, the economic value of CO_2 fixation can be estimated by the total fixed CO_2 amount multiplied by a standard opportunity cost for per unit CO_2 fixation.

The amount of CO_2 storage
According to photosynthesis equation, to produce 180 g glucose and 193 g O_2, plant will absorb 264 g CO_2 and 108 g water and consume 6772 calorie of solar energy. Then 180 g glucose can be transformed to 162 g polysaccharide inside of plant. Therefore, whenever plant produces 162 g dry organic matter, 264 g CO_2 will be fixed, i.e. production of every 1 g dry organic matter can fix 1.63 g CO_2.

$$\begin{aligned} &CO_2\,(264\,\text{g}) + H_2O\,(108\,\text{g}) \\ &\xrightarrow{\text{6772 calorie solar energy}} \text{Glucose}\,(180\,\text{g}) + O_2\,(193\,\text{g}) \\ &\longrightarrow \text{Polysaccharide}\,(162\,\text{g}) \end{aligned}$$

The alternative price of fixed CO_2 amount
Two alternative methods are used to estimate the price (cost) of CO_2 storage.

Carbon tax method. Many countries have established or are developing a carbon tax system to reduce emissions of the greenhouse gases, especially to cut down CO_2 and CO in atmosphere. In 1991, Norway established carbon tax system to manage automobile emission and the charge was 172 USD/t (C). It was adjusted to 227 USD/t (C) in 1992. The charge of carbon tax in Sweden is about 150 USD/t (C). However, carbon tax method is more commonly used in European countries, especially for Scandinavia countries, where they are designed to achieve some predetermined emissions reduction target, rather than in China.

Afforestation cost method. Afforestation is an effective measure to prevent global warming. In 1990, President Bush proposed to plant 1 billion trees per year to absorb 16.38 million t (C), 5% of the total amount of CO_2 emission one year in the United States. The plantation will cost 545 million USD per year, i.e. 33.27 USD/t (C) (Bateman 1992). The FAO (1989) estimated that the cost of carbon fixation by afforesting tropical forests will be 13–17 billion USD/year, equal to 24–31 USD/t (C). Titus estimates that if an amount of 19.1 billion USD is invested to afforest in tropical area within the next 32–46 years, the forests will almost absorb all the CO_2 emitted from industrial sources. The afforestation cost is 38 USD/t (C) (Titus 1992). Furthermore, Myers (1990) proposes that under the condition of 10 t (C)/(ha.a) fixed by tropical forests, it is needed to afforest 300 million ha forests and it costs 130 USD/ha. In light of afforestation cost in China during 1989–1993, the production cost is 125.7 yuan (Chinese currency, 1 USD = 8.27 yuan, same hereinafter)/m^3 (only trunk) (Chen 1994). It will be 62.85 yuan/m^3 for all produced dry organic matter, assuming that the trunk makes up 50% all dry organic matter and branch and root take another 50%. Based on the photosynthesis equation and an average timber gravity of 0.57 t/m^3, the price of CO_2 fixation is 68.32 yuan/m^3 [62.85 (yuan/m^3)/0.92 t (CO_2)/m^3], and further it is 250 yuan (USD30.0)/t C. This figure can be used as an alternative price to estimate the value of CO_2 storage in China.

Nutrient cycling

A tree absorbs mineral nutrients form soil as it grows, and accumulates the nutrients in its body. As seasons change, some accumulated nutrients will return to soil in withered branches and leaves, and the remains are conserved in the stems and roots as a net maintained amount. 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, i.e.

$$\begin{aligned}\text{Total conserved amount} &= \text{whole accumulated amount}\\ &\quad - \text{returned amount by withering}\end{aligned}$$

The value of total nutrient accumulation is

$$\sum_{i=1}^{n} A_i M_i P = \sum_{i=1}^{n} A_i (\mathrm{N}_i + \mathrm{P}_i + \mathrm{K}i) P$$

where A is the area of each standing forest, P the price of synthetic nutrients (N, P and K), M net amount of maintained nutrients and i the types of standing forests (roughly divided into two types in this study).

