Forest ecosystem services of Changbai Mountain in China

WU Gang (吴 钢)[1], XIAO Han (肖 寒)[1], ZHAO Jingzhu (赵景柱)[1], SHAO Guofan (邵国凡)[2] & LI Jing (李 静)[1]

1. Department of Systems Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China;
2. Department of Forestry and Natural Resources, Purdue University, West Lafayette IN47907, U.S.A.

Correspondence should be addressed to Wu Gang (email: wug@mail.rcees.ac.cn)

Received March 13, 2001

Abstract The forest ecosystem of the Changbai Mountain is the most typical upland temperate forest ecosystem in eastern Asia. It is also of the most primitive vegetation type that came into being through the natural succession of soil and vegetation following volcanic eruption. The forest ecosystem has great importance for maintaining the structures and functions of the watershed ecosystems of the Songhua River, the Yalu River and the Tumen River. We combined physical assessment method (PAM) with the value assessment method (VAM) to evaluate the forest ecosystem services of the northern slope of the Changbai Mountain, including eco-tourism, forest by-products, timber, soil and water conservation, air purification, and the recycling of nutritive elements. We also assessed the integrated forest ecosystem service and analyzed its dynamics. The service value provided by the Changbai Mountain forest ecosystem amounts up to RMB 3.38×10^{12} yuan, of which, water conservation is 66%, water conservation and air purification together make up 80%, while the timber value is only 7%. Therefore, developing the ecosystem services besides timber is the best way to exert the integrated value of the forest ecosystem services of Changbai Mountain.

Keywords: ecosystem services, physical assessment, value assessment, Changbai Mountain forest ecosystem.

Forest ecosystem services refer to a wide range of conditions and processes through which forest ecosystems help sustain and fulfill human life[1, 2]. The dominant services of the forest ecosystems include cycling and movement of nutrients, maintenance of biodiversity, purification of air and water, maintenance of the balance and stability of atmospheric chemistry, and the provision of forest products[3, 4]. Due to the unilateral recognition of forest ecosystem services and its importance, people destructively exploited the forest ecosystems in the Industrial Revolution. So the area and quality of forest ecosystems decreased seriously. The services of forest ecosystems declined severely, even threatening people's security and health and restricting economic development[5]. In recent years, with some global and regional environmental problems, such as land deterioration, desertification, sand and dust storm, soil erosion, shortage of water resources, the warming trend of the global environment, the decrease of air quality, and the degradation of land and vegetation, researches on the services provided by forest ecosystems have been emphasized internationally. Forestry scientists have cooperated with botanists, ecologists, eco-economists and scientists in the relevant fields to comprehensively study the maintenance processes of forest eco-

systems and the increase of ecosystem services and economic values of ecosystems, to enrich forest ecosystem services, and to deeply discuss evaluation technology and evaluation methods[6]. Robert Costanza et al. presented an opinion that ecosystems and natural capital contribute to human welfare directly and indirectly. Their result from rough calculation is: the value of ecosystem services provided by the whole biosphere is US$ 16—54 trillion per year, with the average value of US$ 33 trillion per year, while gross national product (GNP) all over the world is only US$ 18 trillion per year[3]. The research by Pimemtel et al. reports that the sedimentation cost caused by deforestation leading to soil erosion is about US$ 6 billion throughout the world[6]. These researches provide macroscopic research methods for the evaluation of ecosystem services of global forests. However, quantitative methods should be applied to the evaluation of the services of typical regional forest ecosystem. This paper studies the services of the most typical, the most complete, and primitive forest ecosystem of Changbai Mountain in Northeast Asia. On the one hand, it provides technological methods to study the services of regional forest ecosystems, especially temperate forest ecosystems. On the other hand, it provides dynamic simulative methods for the services of forest ecosystems and also dynamically evaluates the services of forest ecosystems of Changbai Mountain.

1 Study area

Changbai Mountain is located near the boundary between China and North Korea, in the southeast of Jilin Province in the Northeast China. It is the headstream of the Songhua River, Yalu River, and Tumen River in the northeast area. Baiyun Peak, the highest peak in northeast Area, is 2691.0 m above the sea level (a.s.l.). Because of the special natural conditions, and historic and social accounts, Changbai Mountain has become one of the most completely conserved areas in China, even in the world, having the most typical mountain forest ecosystem in eastern Asia.

The climate of Changbai Mountain greatly changes with the altitude. It is the typical warm temperate climate at the foot of the mountain, while a complex subpolar climate on the top of the mountain. The mean annual temperature is about 2.8℃ at the foot (Changbai Mountain Weather Station, Chinese Academy of Sciences, 740 m a.s.l.) and about −7.3℃ on the top (Tianchi Weather Station, 2623.5 m a.s.l.). The annual and daily ranges of temperature are great. Its frost-free period is short, and freeze-up is long. It is an obvious continental climate[7].

