



Responses of forest eco-service values to biotopes in the China's Conversion of Cropland to Forest Program

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Abstract

The Conversion of Cropland to Forest Program is the largest ecological program of forest in China, which has significantly increased the forest coverage. However, it has been less effective than expected. Understanding the responding features of ecological benefits of forest to their biotopes, the relationships between the categories of 'annual eco-service value of per unit area of forest' (EV) and their biotope conditions is important for maximizing the ecological benefit of forest in the Conversion of Cropland to Forest Program. We analyzed the EV categories of three kinds of forest type in different biotopes, using the methods of 'specifications for assessment of forest ecosystem services in China'. The result showed that the total EV (T_{ev}) varied in the range of 2.6–8.0 e⁴ RMBs hm⁻² a⁻¹. The EV categories performed differently among the forest types and the biotopes. Water conservation EV was the highest and nutrient accumulation EV was the lowest in all the four types of biotopes. Correlations between EV categories and biotope indicators were also analyzed. The T_{ev} of the ecological forest is mainly related to slope gradient, annual average temperature and latitude, which explained 20.1%, 14.3% and 12.6% of the variability of T_{ev} , respectively. The T_{ev} of the economic forest is mainly related to annual sunshine duration, altitude, slope gradient and annual average temperature, which explained 29.8%, 17.6%, 13.5% and 9.7% of the variability of T_{ev} , respectively. The T_{ev} of the shrubbery is associated with latitude and annual average temperature, which explained 49.9% and 22.6% of the variability of T_{ev} , respectively.

Keywords Biotope · Forest type · Eco-service value · Response

Introduction

As a critical component of ecosystem, forest provides many important eco-services (Calder 2007). Aiming at the forest eco-service, many researches (Jonge et al. 2012; Jackson et al. 2005; Yuan et al. 2014) were carried out and many valuable results have been applied in the environmental improvement. Considering the EV categories are related to the biotope conditions including soil, landform, etc. (Zhang and Zhou 2004; Bi and Ge 2009), some scientists divided forests into northern and southern types to discuss forest eco-service (Sheng et al. 2011). Giulia et al. (2012) studied the ecological classification of land and biodiversity conservation at national level in Italy. They found that the low conservation status of biodiversity prevailed in the land facets of the Mediterranean region, and the high conservation status was found along the higher belts of Alpine and Apennine chains. Niu et al. (2012) concluded that the percentages of water conservation EV and soil conservation EV were 40.51% and 9.91%, respectively, in the China's forest

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ecosystem. Moreover, the study of Wang et al. (2011a, b) reported that the correlations between forest cover and precipitation were geographically variable.

However, all above studies only included part of the EV categories, and did not offer comprehensive relationships between EV categories and biotope indicators. The researches on the responses of EV categories to different biotopes on a large scale and in a long term were less addressed.

The Conversion of Cropland to Forest Program (CCFP) provided us a suitable platform for the study on above aspects. As the largest scale of ecological program in China, CCFP has obviously improved the serious ecological deterioration since its implementation in 1999. For the purpose of more systematically observing and studying the functions of forest ecosystem, CFERN (Chinese Forest Ecosystem Research Network) was established in China at the end of 1950s. The number of forest ecological observation stations has reached 110 in CFERN by 2015. Nearly 100 ecological indicators including atmosphere, soil, forest, creature, etc. were involved in the network (Wang and Ding 2010; The Group of Assessment of Forest Ecosystem Services in China 2010). These will strongly promote the national ecological construction and will provide more detail information for the further research on the EV categories.

The widespread and long-running characteristics of CCFP make the detailed research on its ecological benefit significant. Therefore, based on the data from CFERN and the field investigation, we analyzed the EV categories under the classified biotopes. The aim is to find responding features and relationships between the EV categories and the biotope conditions.

Although there were some studies on the similar topic (Niu et al. 2012; Wang et al. 2011a, b), the results in this study will help to understand more about the details of categorized ecological benefit values of forest in response to biotopes, and could be used for references of more effective construction in CCFP in the future.

Methods

Classifications

We grouped the EV into six categories—water conservation EV, soil conservation EV, EV of carbon fixation and oxygen release, nutrient accumulation EV, species conservation EV and atmosphere purification EV (Wang et al. 2009). The forest types were classified as three kinds—the ecological forest, the economic forest and the shrubbery by the reality of CCFP (SFA 2013).

According to the differences of geography and climate feature, four types of biotope were chosen in this

study—‘Temperate Arid and Semi-arid Zone of Northwest Plateau’ (NTAS), ‘Temperate Semi-humid Zone of North Plain’ (NTSH), ‘Central Hilly Subtropical Humid Zone’ (CHSH) and ‘Tropical and Subtropical Humid Zone of Southern Mountainous’ (SMTS) (Fig. 1).

