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# Sustainability assessment for Yanbian forest region, Jilin Province, Northeast China, based on ecological footprint model

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**Abstract** Ecological footprint (EF) is one of the most important indicators in assessing the status and capacity of sustainable development. In this paper, the EF of Yanbian forest region, Jilin Province, Northeast China, was calculated and analyzed by statistical yearbooks and forest yearbooks from 1996 to 2002. Results showed that the EF per capita decreased, ecological carrying capacity (ECC) per capita almost kept a static status, and ecological surplus per capita increased year after year. The EF per 10 thousand Yuan GDP per capita in Yanbian decreased from 1996 to 2002. This trend was similar to that in western China, and distinctly higher than that in eastern China. The forest EF per capita kept a steady status, while the forest production footprint (FPF) and forest export footprint (FEF) decreased. Comparing the two years before and after the implementation of Natural Forest Protection Program (NFPP) with the five years, the mean value of FPF and FEF reduced by 0.341 (46.32%) and 0.327 hm<sup>2</sup> per capita (54.94%), respectively. In conclusion, the regional and forest development in Yanbian was sustainable, and the implementation of NFPP was favorable to improving sustainable development of forest region. However, the sustainability capacity was still lower than those in forest developed countries. Therefore, it is very necessary to improve forest productivity, resource use efficiency and management of forest ecosystems scientifically.

**Keywords** ecological footprint, ecological carrying capacity, sustainable forestry, natural forest protection program, Yanbian forest region

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## 1 Introduction

Sustainable development has now become a universal policy goal all over the world. However, humanity is further away from sustainability (Hanley et al., 1999). China is a developing country with deficient forest resources (Li, 2004). The forestry sustainability shows a more important status, because forestry is the important base for economic and social development, and the major body of ecological construction (Jiang, 2000). Especially recently, ecological environment becomes worse and worse due to overuse of forest resource and decrease in forest quality, which leads to frequent natural calamities and brings large harm to economic and social development in China (Li, 2004). In order to reduce and avoid these negative effects, a series of policies, such as the Natural Forest Protection Project (NFPP), the Grain for Green Project, Forest Tenure Reform, Reform of Forestry Taxation and Charges, Forest Certification, and so on, have been put in practice (Li, 2004; Wang et al., 2004). Among them, the experimental demonstration of NFPP started around the major national forest areas in 1998 due to the great flood disaster in the Yangtze River. Thus, NFPP has entirely been implemented since 2000 (Zhang et al., 2000). Now, effects of NFPP on sustainability of forestry and forest region had been focused.

The ecological footprint (EF) concept has gained much attention in the academic, policy planning since it was introduced by Wackernagel and Rees (1996) in the mid-1990s. The EF represents the areas of land and water required to produce the goods and services for satisfying consumption of a defined human population or economy and to provide environmental assimilation capacity for keeping its environmental quality at a given level (Wackernagel and Rees, 1996; Ferng, 2001). The EF model is popular because it offers a simple but comprehensive way for measuring the sustainability (Wackernagel et al., 1999, 2004). It has frequently been used as one of indicators to assess the sustainability at global, national, regional or personal scale, and is easy to replicate (Xu and Zhang, 2000). Recently, advances of EF in the two

following aspects allow us to assess forestry and forest region sustainability and analyze their dynamics. First, increasing attention is being paid to new applications of the EF in tourism and forestry (Hunter, 2002; Wackernagel et al., 2004; Zhu et al., 2004). Second, in order to get useful information for sustainability, some EF time series has been exploited (Haberl et al., 2001; Erb, 2004; Wackernagel et al., 2004). Because EF at one time is static, which can not meet the requirement of dynamic characteristics of socio-economic and ecological systems. In short, computing EF time series has been becoming a new trend in sustainability assessment (Erb, 2004; Liu and Peng, 2004).

Combined with the advances on EF model and its application, this research are aiming at 1) analyzing the dynamic of EF and ecological carrying capacity (ECC) of Yanbian forest region during 1996–2002; 2) assessing the influence of NFPP on sustainability of forest regional development; 3) providing scientific basis and suggestion for sustainability of forestry and forest region.