Fertility loss of nutrient N, P and K can be valued by market price of fertilizer. In light of statistics data, the current average fertilizer price (synthetic N, P and K) in China is 2549 yuan/t (SEPA 1998).

Pollutant decomposition and disease and pest control

Forests absorb SO_2, HF, Cl_2 and other harmful gases. They play a function of decomposing the pollutants arising from industrial areas, for many trees can absorb and decompose these harmful substances via plant's special organs and physiological functions. Only SO_2 purification is considered in the paper for the pollutant decomposition functions, and it is valued by an average absorption amount per unit forest times a standard alternative cost.

This nature reserve provides animals and other species with a natural environment and ensures sound ecological processes in the ecosystem. There are nearly no plant diseases and insect pests in the primary forests because of their natural enemies' control. This ecological function is also valued by an alternative cost for chemical control based on the state statistical data.

Summary of total value of ecological functions and methods used

Total economic value is the sum of all ecological economic values. Ecological functions are summarized in Table 1, along with valuation methods used. The methods are along similar lines to those used in SEPA (1998). Now consider the economic calculations.

Calculation of ecological function's value

Value of water conservancy

According to the records for many years from the three hydrometric stations distributed in different altitudes (foot, slopes and top) of the mountain, an average

Table 1. Categories of ecological functions and their valuation methods.

Function category	Function indicator	Valuation methods	Calculation path
Water conservancy	Reducing surface runoff	Alternative cost	Water amount × actual cost of reservoir's construction
Soil protection	Controlling erosion	Opportunity cost	Avoided eroding land area × opportunity production per unit area
CO_2 fixation	Reducing green-house effect	Production cost	Amount of fixed CO_2 × afforestation cost
Nutrient cycling	Accumulating nutrients	Alternative cost and market price	Maintained nutrient amount × market price of fertilizer
Pollutant absorption	Absorbing SO_2	Alternative cost	SO_2 amount × engineering control cost
Disease and pest control	Avoiding diseases and pests	Alternative cost	Forest area × chemical control cost

precipitation of 958 mm/a occurs in cmBR. Experiments (Fan et al. 1992) indicate that the evaporation in the area is 335 mm/a, making up 35% total precipitation, and the remains are 623 mm/a for runoff water conserved by the forests. Furthermore, in light of the costs for reservoir construction in China during 1988–1991, the average price for 1 m^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). But, the price should be adjusted though it is an official statistics figure because of the outdated data. The price is that in the early 1990s and it is much higher now because the costs of labor and materials are increased greatly, e.g. labor cost in 1999 is five times the level in 1990, and prices of building materials rose by to over 100% during the same period. Also, the operational costs for reservoirs' maintenance should be added to the cost, which is a very big expense in China for current years because of frequent flood disasters. So, the alternative cost of both construction and maintenance can be estimated to 3.00 yuan for 1 m^3 water. However, reservoir is a long-run project and the longevity of reservoir should be taken into account. Assuming that average length of life of the reservoirs is 20 years, the average price for 1 $m^3$of water storage capacity will be 3.00 yuan divided by 20 years and it will be 0.15 yuan for one unit water. Thus,

$$
\begin{aligned}
&\text{The conserved water amount of the reserve}\\
&\quad = \text{runoff water/a} \times \text{forest area of the reserve}\\
&\quad = 623\ (\text{mm}) \times 1\,67\,081\ (\text{ha})\\
&\quad = 1040.91\ (\text{mill. m}^3)
\end{aligned}
$$

$$
\begin{aligned}
&\text{The value of water conservancy}\\
&\quad = \text{conserved water amount} \times \text{alternative cost/m}^3(\text{water})\\
&\quad = 1040.91\ (\text{mill. m}^3) \times 0.15\ (\text{yuan/m}^3)\\
&\quad = 156.14\ (\text{mill. yuan})
\end{aligned}
$$

Note that this calculation does not take account of the discount rate. If a positive discount rate is allowed, the estimate would be higher.