Data collection

The data of eight forest ecosystem research stations of the CFERN, Xinglong Mountain, Qilian Mountain, Saihanba, Bingla Mountain, Yuxi, pu'er, Zigui and Huitong were cited in the analysis. All these stations are long-term research stations, and adopt the technical standards and management regulations of the observation and evaluation of ecological effects in CCFP (CFERN 2013).

The representative investigation data of 24 sites (six sites for each biotope, flagged in Fig. 1) were also involved in the study. The climate data from the local weather station were adopted, and the geographic data were measured by etrex-20 GPS theodolite.

Data processing

Observation Methodology for Long-term Forest Ecosystem Research (LY/T1952-2011) (SFA 2011), Indicators System for Long-term Observation of Forest Ecosystem (LY/T1606-2003) (SFA 2003), Specifications for Assessment of Forest Ecosystem Services in China (LY/T1721-2008) (SFA 2008) were exploited in the EV calculated process. The software Spss 19.0 was used in the analysis.

Parameters of ecological value were discounted to 2013. They are calculated as follows (SFA 2013):

$$t = (D_r + L_r)/2, \quad (1)$$

where t is deposit and loan equilibrium interest rate, D_r is average deposit rate, and L_r is average loan rate.

$$d = (1 + t_{n+1})(1 + t_{n+2}) \dots (1 + t_m), \quad (2)$$

where d is discount rate, t is deposit and loan equilibrium interest rate, n is the year of obtained parameters, and m is the year of evaluation.

Results

Responses of EV categories to biotopes for different forest types

Ecological forest

Ecological forest, which is mainly constructed to reduce soil erosion and prevent the hazards of sand storm, had maintained the largest area over the CCFP by 2013 (SFA

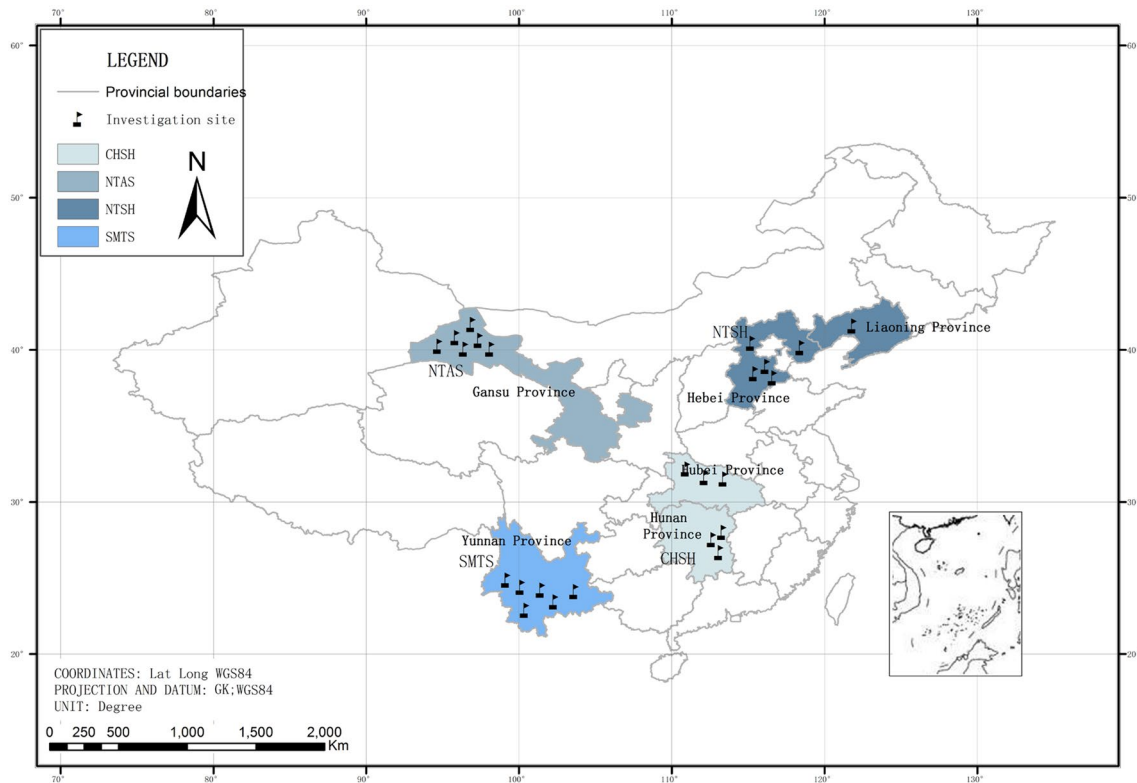


Fig. 1 Biotope zones and investigation sites (flagged). NTAS: cumulative temperature (stabilized day-average temperature ≥ 10 °C) is 3400–4500 °C, aridity is 1.6–16. NTSH: cumulative temperature

is 3400–4500 °C, aridity is 1.0–1.6. CHSH: cumulative temperature is >4500 °C, aridity is <1.0 . SMTS: cumulative temperature is >8000 °C, aridity is <1.0

2013). However, the soil conservation EVs were not the highest for the ecological forest in all the biotopes. The water conservation EVs were the highest and nutrient accumulation EVs were the lowest in all the biotopes (Fig. 2). The $T_{ev,s}$ varied between $3.81 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$ and $8.05 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$ for the ecological forest, and were ranked from high to low as NTAS, SMTS, CHSH and NTSH with the averages of $7.34 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$, $6.86 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$, $6.46 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$ and $4.87 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$, respectively. Species conservation EVs ranked the second in CHSH and SMTS. CHSH had the lowest EVs of carbon fixation and oxygen release with the average of $0.32 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$. Of the four types of biotopes, NTAS possessed the highest water conservation EV (on average of $3.23 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$), soil conservation EV (on average of $1.68 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$) and T_{ev} (on average of $7.34 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$) (Fig. 2).