## 2 Materials and methods

### 2.1 Site description

Yanbian region is located in southeast of Jilin Province, China, and is also the common boundary of China, Russia and Korean. The area is  $4.27 \times 10^6$  hm<sup>2</sup>, occupying 22.9% of the total area of Jilin Province. The area belongs to middle temperate wet monsoon climate. The percentage of mountain, plateau, valley, valley plain, hill to the whole region area is 54.8%, 6.4%, 13.2%, 12.3% and 13.3%, respectively. The forest resource of this region is very abundant. In 2001, the forest area was  $3.53 \times 10^6$  hm<sup>2</sup>, occupies 82.6% to the total area of the research region. The stocking volume was  $3.59 \times 10^8$  m<sup>3</sup>, with the forest coverage rate of 79.59%. Yanbian region is the important base of timber production, and has supplied timber more than  $1.2 \times 10^8$  m<sup>3</sup> since the 1950s. Due to over logging in recent years, both of the available forest resource and the forest quality decreased year by year, the forest construction was unreasonable, and the wood increment was low (Yanbian Statistic Bureau, 2003). In order to restore these forest ecosystems, protect and improve the ecological environment, and sustain national ecological security, the NFPP in Yanbian forest region started in 1998. Meanwhile, much more attention has been paid to the effects of NFPP on forestry and regional sustainability by national and local governments (Yanbian Region Forestry Management Administration, 1998–2003).

### 2.2 Methods

#### 2.2.1 Ecological footprint

The EF represents the critical natural capital requirements of a defined economy or population in terms of the corresponding biologically productive areas (Wackernagel and Rees,

1996). There are six categories of biologically productive areas in conventional ecological footprint model: arable, forest, pasture, sea, fossil energy and built-up (Wackernagel et al., 1999). Equation for assessment of EF per capita is displayed below

$$ef = \sum r_j A_i = \sum r_j (P_i + I_i - E_i) / (N \times Y_i)$$

where *ef* denotes EF per capita (hm<sup>2</sup> per capita), *i* category of consume item, *A<sub>i</sub>* land and water area per capita that is biologically productive, *P<sub>i</sub>* domestic production of various products, *I<sub>i</sub>* imports, *E<sub>i</sub>* exports, and the variable *Y<sub>i</sub>* the country or region specific yields. *N* denotes the population, *r<sub>j</sub>* equivalence factor which transforms the specific land use into a generic biologically productive area by adjusting for world average productivity. In this study, equivalence factor is used as follows: the equivalence factor of arable and built-up land is 2.8, forest and fossil energy is 1.1, pasture is 0.5 and sea is 0.2 (Wackernagel et al., 1999).

#### 2.2.2 ECC

The ECC is the sum of its bioproductive areas in a given region (Zhang et al., 2001). Each bioproductive area is transformed into global hectares by multiplying its area by the appropriate equivalence factor and the yield factor specific to that country (Monfreda et al., 2004). The equation of ECC calculated is displayed below

$$ecc = a_j \times r_j \times y_j$$

where *ecc* is the regional ecological capacity per capita (hm<sup>2</sup> per capita), *a<sub>j</sub>* some kind of biologically productive area per capita, *r<sub>j</sub>* the equivalent factor of different land types, *y<sub>j</sub>* the yield factor of some kind of biologically productive area. Yield factor is the ratio between a country or region and world average productivity. Yield factor for cropland is 1.35, obtained from the ratio of average grain yield in northeastern China to that in world (Liu and Zheng, 2003). Yield factor for forest is 0.95, which is the ratio between average stocking per area in Yanbian region and that in world. Yield factor of pasture and sea is 0.94 and 1. The yield factor of build-up land is equal to the one of arable land, and forest land is also used as fossil energy (Xu et al., 2003). In this study, 12% of the ecological capacity should be deducted for biodiversity (Wackernagel et al., 1999).

#### 2.2.3 Ecological surplus or deficit

A comparison between the footprint and biocapacity reveals that whether existing natural capital is sufficient to support consumption and production patterns (Xu and Zhang, 2000). Ecological surplus (deficit) is the difference between EF and ECC. Ecological surplus indicates that regional ecological consume is sustainable. On the contrary, ecological deficit means unsustainably regional ecological consumption.