The precipitation of Changbai Mountain area is one of the greatest to the north of Yangtze River. It is flush and increases with the rising altitude. The average annual precipitation is 600—900 mm at the foot, and 1340 mm on the top, even up to 1809 mm. The annual days of snow are 130—150 at the foot, and 257 on the top. The average annual relative humidity is about 70%.

Because of the different hydrothermal conditions and topography, vertical zonality of soil on the northern slope of Changbai Mountain is obvious. From the top to the foot: alpine tundra soil (over 2000 m a.s.l.), upland plaggudent forest soil (1800—2000 m a.s.l.), upland brown conifer

forest soil (1000—1800 m a.s.l.), upland auburn forest soil (below 1100 m a.s.l.) (Forest Ecosystem Orientation Research Station of Changbai Mountain, Chinese Academy of Sciences, 1981).

The flora of Changbai Mountain is complex. The biodiversity in this area is the most abundant among areas along the same latitude in the Northern Hemisphere. Changbai Mountain, with a complete forest ecosystem and obvious vertical belts of vegetation, with the only complete alpine tundra in the Far East, is the typical area in Eurasia, especially in northeast Asia[7]. The floristic belts along the altitudinal gradient have a great diversity at all levels (genetic diversity, species diversity, ecosystem diversity). Conifer and deciduous (below 1100 m a.s.l.) at the foot of Changbai Mountain is the only primitive coniferous-latifoliate mixed forest of great area in the world. Compared with Euro-American areas at the same latitude, this forest is famous for complex structure, peculiar composition and abundant biodiversity. Dark coniferous forest (1100 m—1800 m a.s.l.) whose constructive species are *Picea koraiensis* and *P. jezoensis*, the dominant vegetation of the northern slope of Changbai Mountain, has the typical characteristics of the northern upland forests. Subalpine *Betula ermanii* forests (1800 m—2000 m a.s.l), which constitute the peculiar forest landscape of subalpine belts, are the forest-line vegetation dominated by single arboreal tree species[8]. Alpine tundra of Changbai Mountain (2000 m—2600 m a.s.l.) is the unique typical vegetation with the characteristics of arctic tundra. This research mainly concentrates on forest ecosystems on the northern slope of Changbai Mountain from 700 m to 1900 m. This slope demonstrates the vertical distribution of the climate, topography and vegetation of Changbai Mountain[9].

2 Research methods

Forests are renewable resources. Forest ecosystems, whose services dynamically change with resource quantity, are the dynamic pool of these resources. This paper dynamically assesses the ecosystem service value and forest goods value provided by the Changbai Mountain forest.

2.1 Forest ecosystem services

2.1.1 Forest eco-tourism. Eco-tourism services of Changbai mountain have four beauty spots, i.e. Tianchi, alpine tundra, forest ecosystems, and natural museum. We investigated tourists at different consuming levels to give their weightings, and then calculated tourism values according to traveling expense, value of traveling time, consumer surplus and other consumption.

$$P_a(t) = TV(t) + P_b(t) + \int_0^{P_m} y(x)\mathrm{d}x(t) \ , \tag{1}$$

where P_a is value of eco-tourism services of forest ecosystem; TV, travel expense; P_b, value of traveling time; P_m, maximum expense; $y(x)$, functional relationship between expense and traveling person-time; t, year (1990, …, 1999).

2.1.2 Water conservation. This paper adopts the water quantity balance method[3] to calculate conserved water quantity and its value provided by forest and forest soil ecosystems of

Changbai Mountain (Field research was made from May 1998 to August 1999). Here soil filter loss is not considered . The main reason is that the soil filter loss of Changbai Mountain ecosystems is little because the slope grade is small and the forest soil humus is thick.

$$R(t) = \left(P(t) - \sum_l (R_i(t) + E_i(t)) S_i(t) \right) \times WP(t) \ , \tag{2}$$

where R is value of water conservation by forest and forest soil ecosystems of Changbai Mountain; P, annual precipitation; R_i, annual runoff per unit area of the ith type forest crop; E_i, annual average evaporation capacity per unit area of the ith type forest crop; S_i, area of the ith type forest crop; WP, water price per unit volume.