Water conservation EVs accounted for 47.83%, 44.00%, 43.53% and 40.23% of the relevant $T_{ev,s}$ in CHSH, NTAS, NTSH and SMTS, respectively. In the same order of the biotopes, species conservation EVs accounted for 32.35%, 11.04%, 16.22% and 23.07%, and soil conservation EVs

accounted for only 4.95%, 22.89%, 7.60% and 10.35%, respectively.

Economic forest

Economic forest is mainly aimed at producing fruits, edible oil, beverage, sauces, industrial materials, medicinal materials and creating ecological benefits as well (SFA 2013). Unlike ecological forest, the $T_{ev,s}$ of the economic forest varied between $3.25 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$ and $6.26 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$, and were ranked from high to low as CHSH, SMTS, NTSH, and NTAS with the averages of $6.17 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$, $4.99 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$, $4.15 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$, and $3.90 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$, respectively. Similar to the ecological forest, water conservation EVs were the highest and nutrient accumulation EVs were the lowest in all the biotopes. The economic forest had the highest T_{ev} (average $6.17 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$), water conservation EV (average $3.95 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$) and the species conservation EV (average $1.25 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$) in CHSH. SMTS had the highest soil conservation EV (average $0.65 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$) and NTSH had the highest

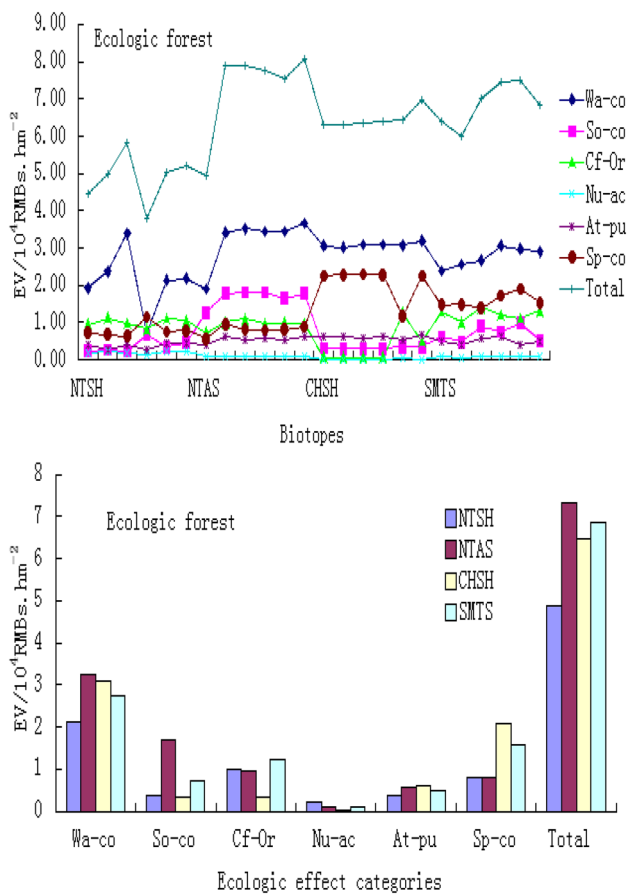


Fig. 2 Annual EV categories of ecological forest in different biotopes. *Wa-co* water conservation EV, *So-co* soil conservation EV, *Cf-Or* EV of carbon fixation and oxygen release, *Nu-ac* nutrient accumulation EV, *At-pu* atmosphere purification EV, *Sp-co* species conservation EV

EV of carbon fixation and oxygen release (average $0.48 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$) (Fig. 3).

Water conservation EVs accounted for 64.87%, 64.13%, 64.02% and 54.22% of the relevant $T_{ev,s}$ in NTAS, SMTS, CHSH and NTSH, respectively. In the same order of the biotopes, species conservation EVs accounted for 8.97%, 11.22%, 20.26% and 14.94%, and soil conservation EVs accounted for 12.82%, 13.03%, 4.70% and 11.57%, respectively.