### 2.2.4 EF per 10 thousand Yuan GDP

The EF per 10 thousand Yuan GDP equals the ratio of EF per capita to GDP per capita. It can reflect the utilization efficiency of biologically productive area (Zhang et al., 2001).

### 2.2.5 Forest production footprint (FPF), forest EF and forest export footprint (FXF)

The PPF is the ratio of forest resources production in a given region to world average productivity. In this study, the production of forest resources includes all kind of forest timber products, which are cultivated, harvested, or manufactured, but not necessarily consumed in the region. Forest EF equals production footprint plus imports footprint minus exports footprint (Wackernagel et al., 2004). The FXF indicates the export sum of fuelwood, sawnwood, wood-based panels, wood pulp, paper and paperboard (Zhu et al., 2004). In this study, imports of wood forestry products were ignored because the imports of wood forestry products were very few in Yanbian (Yanbian Region Forestry Management Administration, 1998–2003).

## 2.3 Data sources and treatment

Data mainly are sourced from Yanbian Statistic Yearbook (Yanbian Statistic Bureau, 1997–2003), Yanbian Forestry Yearbook (Yanbian Region Forestry Management Administration, 1998–2003). The average consumption per capita of wood and forest products refers to the book by Bai (2004). All data are calculated and analyzed with Excel (2003).

## 3 Results

### 3.1 Dynamics of EF, ecological capacity and ecological surplus

According to the dynamics of EF per capita in Yanbian forest region during 1996–2002, EF per capita during 1996–2000 (except 1998) showed a small fluctuation, and kept a steady status on a whole (Table 1). Then, EF per capita followed a consecutive decrease in 2001 and 2002. The average EF per

capita for the later two years (2001 and 2002) decrease by 0.089 1 hm<sup>2</sup> per capita (5.83%) compared with the former four years (from 1996 to 1999) (Table 1).

According to the components of EF (Table 1), the average arable EF per capita in 1997 and 2002 decreased by 0.064,8 hm<sup>2</sup> per capita (15.63%) and 0.117,8 hm<sup>2</sup> per capita (28.78%) than those in 1996 and 2001, respectively. The average forest EF per capita showed a decrease tendency year by year, and that for the following five years after NFPP lower by 0.016,5 hm<sup>2</sup> per capita (11.74%) than that for the former two years before NFPP with the threshold of 1998. However, the average pasture and sea EF showed an increase tendency year by year, and compared with these before NFPP, both of these after NFPP increased by 0.061,1 hm<sup>2</sup> per capita (24.32%) and 0.001,7 hm<sup>2</sup> per capita (13.67%), respectively. The average fossil energy EF per capita, which occupied more than 40% of the total EF, showed a decrease tendency like forest EF, and that after NFPP lower by 0.093,2 hm<sup>2</sup> per capita (20.22%) than that before NFPP. The built-up land EF after NFPP increased by 0.003,3 hm<sup>2</sup> per capita (20.22%) compared with that before NFPP with a similar change tendency like pasture land and sea EF (Table 1). From all above, it was found that the effects of NFPP on the average EF and the components were obvious, and showed a time lag. The EF was closely related with the level of economic and social development.

From the dynamics of ECC during 1996–2002 (Table 2), the average ECC per capita showed a slight fluctuation. According to the components of ECC, the forest and pasture ECC showed an obvious fluctuation. The forest ECC increased by 0.060,1 hm<sup>2</sup> per capita (3.62%), while the pasture ECC decreased by 0.041,2 hm<sup>2</sup> per capita (83.17%) from before NFPP to after NFPP. It is mainly caused by the afforestation in free-mountain, free-land and grassland under the implement of NFPP. The arable ECC had kept a steady status during 1996–2001, while that in 2002 showed a rapid increase, because the agriculture policy was adjusted to enlarge some cropland. The sea and built-up land ECC always kept a static level from 1996 to 2002.