2.1.3 Soil conservation. The value of soil conservation service is represented by economic value of nutrient loss (N, P, K, organic matter) and ruined area caused by soil erosion under conditions without vegetation.

$$P_{\mathrm{s}}(t) = \sum_j S_i(t) P_{sj}(t) + \sum_k N_k P_k(t) \ , \tag{3}$$

where P_{s} is value of soil conservation; S_j, area of the jth type soil; P_{sj}, value of recovering soil erosion per unit area of the jth type soil; N_k, loss of the kth type nutrient element per unit area; P_k, price of per unit weight of the kth type nutrient.

2.1.4 Air purification. This paper mainly evaluates the CO_2 fixation service provided by the forest ecosystem of Changbai Mountain. Forest ecosystem is a complex ecosystem, which includes the photosynthesis and respiration of plants, the respiration of fallen layer and soil. The value of CO_2 fixed by forest ecosystem is reckoned by carbon taxation method.

$$Q(t) = A(t) - R_{\mathrm{d}}(t) - R_{\mathrm{s}}(t) \ , \tag{4}$$

where Q is CO_2 quantity fixed by forest ecosystem; A, CO_2 quantity assimilated by net primary productivity; R_{d}, CO_2 quantity released by the respiration of fallen layer; R_{s}, CO_2 quantity released by soil respiration.

2.1.5 Nutrient element cycling. During the growth process, forest ecosystems absorb nutrient elements from the surrounding environment, which are fixed in the plant body. Some of these nutrient elements are returned to the soil in the form of litter through the biogeochemical cycle, or flow into the water systems through surface runoff, while the others are exported from the ecosystems in the form of forest products, and then released to the surrounding environment. This paper calculates the accumulated value of the nutrient elements of forest ecosystems.

$$P_{\mathrm{e}}(t) = \sum_i \sum_k S_i(t) M_{ik}(t) P_k(t) \ , \tag{5}$$

where P_{e} is value of nutrient element cycling; S_i, area of the ith type forest crop; M_{ik}, reserving quantity of the kth nutrient element of the ith type forest crop; P_k, price of the kth type nutrient element.

2.2 Forest ecosystem goods

2.2.1 Forest by-products.

$$P_{\mathrm{v}}(t)=\sum_{l=1}^{n}Q_l(t)P_l(t)\ , \tag{6}$$

where P_{v} is value of forest by-products per year; Q_l, quantity of the lth type by-product; P_l, price of the lth type forest products.

2.2.2 Stumpage output[10].

$$P_{\mathrm{f}}(t)=\sum_{i=1}^{n}S_i(t)V_i(t)P_{\mathrm{w}i}(t)\ , \tag{7}$$

where P_{f} is timber value of regional forest ecosystems; S_i, area of the ith type forest crop; V_i, net increment per unit area of the ith type forest crop; $P_{\mathrm{w}i}$, timber price of the ith type forest crop.

3 Results

3.1 Forest ecosystem services

3.1.1 Value of forest eco-tourism services. The value of forest eco-tourism services has two meanings: one is the traveler's direct consumption value, which embodies the economic degree of forest ecosystem eco-tourism services; and the other is the economic value of the maximum loading capacity of forest ecosystem eco-tourism, which embodies the total value of eco-tourism services of ecosystem. This total value is dynamic and changes with the structure, function and resource stock of the forest ecosystem. The forest ecosystem eco-tourism services of Changbai Mountain have dynamic potential values, which change with the loading capacity of forest resources. This potential value of eco-tourism services reflects the loading capacity of eco-tourism, and completely embodies the value of eco-tourism services of the forest ecosystem. The forest ecosystem is the main body of Changbai Mountain Nature Reserve. The financial support from national and local governments is essential to maintain the forest ecosystem services of Changbai Mountain. So it also embodies the value of forest eco-tourism services. The investment from 1990 to 1999 added up to RMB 2.74×10^7 Yuan.

The economic degree of eco-tourism services of the forest ecosystems of Changbai Mountain was calculated according to eq. (1). According to the annual increment of forest resources, the potential maximum functional value of the eco-tourism services of the forest ecosystems was calculated (fig. 1).

The dynamic trend of the potential maximum value of eco-tourism service value of the forest ecosystems of Changbai Mountain increases in polynomial form. The function between value and time is: $y = 0.0692x^2 - 275.74x + 274550$ ($R^2 = 0.9914$). In 1999, the value was RMB 3.13×10^{11} yuan. From 1990 to 1999, the eco-tourism value of forest ecosystem of Changbai Mountain kept increasing. But under the condition of stable forest area, forest resource extent has a maximum, so