Value of soil protection

Total amount of soil loss

At first, the total amount of soil loss under a non-forest condition can be reckoned as follows:

$$
\begin{aligned}
\text{Total amount} \ &= \ \text{erosion difference between forest land and non-forest land}\\
&\quad \times \text{forest area of the reserve}\\
&= \ 30\ (\text{mm/a}) \times 1\,67\,081\ (\text{ha}) = 50.12\ (\text{mill. m}^3/\text{a})
\end{aligned}
$$

Opportunity value of abandoned land

Assuming an average surface soil thickness of woody land is 0.6 m, the abandoned land area is equal to the total eroded soil amount divided by 0.6 m, the average soil thickness. Furthermore, the opportunity cost can be estimated by the average net profit of per unit forestry land for timber production per year, which is 263.58 yuan/ha.a according to the state's official statistics (SEPA 1998).

$$\text{The abandoned land area/a} = \frac{\text{total amount of soil loss/a}}{\text{average soil thickness (m)}} = \frac{50.12\,(\text{mill. m}^3/\text{a})}{0.6\,(\text{m})} = 8354.05\,(\text{ha/a})$$

$$\begin{aligned}&\text{The value of avoided soil erosion}\\ &\quad = \text{estimated abandoned land area} \times \text{opportunity production profit}\\ &\quad = 8354.05 \times 263.58\,(\text{yuan/ha.a})\\ &\quad = 2.20\,(\text{mill. yuan/a})\end{aligned}$$

This, however, assumes that the 'abandoned' land would produce nothing of economic value, but this may not be so. So this could somewhat overstate the economic cost of soil loss.

Value of CO_2 fixation

The method used to value CO_2 storage in this study is alternative cost for afforestation cost. In the light of Chinese afforestation cost, the figure of 250 yuan/t C is employed. The calculation approach for CO_2 storage value is firstly to estimate the biomass production by biomass growth standards of various vegetation types. Then the total amount of CO_2 storage is calculated, based on that production of every 1 g dry organic matter can fix 1.63 g CO_2 as the photosynthesis equation shows. The result is 292.53 (mill. yuan/a) (Table 2), which presents the value of CO_2 storage by the forests in CMBR.

Value of nutrient cycling

To facilitate calculation, the vegetation in CMBR is roughly divided into two main types: mixed Korean pine and broad-leaved species, and mixed Korean pine and fir and spruce. Based on the experimental results on nutrient amount maintained in the two types of standing forests (Xu et al. 1995a, b), the total amount of maintained nutrients (N, P and K) in CMBR forest is up to 17021.9 t/a, and by multiplied an alternative synthetic price (2549 yuan/t) of fertilizer, the total value amounts to 43.39 (mill. yuan/a) (Table 3).

Table 2. CO_2 fixation and its economic value in CMBR.

Vegetation	Biomass growth standard[a] [t/(ha.a)]	Forest area[b] (ha)	Biomass production (t/a)	Amount[c] of CO_2 storage (t/a)	Convert[d] to pure carbon (t/a)	Value of CO_2 storage (mill. yuan.a)
Broad-leaved and Korean pine	20.19	65 836.0	13 29 229	21 66 643	5 91 323	147.83
Fir and spruce	13.45	80 295.9	10 79 979	17 60 366	4 80 442	120.11
Sub-alpine dwarf Ermans birch	5.15	6018.6	30 996	50 523	13 789	3.45
Alpine shrub	2.38	392.9	935	1524	416	0.10
Larch	9.50	9523.2	90 470	1 47 467	40 247	10.06
White birch and Poplar	14.19	7591.0	1 07 716	1 75 578	47 919	11.98
Total		1 69 658	26 39 326	43 02 101	11 74 135	292.53

[a] The growth standard is based on the experiments of Li et al. (1981), and it is dry organism.
[b] The forest area is in line with the data of Chinese Academy of Sciences, a little difference with that of CMBR Administrative Office.
[c] The amount of CO_2 fixation/a = plant's biomass production amount/a $\times$ 1.63.
[d] The pure carbon amount = fixed CO_2 amount $\times$ 0.2729 (atomic weight C/CO_2 = 0.2729).

Table 3. Nutrient maintenance and its economic value in CMBR.