The supply of EF was higher than the demand in Yanbian forest region during 1996–2002, and the ecological surplus increased year by year. The annual increment of ecological surplus during 1996–1997 (before NAPP) and 1998–2002 (after NAPP) was 0.020,0 hm<sup>2</sup> per capita (6.61%) and 0.036,7 hm<sup>2</sup> per capita (9.27%), respectively (Fig. 1). All

**Table 1** Ecological footprint of Yanbian region during 1996–2002 (unit: hm<sup>2</sup> per capita)

Categories	Year					
	1996	1997	1999	2000	2001	2002
Arable	0.414,5	0.349,7	0.435,1	0.403,8	0.409,3	0.291,5
Forest	0.141,6	0.139,9	0.128,9	0.125,7	0.123,5	0.118,8
Pasture	0.251,0	0.251,7	0.283,8	0.310,9	0.322,9	0.332,3
Sea	0.011,7	0.012,8	0.013,5	0.013,6	0.013,7	0.014,9
Fossil energy	0.700,6	0.742,0	0.656,7	0.648,3	0.587,9	0.619,4
Built-up	0.016,1	0.016,3	0.017,0	0.020,4	0.017,8	0.022,7
Total	1.535,4	1.512,3	1.535,0	1.522,7	1.475,0	1.399,6

**Table 2** Ecological carrying capacity of Yanbian region during 1996–2002 (unit:  $\text{hm}^2$  per capita)

Categories	Year					
	1996	1997	1999	2000	2001	2002
Arable	0.384,3	0.383,4	0.383,8	0.383,5	0.376,8	0.393,6
Forest	1.660,6	1.661,2	1.732,5	1.733,3	1.731,7	1.686,6
Pasture	0.049,6	0.049,6	0.008,4	0.008,4	0.008,3	0.008,3
Sea	0.004,8	0.004,8	0.005,8	0.005,8	0.005,9	0.005,9
Built-up	0.037,8	0.037,8	0.037,8	0.037,8	0.037,8	0.037,8
12% for biodiversity protection area	0.256,5	0.256,4	0.260,2	0.260,2	0.259,3	0.255,9
Total	1.880,7	1.880,4	1.908,0	1.908,5	1.901,3	1.876,3

Note: the supply of built-up area comes from the reference of Wackernagel et al. (1999).

above showed that the total amount of consumption for local citizen and production for waster was smaller than the production of available resource, which indicated that Yanbian forest region could provide some consumptions for other regions or leave some spaces for other species living. Moreover, the implement of NAPP was advantageous to improve ecological capacity and ecological security of the region and nation.

According to the comparison between EF demand (Table 1) and supply (Table 2), component structure in Yanbian forest region had some conflict. In detail, the supply of forest and built-up land EF was bigger than their ecological demand, while the supply of arable, pasture and sea was smaller than their ecological demand. Moreover, the demand of pasture EF was five times more than its ecological capacity even in 1996. From the demand component structure of EF, both of the fossil energy and arable land occupied more than 65% in the total need, followed by pasture and forest, and other lands. Among all supply categories, that of forest was the biggest type, and occupied over 90% in total supply EF. Thus, the supply EF of forest was far higher than the demand, which indicated that forest could supply abundant ecological EF to satisfy humanity demand.

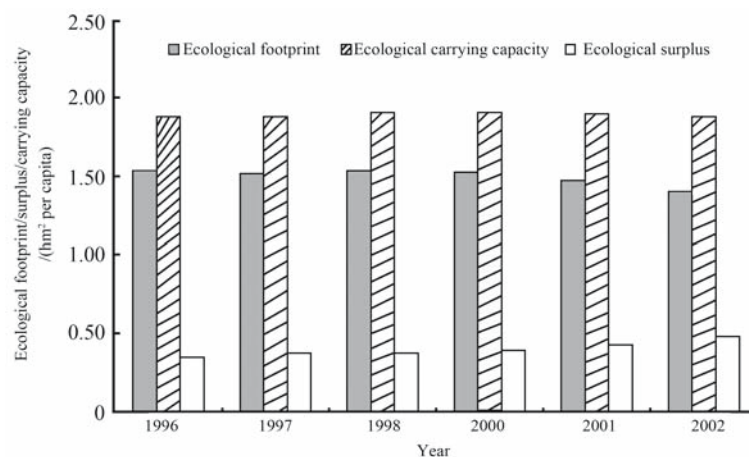
### 3.2 EF per 10 thousand Yuan GDP

The EF per 10 thousand Yuan GDP reflects the resource use efficiency (Zhang et al., 2001). The average EF per 10