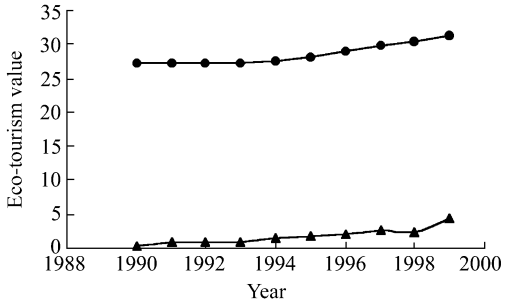

Fig. 1. Eco-tourism service value of forest ecosystem of Changbai Mountain. ▲, Embodied economic value (10^8 yuan); ●, potential maximum functional value (10^{11} yuan).

the forest eco-tourism value has a limitation. The embodied eco-tourism value also increases in polynomial form (except for 1998). The actual function between value and time is: $y = 0.0484x^2 - 192.71x + 191852$ ($R^2 = 0.8883$). The value of the eco-tourism services in 1999 was RMB 4.19×10^7 yuan (fig. 1). The economic increase of eco-tourism services of forest ecosystems has a limitation, i.e. the potential maximum value of eco-tourism services of forest ecosystem. This is just a theoretic value determined by the management level and traveler's culture. The actual value is far smaller than the theoretic value.

3.1.2 Value of water conservation by forest ecosystem. Forest is called "green reservoir". Water conservation is one of the primary services of forest ecosystem. Water sustains the ecosystems and maintains ecological balance. Water is also the important vehicle for energy flow cycling and material flow cycling. A forest has great filtering and water-conserving capabilities. Through water uptake and infiltration, forest ecosystems adjust the water quantity and its time to enter rivers, weaken flood peaks and decrease flood runoff. Therefore, the service value of water conservation by forest ecosystems embodies increasing effective water, improving water quality and adjusting runoff. Fu et al.[11] reckon that the forest precipitation value of global terrestrial ecosystems is about US$ 2.69 trillion, 23 times of the global timber value per year.

According to a field simulating experiment by Pei[12], the mean annual precipitation times in the Korean pine broad-leaved forest ecosystem of Changbai Mountain are 60.5. The times of precipitation below 10 mm per time cover 77.7%. Precipitation above 50 mm per time is few, so there is little surface runoff. During the growing season for this forest type, forest crown cuts off 17% precipitation, litters 11%, the impoundment and leakage of forest soil 72%. In the forest ecosystems of Changbai Mountain (northern slope), the annual average flow of the rivers is 2.4×10^{10} m^3. Subsurface runoff accounts for 86%. Surface runoff accounts for 14%, mainly occurring in Ermans Birch forest and dark coniferous forest. Forest soils of Changbai Mountain develop from volcanic rock and volcanic ash, with Non-capillary porosity of 16.8% and 20.9%, respectively. The average depth of forest soil of Changbai Mountain is about 1.0 m[7]. The mean annual dissipating water accounts for 35% of mean annual precipitation, and runoff coefficient is 0.65[7]. The amount of water conservation by forest ecosystem on the northern slope of Changbai Mountain is estimated to be 1.04×10^9 m^3. Generally, reservoir capacity cost is 0.67 yuan $\cdot m^{-3}$[7]. According to eq. (2), the service value of water conservation by the forest ecosystem on the northern slope of Changbai Mountain is (calculated by engineering method) RMB 6.97×10^8 yuan.

3.1.3 Value of soil conservation by forest ecosystem. Soil conservation is one of the main services of the forest ecosystem, by reducing soil erosion, mitigating the silt in rivers, lakes and reservoirs and protecting soil fertility. This research mainly calculates the economic loss caused by soil erosion and fertility loss, which substitutes for the service value of soil conservation by forest ecosystems. According to the current research[7], erosion odds ratio between forest and non-forest volcanic-rock soil is 0.01∶10.0 mm per year and that of the volcanic-ash soil is 0.01∶5.0 mm per year[7]. According to the areas of different forest soil types, the amount of decreased soil erosion is 5.0×10^7 m^3 per year in the forest ecosystem of Changbai Mountain. The economic loss caused by soil erosion mainly embodies two aspects: one is soil desolation; the other is loss of nutrient elements (N, P, K). According to eq. (5), the economic loss caused by soil desolation is 2.36×10^6 yuan per year, and the value of nutrient element loss is 2.07×10^7 yuan per year. Therefore, the total service value of soil and water conservation is RMB 2.307×10^7 yuan per year.

3.1.4 Value of air purification by forest ecosystem. Based on Li's study[13], according to eq. (6), the service value of CO_2 fixation by forest ecosystems is calculated by the carbon taxation method (table 1).