Type of standing forests	Areas (ha)	Maintained net amount (t/a) N	P	K	Total amount (t/a)	Total value (mill. yuan/a)
Mixed Korean pine and broadleaved spp.	88 969	2952.9	293.6	1291.8	4538.3	11.57
Mixed Korean pine and fir and spruce	80 296	7868.2	990.0	3625.4	12 483.6	31.82
Total	1 69 265	10 821.1	1283.6	4917.2	17 021.9	43.39

Values of pollutant decomposition and disease and pest control

Value of pollutant decomposition

In the light of China Biodiversity Country Study (SEPA 1998), an absorption capacity to SO_2 is 88.65 kg/(ha.a) for broad-leaved forests and 215.60 kg/(ha.a) for coniferous forests, with an average capacity for both is 152.13 kg/(ha.a). 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). So,

$$\begin{aligned}\text{The value} = &\ \text{forest area in reserve} \times SO_2 \text{ absorption amount per unit}\\ &\times SO_2 \text{ control cost per unit}\end{aligned}$$

$$= 1\,67\,081\,(\text{ha}) \times 152.13\,[\text{kg/(ha.a)}] \times 600\,(\text{yuan/t})$$
$$= 15.25\,(\text{mill. yuan/a})$$

Value of diseases and pests control

The statistical data from Ministry of Forestry (MOF 1996) shows that the whole cost to control forest diseases, pests and mice by chemical application in 1995 in China is 334.09 (mill. yuan). Assuming 70% of whole forests (i.e. 93.59 mill. ha in 1995) needs artificial control, the control cost is 3.57 yuan/ha. This control cost was used to estimate the value of these ecological functions in the reserve, i.e.

$$\begin{aligned}\text{The value} &= \text{per unit control cost} \times \text{whole forest area of the reserve}\\ &= 3.57\,\text{yuan/ha} \times 1\,67\,081\,(\text{ha})\\ &= 0.60\,(\text{mill. yuan/a})\end{aligned}$$

The total value for pollutant decomposition and pest control

$$\text{The total value} = 15.25 + 0.6 = 15.85\,(\text{mill. yuan/a})$$

The total value of ecological functions in CMBR

$$\begin{aligned}\text{Total value} &= \text{value of water conservancy} + \text{value of soil protection}\\ &\quad + \text{value of } CO_2 \text{ fixation} + \text{value of nutrient maintenance}\\ &\quad + \text{value of pollutant decomposition and pest control}\\ &= 156.14 + 2.20 + 292.53 + 43.39 + 15.85\\ &= 510.11\,(\text{mill. yuan/a})\ (\text{USD } 61.68\,\text{mill./a})\end{aligned}$$

Analysis and discussion

On value of O_2 release

A plant producing 1 g dry organic matter will absorb 1.63 CO_2, but in the meantime the plant releases 1.19 g O_2. Fresh O_2 can be directly used by human beings and animals, and it is beneficial to environment. Also O_2 has many commercial values and there is special industrial O_2 production. So some studies valued O_2 release too when they valued CO_2 fixation, based on an alternative price of industrial O_2 production (Chen 1994; SEPA 1998). However, the value of O_2 release is ignored in this study for the following two reasons. First, O_2 is an extra product because all alternative costs have already been put to CO_2 fixation. CO_2 fixation and O_2 release are joint products from one process and involve only one cost. It will double-count alternative cost if two values are calculated. Secondly, policy measures such as carbon tax and afforestation are mainly intended to cut down CO_2, and CO_2 reduction has an urgency and practical significance for global warming improvement. However, O_2 is not a rare substance and generally release of O_2 by plants has no practical economic significance.

On value of organic matter

Photosynthesis of plants can produce a great deal of organic matter, of which no more than 10% (like timber) can be directly used by human beings, and the rest is maintained in the ecosystem and decomposed by soil micro-organisms. Organic matter can provide many valuable ecological functions for animals, plants and micro-organisms. As they are very difficult to value in monetary form, the functions are ignored in this paper. This paper involves in valuation of nutrients, but the methodologies are very limited. At first, we did not cover the great loss of a huge loss of organic matter accompanied with soil erosion, even not involving the loss of N, P and K, because of lack of an alternative price. Secondly, the valuation of nutrient cycling only focused on three main elements (N, P and K), but ignored many other important elements like Ca, Mg and so on. Finally, the value of humus formed from withered leaves and grasses was also not dealt with.