Shrubbery

In CCFP, the shrubbery was mainly applied in the arid and semi-arid zones (Zhang et al. 2008) and the regions with fragile ecological environment or above the upper limit of trees (SFA 2004; China's State Council 2002) with its characters of extensive root system and drought tolerance. Hence,

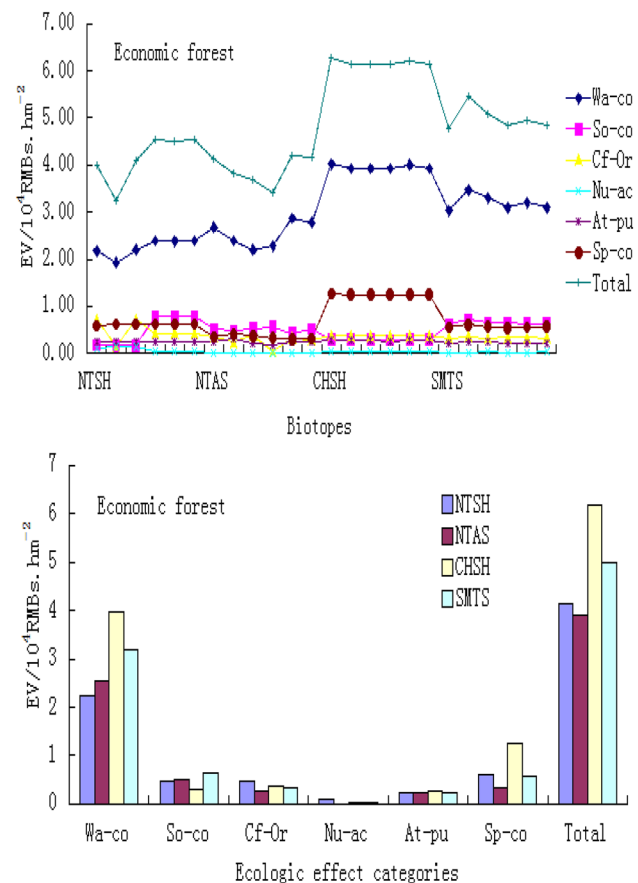


Fig. 3 Annual EV categories of economic forest in different biotopes. *Wa-co* water conservation EV, *So-co* soil conservation EV, *Cf-Or* EV of carbon fixation and oxygen release, *Nu-ac* nutrient accumulation EV, *At-pu* atmosphere purification EV, *Sp-co* species conservation EV

there was very little shrubbery in CHSH. However, our result suggested that shrubbery had the highest EV categories with the average T_{ev} of $6.16 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$ in CHSH. The $T_{ev,s}$ of shrubbery varied between $2.69 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$ and $6.16 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$, and were ranked from high to low as CHSH, SMTS, NTAS and NTSH with the averages of $6.16 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$, $5.74 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$, $3.81 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$ and $3.54 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$, respectively. Water conservation EVs were still the highest and nutrient accumulation EVs were the lowest in all the biotopes. Southern regions (CHSH, SMTS) possessed higher $T_{ev,s}$, water conservation EVs and species conservation EVs. NTAS produced the highest soil conservation EV ($0.96 \text{ e}^4 \text{ RMBs hm}^{-2} \text{ a}^{-1}$) (Fig. 4).

Water conservation EVs accounted for 57.32%, 52.54%, 51.79% and 47.77% of the relevant $T_{ev,s}$ in SMTS, NTSH, CHSH and NTAS, respectively. Species conservation EVs accounted for 21.08%, 12.99% and 9.47% of the relevant

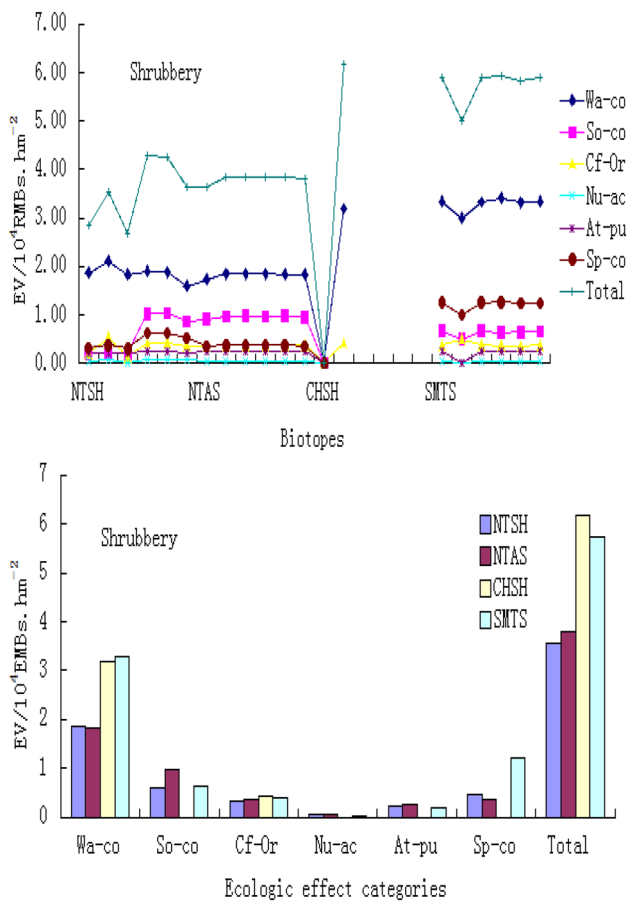


Fig. 4 Annual EV categories of shrubbery in different biotopes. *Wa-co* water conservation EV, *So-co* soil conservation EV, *Cf-Or* EV of carbon fixation and oxygen release, *Nu-ac* nutrient accumulation EV, *At-pu* atmosphere purification EV, *Sp-co* species conservation EV

T_{ev} s in SMTS, NTSH and NTAS, and soil conservation EVs accounted for 10.98%, 16.67% and 25.20% in the same order of the biotopes, respectively.