Table 1 CO_2 fixation amount and its value of forest ecosystem of Changbai Mountain

Vegetation type[a)]	Increment /t • ha^{-1} • a^{-1}	Area/ha	Increment /t • a^{-1}	CO_2 fixation amount[b)] /t • a^{-1}	Pure C /t • a^{-1}	Value of CO_2 fixation (10^4 yuan)
Conifer and deciduous mixed forest	20.19	65836.00	1329228.70	2166642.70	591323.20	73619.70
Dark coniferous forest	13.45	80295.87	1079979.30	1760366.20	480441.60	59815.00
Subalpine *Betula ermanii* forest	5.15	6018.63	30995.95	50523.40	13788.90	1716.70
Alpine brush	2.38	392.92	935.16	1524.30	416.00	51.80
Larix olgensis forest	9.50	9523.19	90470.30	147466.60	40246.80	5010.70
Deciduous forest	14.19	7591.00	107716.29	175577.60	47918.90	5965.90
Sum	64.86	169657.58	2639325.50	4302100.80	1174135.40	146179.80

a) The above six kinds of forest vegetations are all woody vegetation types of Changbai Mountain. Annual increment per unit comes from the research result of biological increment of main forest ecosystems of Changbai Mountain by Li Wenhua[11]. The area of all kinds of vegetation type is from the statistic data of Forest Ecosystem Orientation Research Station of Changbai Mountain, Chinese Academy of Sciences. b) According to the photosynthesis equation.

Forest vegetation community on the northern slope of Changbai Mountain is the stable zonal community type. Its annual biological growth can be regarded as constant. Thus the service value of CO_2 fixation by forest ecosystem on the northern slope of Changbai Mountain between 1990 and 1999 totaled RMB 1.4×10^9 yuan.

3.1.5 Value of nutrient element cycle by forest ecosystem. A forest ecosystem is a pool of nutrient elements. Some elements are transferred to the soil pool in the form of litters, some are transferred to soil in the form of precipitation lixiviation, while most are conserved in the floristic pool, and finally transferred to the environment through combustion and decomposition. The service value of nutrient-accumulation of forest ecosystems is determined by the forest area, forest

quality, nutrient retention time per unit of forest ecosystem, and fertilizer price. According to a field survey, indoors analysis and research data by Xu[14], the service value of nutrient element cycling of forest ecosystems on the northern slope of Changbai Mountain is calculated by eq. (5) (table 2).

Table 2 The value of nutrient element cycle by forest ecosystem on the northern slope of Changbai Mountain

Vegetation type	Area/ha	Nutrient element type	Nutrient element retention amount crop/kg • hm^{-2} • a^{-1}			Nutrient element sum/t • a^{-1}	Service value/10^4 yuan • a^{-1}
			N	P	K		
Conifer and deciduous mixed forest	65836.00	absorbing from soil	94.90	11.63	61.19	4538.30	4049.62
		returning through litters	58.60	7.18	35.57		
		returning through precipitation lixiviation	3.11	1.15	11.10		
		retaining in crops	33.19	3.30	14.52		
Dark coniferous forest	80295.87	absorbing from soil	125.69	16.03	55.64	11152.29	
		returning through litters	27.70	3.70	10.49		
		returning through precipitation lixiviation	3.46	1.24	11.88		
		retaining in crops	94.53	11.09	33.27		
Subalpine *Betula ermanii* forest	6018.63	absorbing from soil	8.32	1.05	6.05	29.25	
		returning through litters	5.23	0.75	3.42		
		returning through precipitation lixiviation	0.32	0.11	1.09		
		retaining in crops	3.12	0.34	1.40		
Alpine brush	392.92	absorbing from soil	4.55	2.13	2.61	1.41	
		returning through litters	3.25	0.98	0.68		
		returning through precipitation lixiviation	0.38	0.35	0.21		
		retaining in crops	3.10	0.29	0.20		
Larix olgensis forest	9523.19	absorbing from soil	9.89	1.86	8.26	96.95	
		returning through litters	5.68	1.10	4.32		
		returning through precipitation lixiviation	1.32	0.88	1.26		
		retaining in crops	6.25	1.06	2.87		
Deciduous forest	7591.00	absorbing from soil	8.11	1.58	8.08	68.93	
		returning through litters	5.10	1.06	4.16		
		returning through precipitation lixiviation	1.42	0.51	1.32		
		retaining in crops	5.05	1.58	2.45		

The average fertilizer price is 2549 yuan • t^{-1} (fixed price in 1990).

3.2 Forest ecosystem goods

3.2.1 Value of forest by-products. Forest by-products of Changbai Mountain include 8 groups: floristic medical materials, animal medical materials, dry fruit, domestic fungus, potherb, honey products, animal meat and fur. Their reserves and annual change are not clear. This paper only analyzes forest by-products entering the market.