thousand Yuan GDP was  $2.61 \text{ hm}^2$ , and decreased year by year in Yanbian forest region during 1996–2002 (Fig. 2). It indicated that the resource use efficiency for biological production increased step by step, with corresponding to the sustainable development of local economy, and increment of land productivity, science and technology. Comparison of Yanbian forest region with other regions in 1999 showed that the EF per 10 thousand Yuan GDP in Yanbian ( $2.77 \text{ hm}^2$ ) was almost equal to average value of the 12 provinces in western China ( $2.72 \text{ hm}^2$ ), slightly lower than that of Jilin Province ( $2.85 \text{ hm}^2$ ), and two times higher than the average value in eastern China ( $1.29 \text{ hm}^2$ ) (Zhang et al., 2001; Xu et al., 2003). Thus, the resource use efficiency in Yanbian forest region was distinctly lower than that in eastern China. Thus, the improvement of resource use efficiency in Yanbian forest region has potential in the future.

### 3.3 Forestry EF

Forestry EF includes FPF, forest EF and FXF (Wackernagel et al., 2004). Figure 3 showed the time series of FPF, forest EF and FXF in Yanbian forest region. Both of FPF and FXF had a similar change tendency of decrease year by year. Especially from 1997 to 1998, the decrease attained 35.90% for FPF and 44.10% for FXF, mainly due to the amount of harvested timber reduced from  $2.48 \times 10^6 \text{ m}^3$  in 1997 to  $2.21 \times 10^6 \text{ m}^3$  in 1998. The FPF and FXF before NFPP



**Fig. 1** Dynamics of ecological footprint, ecological carrying capacity and ecological surplus in Yanbian forest region during 1996–2002

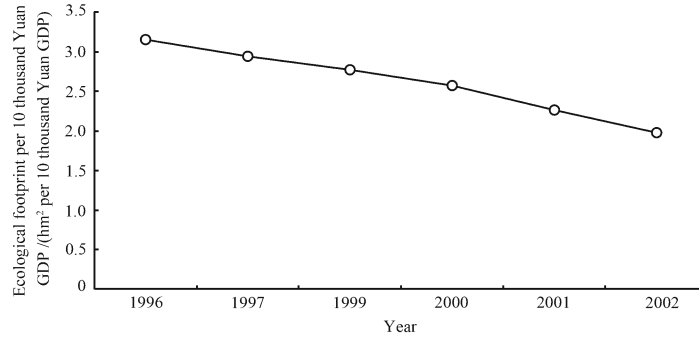


Fig. 2 Dynamics of ecological footprint per 10 thousand Yuan GDP in Yanbian forest region during 1996–2002

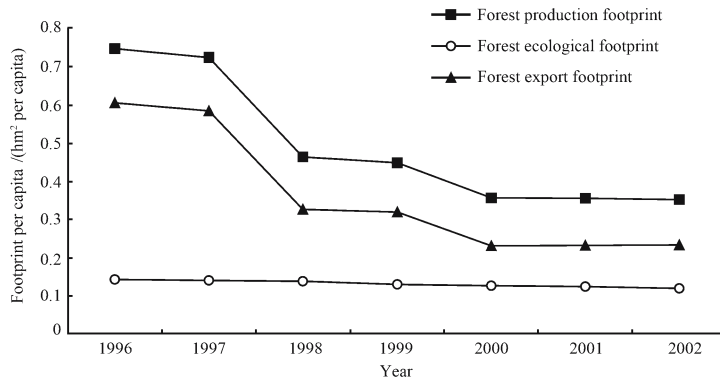


Fig. 3 Dynamics of forest production footprint, ecological footprint, export footprint in Yanbian forest region during 1996–2002

decreased by 0.341 hm<sup>2</sup> per capita (46.32%) and 0.327 hm<sup>2</sup> per capita (54.94%) than these after NFPP, respectively. Obviously, the policy of reducing amount of harvested timber could decrease consumption of forest resource, which favors to realize the goal of resource increment beyond the consumption. Meanwhile, the forest EF in Yanbian forest region showed a slow decrease tendency during 1996–2002 (Fig. 3). Compared with FPF and FXF, the decrease in forest EF was very small because the amount mainly caused by consumption of firewood. Consumption of firewood could not be inhibited under current economic and social condition in a short term, although some laws had been issued to limit local farmer to use timber as firewood.