Table 1 Correlations of the EV categories of economic forest to the biotope indicators

EV categories, e^4 RMBs $hm^{-2} a^{-1}$	T , °C	R , mm	A , m	L , °N	S_g , °	S_d , h
Wa-co	0.705**	0.686**	0.238	-0.718**	0.240	-0.867**
So-co	-0.264	-0.112	0.318	-0.062	0.305	0.245
Cf-Or	0.009	0.082	-0.457*	0.124	-0.504**	-0.024
Nu-ac	-0.011	0.011	-0.766**	0.327	-0.836**	0.102
At-pu	-0.115	-0.031	-0.279	0.218	-0.161	-0.062
Sp-co	0.553**	0.618**	-0.345*	-0.380*	-0.302	-0.771**
Total	0.654**	0.711**	0.013	-0.637**	0.021	-0.859**

Wa-co water conservation EV, *So-co* soil conservation EV, *Cf-Or* EV of carbon fixation and oxygen release, *Nu-ac* nutrient accumulation EV, *At-pu* atmosphere purification EV, *Sp-co* species conservation EV, T annual average temperature, R average annual rainfall, A altitude, L latitude, S_g slope gradient, S_d annual sunshine duration

** $p < 0.01$; * $p < 0.05$

Relationships between EV categories and biotope indicators

Economic forest

Twenty-four arrays of EV categories and biotope indicators, collected from the investigation sites, were analyzed for the economic forest. Except soil conservation and atmosphere purification EVs, all the EV categories including T_{ev} are significantly correlated with several natural conditions. Some of the correlations were positive and others were negative.

T_{ev} was positively correlated with two natural conditions, annual average temperature (T) and average annual rainfall (R) on the level of $P < 0.01$; negatively correlated with other two conditions, latitude (L) and annual sunshine duration (S_d), on the same level (Table 1).

Some binary regressions between the T_{ev} and the biotope indicators of economic forest showed that the T_{ev} increases with the increase of average annual rainfall, and decreases with the increase of annual sunshine duration (Fig. 5a, b). The multiple enter regression, formula (3), suggested that the T_{ev} of the economic forest mainly depends on annual sunshine duration, altitude (A), slope gradient (S_g) and annual average temperature. Annual average temperature, altitude, latitude, slope gradient and annual sunshine duration account for 9.7%, 17.6%, 6.9%, 13.5% and 29.8% of the variability of T_{ev} , respectively:

$$T_{ev} = 9.908 - 0.059T + 3.302e^{-5}R - 0.001A - 0.029L + 0.095S_g - 0.002S_d \quad (r^2 = 0.782, p < 0.01) \quad (3)$$

Ecological forest

We also analyzed 24 arrays of EV categories of the ecological forest and their corresponding biotope indicators.

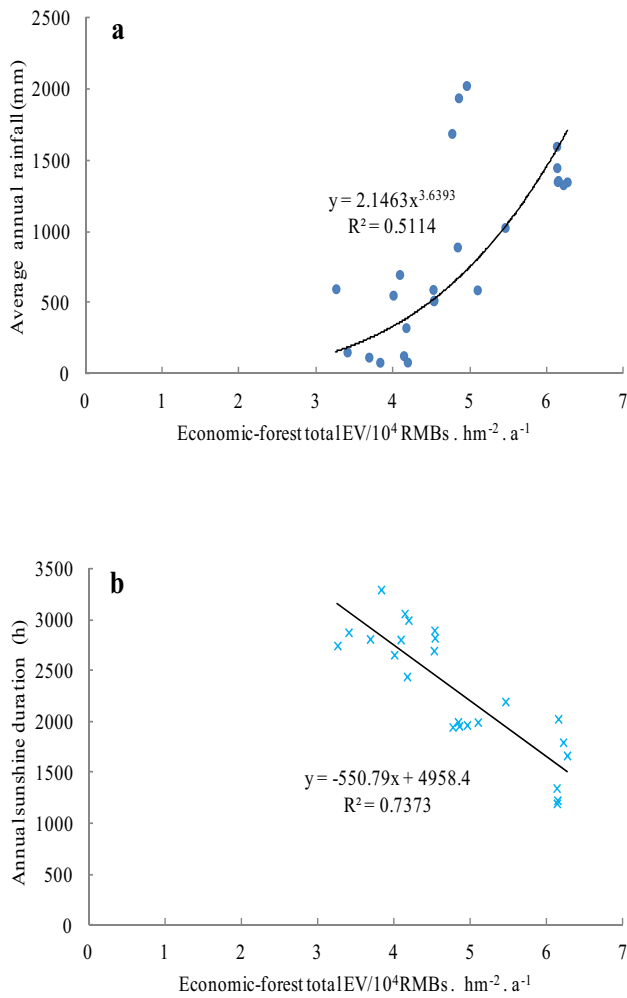


Fig. 5 Linear regressions between $T_{ev,s}$ and indicators for economic forest

Positive or negative, significant correlations exist between all the EV categories and some of their natural conditions.