The number of forest by-products of Changbai Mountain in the market decreased after 1993, especially animal medical materials, animal meat and fur. This result demonstrates that the force of natural conservation is increasing (fig. 2). As for the service value of forest by-products, pot-

herb is the greatest, accounting for 44%—60%; animal meat takes the second place, 3% — 22%; floristic medical materials, 9%—12%; animal medical materials, about 7%; dry nut, about 6%; domestic fungus, 6%—13%; animal fur, 0.4%—2.5%. The forest ecosystem of Changbai Mountain is the source of the three rivers (Songhua River, Yalu River, and Tumen River) in Northeast China. Protecting the forest ecosystem has great importance by protecting the watershed ecosystem of the three rivers[15]. The decrease of forest by-products shows that a protecting policy is being carried out in the natural reserve.

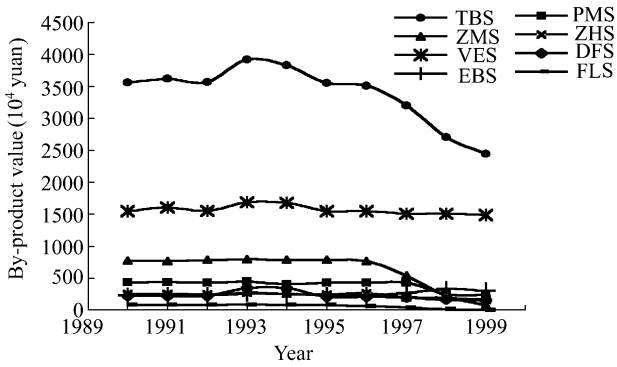

Fig. 2. Ecosystem service value of forest by-products.

3.2.2 Value of forest timber. According to the survey data analysis of forest resources in 1985, 1990, 1995, by simulating the dynamic model of biological productivity of forest ecosystems of Changbai Mountain (annual net timber increment of the main forest type), we calculated the timber reserves and the net increment from 1990 to 1999 (figs. 3 and 4).

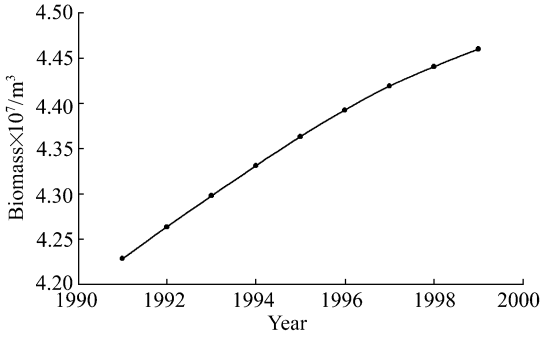

Fig. 3. The change of biomass of wood of forest ecosystem of Changbai Mountain.

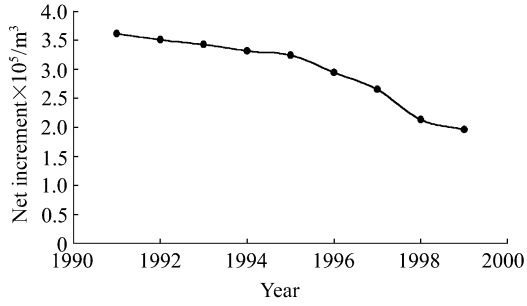

Fig. 4. The annual net increment of wood of forest ecosystem of Changbai Mountain.

According to the data of biomass (fig. 3) and annual net increment (fig. 4), timber price used adopts the average price of all kinds of timber in 1995 and 1996. Then the dynamic change of the timber service value of the forest ecosystem of Changbai Mountain can be assessed. The dynamic change trend of service value of biomass is logarithmic. The function between value and time is: $y = 58.633\ln(x) - 441.16$ ($R^2 = 0.9915$), from which the service value of timber of the forest ecosystem of Changbai Mountain is determined to be 15.6 billion yuan. The dynamic change trend of annual net growing value of timber service value of the forest ecosystem of Changbai Mountain is polynomial. The function between value and time is: $y = -0.0262x^2 + 104.51x - 104032$ ($R^2 = 0.9852$). From this function, we can see that the annual net growing service value of the forest

ecosystem is RMB 6.87×10^7 yuan.

3.2.3 Integrated service value of forest ecosystem of Changbai Mountain. According to the above results, we can estimate the dynamic change of the total value of the forest ecosystem services of Changbai Mountain (fig. 5). Fig. 6 shows the percentage of various forest ecosystem services as total values.