### 3.4 Comparison with forestry developed countries all over the world

Yanbian is the Chinese typical forest region, where forestry is the mainstay industry of the whole economic development (Yanbian Statistic Bureau, 2003). Thus, it has important reference value for Yanbian forestry development situation to compare EF and ECC in Yanbian with those in forestry developed countries all over the world.

In this study, EF and ECC per capita in forestry developed countries in 1997 was used as the control value to compare with Yanbian forest region (Table 3). The EF per capita in

Yanbian forest region was far lower than those in forestry developed countries, and was only equal to 14.56% of USA and 16.67% of Australia. These were accorded with the conditions that Yanbian was an economic underdeveloped and minority region, the consumption of local people was mainly to satisfy their basic living demand as a single consumption structure and type.

Table 3 Ecological footprint, ecological carrying capacity and ecological deficit or surplus in Yanbian forest region compared with those in forestry developed countries all over the world (unit: hm<sup>2</sup> per capita)

Regions/countries	Ecological footprint	Ecological carrying capacity	Ecological deficit/surplus
Yanbian region	1.5	1.9	0.4
Canada	7.7	9.6	1.9
Russian Federation	6.0	3.7	-2.3
Japan	4.3	0.9	-3.4
Brazil	3.1	6.7	3.6
Sweden	5.9	7.0	1.1
United States of America	10.3	6.7	-3.6

The ECC per capita in Yanbian forest region was far lower than that in forestry developed countries like EF, and was only equal to 13.57% of Australia and 19.79% of Canada. The forest area per capita in Yanbian forest region was 1.6 hm<sup>2</sup> per

capita, and was nearly equal to half of Brazil and Sweden. However, the ECC per capita was just 17% of Brazil and 16% of Sweden. The forest area per capita in Yanbian forest region was two times of USA, and eight times of Japan. However, the ECC per capita was just 1.22 times of USA and 5.93 times of Japan. All these above indicated that accumulation biomass of forest land in Yanbian forest region was far lower than those in forestry developed countries, and even lower than average level of all countries all over the world, due to over consumption of forest resources and unreasonable management. In addition, the annual increment of wood growth per  $\text{hm}^2$  in Yanbian forest region in 1999, 2000 and 2001 was 1.97%, 0.53% and 2%, respectively, and was far lower than those in forestry developed countries. The status described above indicated that forest quality should be improved; stand structure should be adjusted; timber use and resource transformation efficiency should be emphasized in Yanbian forest region. The detailed measures included introducing the forestry science and technology, ensuring enough economic investment and improving the management level.

#### 4 Conclusions and discussion

Regional and forest development in Yanbian was sustainable according to the status of EF, ECC and EF per 10 thousand Yuan GDP and forestry EF during 1996–2002. Moreover, the implement of NFPP was advantageous to decrease EF per capita, EF per 10 thousand Yuan GDP, FPF, FFXF, and to improve ecological surplus, regional and forestry sustainability. However, all indexes in Yanbian forest region were far worse than those in forestry developed countries. Therefore, it was very important to improve productivity of forest land by developing science and technology during forest ecosystem management.

In addition, EF model to assess sustainability still needs to be improved in the future. First, the EF calculated by global average wood yield per  $\text{hm}^2$  instead of Yanbian forest region becomes smaller for wood yield per  $\text{hm}^2$  in Yanbian was lower than global average wood yield. Second, EF becomes smaller when some consumption items, such as medicine, chemical, water resource and travel, were not calculated. Third, EF becomes bigger when the productivity of sparse forest, shrub, young forest and middle forest did not consider the difference from that of the mature forest, and only summed with mature forest. Fourth, EF model applied by current stage does not consider differences between human living quality and regional development level, and is generally considered by the global average level. In order to comprehensively reflect regional sustainability, EF model should be combined with other assessment indexes, for example ecosystem service and function, energy analysis and regional sustainable development capacity, in the future.

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