The T_{ev} is positively correlated with altitude and slope gradient on the significant level of $P < 0.01$. Other correlations between EV categories and natural conditions are also listed in Table 2.

Part of binary regressions (Fig. 6a, b) and the multiple enter regression analyses, formula (4), were conducted in this study. These binary regressions showed that the T_{ev} increases with the increases of altitude and slope gradient. The multiple regression analysis suggested that the T_{ev} of the ecological forest is mainly dependent on slope gradient, annual average temperature and latitude. Slope gradient, annual average temperature and latitude explain 20.1%, 14.3% and 12.6% of the variability of T_{ev} , respectively:

$$T_{ev} = 0.914 + 0.105T + 7.830e^{-5}R + 0.065L + 0.170S_g + 6.625e^{-5}S_d \quad (r^2 = 0.557, p < 0.05). \quad (4)$$

Shrubbery

Nineteen arrays of EV categories of the shrubbery and their biotope indicators were analyzed. Except EV of carbon fixation and oxygen release, and atmosphere purification EV, all the EV categories were significantly correlated with some natural conditions at different levels. Some of the correlations were positive and others were negative.

T_{ev} is positively correlated with annual average temperature, average annual rainfall, altitude and slope gradient; negatively correlated with latitude and annual sunshine duration. Other correlations are also shown in Table 3.

Some binary regressions (Fig. 7a–c) and the multiple enter regression analyses were conducted as well. The binary regressions showed that the average annual rainfall and altitude have positive influence on T_{ev} ; annual sunshine duration has negative influence on T_{ev} . The multiple regression, formula (5), suggests that T_{ev} of the shrubbery is mainly

Table 2 Correlations of the EV categories of ecological forest to the biotope indicators

EV categories, e^4 RMBs $hm^{-2} a^{-1}$	T , °C	R , mm	A , m	L , °N	S_g , °	S_d , h
Wa-co	0.221	0.055	0.460*	-0.216	0.479**	-0.208
So-co	-0.481**	-0.601**	0.595**	0.288	0.654**	0.532**
Cf-Or	-0.210	-0.253	0.206	0.115	0.141	0.502**
Nu-ac	-0.547**	-0.447*	-0.485**	0.627**	-0.517**	0.660**
At-pu	0.284	0.112	0.407*	-0.347*	0.482**	-0.428*
Sp-co	0.771**	0.769**	0.136	-0.772**	0.117	-0.882**
Total	0.212	0.031	0.710**	-0.339	0.723**	-0.141

Wa-co water conservation EV, So-co soil conservation EV, Cf-Or EV of carbon fixation and oxygen release, Nu-ac nutrient accumulation EV, At-pu atmosphere purification EV, Sp-co species conservation EV, T annual average temperature, R average annual rainfall, A altitude, L latitude, S_g slope gradient, S_d annual sunshine duration

** $p < 0.01$; * $p < 0.05$

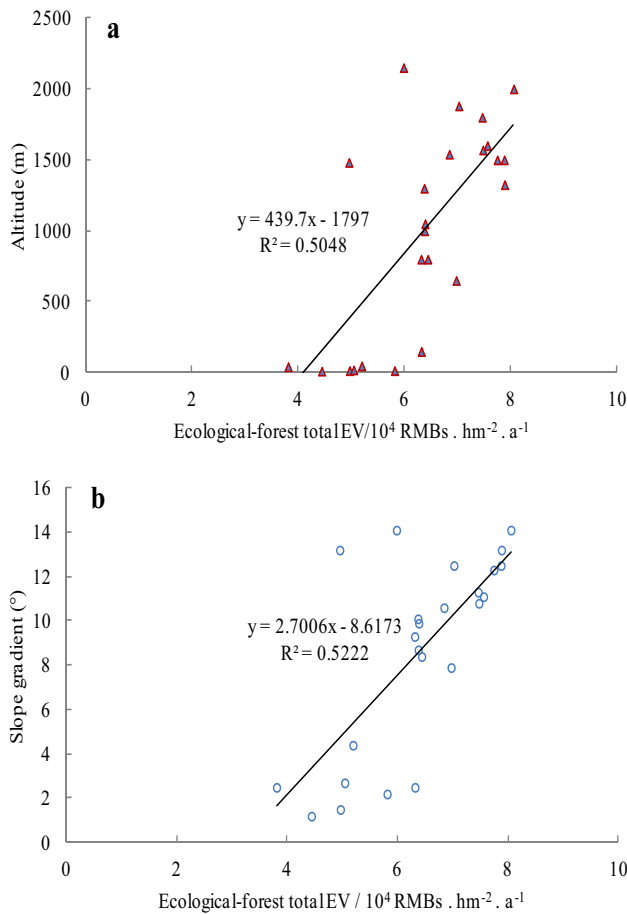


Fig. 6 Linear regressions between $T_{ev,s}$ and indicators for ecological forest