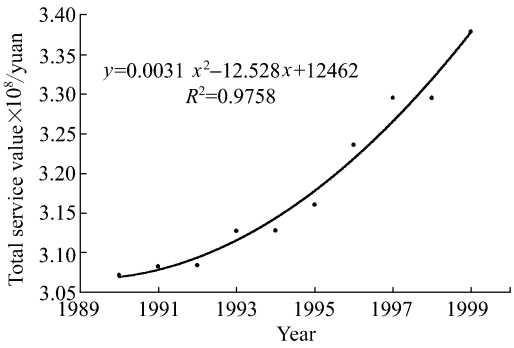

Fig. 5. The dynamic model of total value of forest ecosystem services of Changbai Mountain.

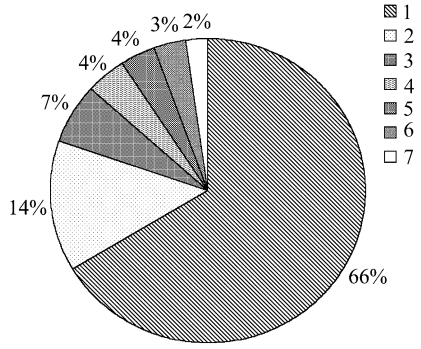

Fig. 6. The percentage of various forest ecosystem services of Changbai Mountain. 1, Water conservation; 2, air purification; 3, timber; 4, eco-tourism; 5, nutrient cycle; 6, minor forest products; 7, water and soil conservation.

The change of the total value of the forest ecosystem services of Changbai Mountain is in the form of a polynomial (fig. 5). The function between value and time is $y = 0.0031x^2 - 12.528x + 12462$ ($R^2 = 0.9758$). The total value of the forest ecosystem services of Changbai Mountain in 1999 was RMB 3.38×10^{12} yuan. The value of water conservation is the main part of the forest ecosystem services of Changbai Mountain, covering 66%. Water conservation and air purification are the most important service provided by forests, accounting for 80%. Although Northeast Forestry Center is an important timber base, the value of the timber is only 7% of the total value. Therefore, developing the ecosystem services besides timber is the best way to exert the integrated value of the forest ecosystem services of Changbai Mountain.

4 Results and discussion

The value of the forest ecosystem services of Changbai Mountain is mainly represented by water conservation and air purification. The eco-tourism service value gradually increased with annual net increment, from 2% in 1990 to 4% in 1999. The timber value decreased step by step with the development of society, from 10% in 1990 to 7% in 1999. This study shows that the value of timber is far less than that of water conservation and air purification services of Changbai Mountain although the region is an important Chinese timber base. Therefore, forest ecosystem services are the foundation of forest goods. As to the forests at the headstream of big rivers, governments should pay more attention to these forest ecosystem services, including the quality and the ecological effects of these forests.

The forest ecosystem of Changbai Mountain is the most intact forest ecosystem in eastern Asia. It sustains the structure and function of three watershed ecosystems (the Songhua River, Yalu River and Tumen River). The structure of the forest ecosystem is complex with ample species. Forest types are distributed by altitude. This paper primarily studies three typical forests. The result is less than the service value of the whole forest ecosystem of Changbai Mountain. The service values of forests below 700 m a.s.l. level are also important and worthy of study.

Tundra of Changbai Mountain spreads from 1950 m to 2600 m. This tundra is typical subpolar vegetation in eastern Asia. In this area, there are plants of 176 genera and 336 species, including 60 types of woody plants whose average covering depth is about 10 cm. This tundra vegetation has a strong ability to fix soil, hardiness and moisture resistance. This area has larger slope grade, so this arctic vegetation ecosystem plays an important role in preventing earth slide, mud-rock flow and soil erosion, and sustaining the forest ecosystem below and the regional aquatic system. Tundra is a special part of the vegetation ecosystem in Changbai Mountain[16]. Its services value needs to be carefully studied.

For the service value of eco-tourism, we consider that the service value increases with the increase of forest resource. Although they do not have linear relationship, this paper applies linear relationship, which only provides some direct ratios. This algorithm needs to be studied further. We systematically analyzed the potential eco-tourism service value of Changbai Mountain. When calculating the whole service value, potential service value is also considered. This algorithm also needs to be studied further[17].

Two methods of assessing ecosystem services are the physical assessment method (PAM) and the value assessment method (VAM). The former makes the whole evaluation on forest services from the physical quantity and the latter evaluates forest services from value quantity. This paper evaluates the service value of the forest ecosystem of Changbai Mountain by combining these two methods[18]. PAM objectively reflects the ecological process of the forest ecosystem, and the ecological process determines the sustainability of these forest ecosystem services. Therefore, for assessing the sustainability of the forest ecosystem services of Changbai Mountain, PAM is much better. On the other hand, VAM mainly reflects the whole scarcity of forest ecosystem services[19]. Both methods promote and complement each other to some extent. Therefore in theoretic research and practice, both methods should be emphasized.