On value of habitat for wild species

A forest provides a natural habitat for many mammals, birds, micro-organisms and plants, and ensures an environment for their growth, breeding and evolution. For some economic species, as its population is expanded, many products (medicine, meat, fur, fruit, nuts, honey and vegetables) can be provided to market and so produce a direct value. Birds are beneficial to farmlands surrounding the reserve by controlling pests and promote agricultural production. Also they have a special function to disseminate seeds and nuts of trees. Insects are helpful for pollination of plants and thus can enrich the genetic diversity in the system. Invertebrates and micro-organisms play an essential function in decomposing organic matters, thereby increasing soil fertility and promoting tree growth. Besides, wild animals and plants can attract eco-tourists. However, these ecological functions have been not valued in this paper.

On value of genetic diversity

Due to the reserve's establishment, the forest ecosystem obtains effective protection. This natural ecosystem ensures a normal energy flow among species and a sound substance cycling between biological communities and their environments. It helps maintain natural ecological processes of species' evolution and improve genetic stability and viability of bio-populations. Consequently genetic diversity is protected and enriched in the ecosystem. Genetic diversity can produce unforeseen economic benefits. For example, through genetic breeding, many fine tree varieties are developed with the properties of quick-growth, disease-resistant and high quality for timber. In CMBR, there exist more than 50 timber tree species and more than 800 medicinal plants. The reserve is in itself a precious gene bank. It will provide descendants with varied genetic materials for their sustainable utilization of biodiversity in the future. The bequest value is not covered in the paper.

On the value of climate regulation

The reserve's huge forest can exert a great influence on climatic factors such as temperature, precipitation, wind and so on of the surrounding areas. The improved micro-climate is beneficial to agricultural production by providing a wind-break, temperature regulation and water adjustment, especially helpful to reduce some disasters like frost and hail. It is also favorable to tourists and they usually like to spend their summer holidays in this forest area. However, It is difficult to quantify these kinds of ecological functions.

Overall evaluation

To sum up, ecological functions are very diverse but they are difficult to value sometimes because of lack of suitable available methodologies and data. In this paper, just a few ecological functions are evaluated, even though the methods used are not 'mature' and are with limitations. These valuation methods indicates that the value of the ecological services provided by the ecological functions of CMBR amounts to at least 510.11 million yuan per year, while the opportunity cost for normal timber production in CMBR would be of the order of 51.78 million yuan if the average net profit of 263.58 yuan/ha.a for timber production in the whole China (SEPA 1998) is used for this estimate. Thus, the ecological economic value of the reserve is 10 times higher than its value for regular timber production.

Concluding remarks

As this article indicates, China has heeded the admonitions of UNEP to undertake assessments of the economic value of the ecological functions of its protected areas. However, China's application of economic evaluation methods is still in its infancy. So far it has relied mainly, but not exclusively, on cost of replacement and opportunity cost methods, similar to those used by some Western scholars. It has been provided with aid both by UNEP and the World Bank for this purpose. While attention to economic evaluation methods in China's ecological context is admirable, the shortcomings of some of the methods must also be taken into account. For instance, the cost of replacement method for an ecological function will overstate the value of an ecological function if the willingness to pay for it is less than the cost of its replacement. Furthermore, when the opportunity cost method is used considerably care is needed to make sure that the appropriate alternative land-use is considered.

Moreover, in the latter respect it needs to be recognized that some forms of alternative land-use to protecting an area completely will still continue to supply similar ecological functions to those provided by a protected area, even if those functions are somewhat diminished. For instance, forested areas used for timber production will as a rule continue to supply some of the ecological functions of protected areas even if in diminished measure e.g. water conservancy, control of soil erosion (cf. Tisdell 1999, p. 6). Not to recognize this can overstate the comparative economic value of a protected area. The unfortunate fact is that very little effective economic evaluation of biodiversity conservation per se has been done either in Western countries or elsewhere. Much improvement in economic assessment methods for biodiversity and protected areas is required.

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