dependent on annual average temperature, latitude and annual sunshine duration, where latitude, annual average temperature and annual sunshine duration explained 49.9%, 22.6% and 6.9% of the variability of T_{ev} , respectively:

Table 3 Correlations of the EV categories of shrubbery to the biotope indicators

EV categories, e^4 RMBs $hm^{-2} a^{-1}$	T , °C	R , mm	A , m	L , °N	S_g , °	S_d , h
Wa-co	0.894**	0.796**	0.477*	-0.976**	0.337	-0.92**
So-co	-0.537*	-0.361	0.290	0.231	0.429*	0.317
Cf-Or	-0.019	0.017	0.236	-0.124	0.227	-0.090
Nu-ac	-0.587**	-0.439*	-0.567**	0.686**	-0.455*	0.552**
At-pu	-0.193	-0.124	-0.168	0.211	-0.100	0.166
Sp-co	0.798**	0.798**	0.402*	-0.931**	0.285	-0.900**
Total	0.710**	0.702**	0.533*	-0.902**	0.441*	-0.834*

Wa-co water conservation EV, So-co soil conservation EV, Cf-Or EV of carbon fixation and oxygen release, Nu-ac nutrient accumulation EV, At-pu atmosphere purification EV, Sp-co species conservation EV, T annual average temperature, R average annual rainfall, A altitude, L latitude, S_g slope gradient, S_d annual sunshine duration

** $p < 0.01$; * $p < 0.05$

$$: 0.878, p < 0.01). \tag{5}$$

Discussion

In this study, we took the CCFP as object. The results are also of common interest to general forest management.

Responding feature of EV categories

Regional EV categories are related to the natural conditions including soil, landform, climate, etc. (Zhang and Zhou 2004; Bi and Ge 2009; SFA 2014). Our study also indicated that T_{ev} , species conservation EV and water conservation EV were higher in the southern biotopes (Figs. 2, 3, 4). This indicates that the abundant water and heat resources in the southern biotopes made it easy for forest and other species to grow and propagate, and hence increased the species diversity and water-holding ability. NTAS produced higher soil conservation EV because of the loose barren soil and the less precipitation of the Loess Plateau (Zhang et al. 2010), which is likely to result in soil loss and unfavorable growth of trees, and these features made the soil conservation EV more obvious. The species conservation EV in CHSH was obviously higher than that of other biotopes. This might be due to the mild and varied environmental conditions without human intervention, which is suitable for more species to grow there.

Many previous reports demonstrated that the water conservation EV accounted for the largest proportion of the forest ecological services. Wang et al. (2014) showed the water conservation EVs of different forest types were the largest in CCFP. Qin et al. (2009) concluded that water conservation economic value was the largest, which accounted for 39.92% of the total value for the forest, 33.73% for shrubbery and 26.35% for meadow in the upper Minjiang River.