Acknowledgements This work was supported by the KIP of Chinese Academy of Sciences, National Natural Science Foundation of China (Grant Nos. 79930800 & 40173033), and Long Term Research Station for Forest Ecosystem in Changbai Mountain, Chinese Academy of Sciences.

References

1. Daily, G., What are ecosystem services? in Natures Services: Societal Dependence on Natural Ecosystems (ed. Daily, G.), Washington, DC : Island Press, 1997, 1—10.
2. Harold, A. M., Paul, R. E., Ecosystem services: A fragmentary history, in Natures Services: Societal Dependence on Natural Ecosystems (ed. Daily, G.), Washington: Island Press, 1977, 11—28.
3. Costanza, R., Arge, R. D., Groot, R. D. et al., The value of the world's ecosystem services and natural capital, Nature, 1997,

387: 253—260.
4. Alexander, S., Schneider, S., Lagerquist, K., Ecosystem services: interaction of climate and life, in Nature's Services: Societal Dependence on Natural Ecosystems (ed. Daily, G.), Washington, DC: Island Press, 1997, 71—92.
5. Bormann, F., Likens, G., Fisher, D., Nutrient loss accelerated by clear-cutting of a forest ecosystem, Science, 1968, 159: 882—884.
6. Pimentel, D., Harvey, C., Resosudarmo, P., Environmental and economic costs of soil erosion and conservation benefits, Science, 1995, 267: 1117—1123.
7. Xue Dayuan, Economic Valuation of Biodiversity: A Case Study on Changbai Mountain Biosphere Reserve in Northeast China (in Chinese), Beijing: China Environmental Science Press, 1997, 11—103.
8. Zhao Shidong, Biodiversity and conservation in Changbai Mountain biosphere reserve, Ambio, 1999, 28(8): 639—641.
9. Wu Gang, Dai Limin, Structure and dynamics of a temperate deciduous conifer mixed forest in Changbai mountain, Acta Ecologica Sinica, 1998, 18(5): 470—477.
10. Yang Hanxi, Li Dingjia, Wang Bennan et al., Spatial patterns of principal trees of the Korean-pine broadleaf forest at Changbai Mountain, in Forest Ecosystem Research (in Chinese), Vol. 5, Beijing: China Forestry Publishing House, 1985, 1—14.
11. Fu Lixun, Improving Ecological Environment (in Chinese), Beijing: Scientific Books and Periodicals Press, 1989, 43—44.
12. Pei Tiefan, Fan Shixing, Han Shaowen et al., Hyorological function and simulation of the broad leaved Korean pine forest in Changbai Mountain, Acta Ecologica Sinica (in Chinese), 1995, 15(Supp. B): 113—119.
13. Li Wenhua, The biomass of main forest ecosystem of Changbai Mountain, in Forest Ecosystem Research (in Chinese), Vol. 2, Beijing: China Forestry Publishing House, 1981, 34—50.
14. Xu Guangshan, Zhang Yuhua, Liu Chunping, Biological nutrient cycling in a Korean pine-spruce-fir forest stand in Changbai Mountain, Acta Ecologica Sinica (in Chinese), 1995, 15(Supp. B): 54—60.
15. Li Wenhua, Deng Kunmei, Shao Bin et al., Studies on the community characteristics of dark conifer forest of Changbai Mountain, in Forest Ecosystem Research (in Chinese), Vol. 7, Beijing: Knowledge Press, 1995, 1—15.
16. Chen Dake, Feng Zongwei, Vegetation in the alpine and subalpine zone of the Changbai Mountain area, in Forest Ecosystem Research (in Chinese), Vol. 5, Beijing: China Forestry Publishing House, 1985, 49—56.
17. Qian Hong, Liu Qijing, Shao Guofan et al., Preliminary study on synecology of early-spring herbs in broadleaved-Korean pine forest of the Changbai Mountain, in Forest Ecosystem Research (in Chinese), Vol. 6, Beijing: China Forestry Publishing House, 1992, 31—44.
18. Zhao Jingzhu, Xiao Han, Wu Gang, Comparison analysis on physical assessment method and value assessment method for ecosystem services, Chinese Journal of Applied Ecology (in Chinese), 2000, 11(2): 290—292.
19. Wu Gang, Regeneration dynamics of tree species in gaps of Korean pine broad-leaved mixed forest in Changbai Mountain, Chinese Journal of Applied Ecology (in Chinese), 1998, 9(5): 449—452.