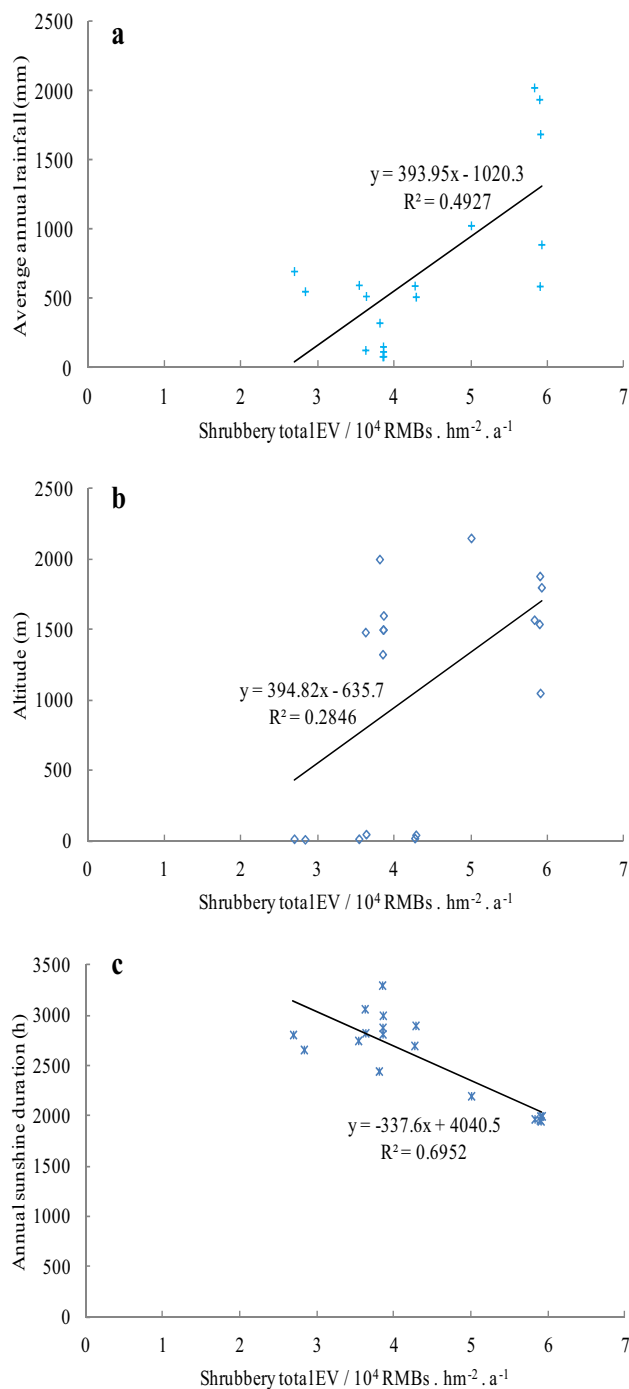


Fig. 7 Linear regressions between $T_{ev,s}$ and indicators for shrubbery

Niu et al. (2012) found that the percentages of water values were 40.51% of the total value in Chinese forest ecosystem. Shi et al. (2016) reported that the percentages of water values were 28.90% in CCFP. The similar and more detailed

result of our study also showed that water conservation EVs maintained the highest among the EV categories for all the forest types in CCFP. In this study, the percentages of water conservation EV on unit area scale are 40.23–47.83% for the ecological forest, 54.22–64.87% for economic forest, and 47.77–57.32% for the shrubbery in different biotopes. Knowing that EV categories are related to the habitat conditions, the similar and different proportions of water conservation EVs in the total values seem to come from the diverse natural conditions and the geographical scales of data acquisition.

Our results also indicate that water conservation EV is positively correlated with the average annual rainfall and the annual average temperature, and negatively correlated with the latitude and the annual sunshine duration in all the four kinds of biotopes and all the forest types (though it was not significant for ecological forest). The study of Xu et al. (2013) revealed that water conservation capacity of soil is positively correlated with above-ground biomass and under-ground biomass. Although their study focused on alpine meadow, this trend also seems to work in the forest of CCFP—more precipitation and higher temperature are always consistent with more forest biomass.

According to the result of Wang et al. (2014), the soil conservation EV ranked the second in shrubbery, ranked the third in economic forest and ranked the fourth in ecological forest. Our result showed the similar trend occurred in the shrubbery (except in SMTS, where the species conservation EV ranked the second). However, the soil conservation EV ranked the second for ecological forest in NTAS, and for economic forests in NTAS and SMTS (Figs. 2, 3, 4). These differences might come from the calculating scale and the habitat diversity. The previous study gave the feature of overall region of CCFP, and our study revealed the feature of unit area. We think the feature of unit area could more authentically reflect the reality of the ecosystem service.

The order of total ecological value from high to low was ecological forest, economic forest and shrubbery on overall scale of CCFP (Wang et al. 2014). However, our results revealed that it varied with different biotopes for unit area of T_{ev} . For example, the order of T_{ev} in SMTS was ecological forest, shrubbery and economic forest (Figs. 2, 3, 4). We think many factors could affect the overall forest ecological value, such as area, regional conditions, forest types, restoration ways, and so on. The unit area of forest ecological benefits could better reveal the facts of eco-values.

Knowing about the EV responding features of different forest types to biotopes could be useful for making the future forestation more efficient. We suggest that EV-based forestation should refer to the concrete feature of biotope rather than the overall.

Some impact factors of biotope on EV categories and their working characteristics

Habitat conditions affect many aspects of forest property in various ways, such as the influences of water stress (Eric et al. 2016), marginal forest, percentage vegetation cover, percentage shade, water factor on species composition, richness and diversity (Augustine and Michael 2005). They will naturally affect the expression of ecological benefit.

There were many studies on the relationships between forest properties and environmental conditions. Some results revealed the relationships and some did not.

Turco et al. (2004) concluded that the forest community distribution in mountainous areas is strongly related to some primary ecological factors. Lochhead and Comeau (2012) concluded that the abundance and growth of natural regeneration is strongly related to both light and understorey vegetation of stands. In fact, these forest properties would inevitably affect the ecological value of forest, which indirectly indicated the existence of the relationships between EV and biotope conditions. Our result also showed there were correlations between EV categories and biotope indicators at different levels, though some of them were significant and some were not (Tables 1, 2, 3). Furthermore, the regressions of this study showed that the annual average temperature is commonly the main impact indicator to the $T_{ev,s}$ of the three kinds of forest type.

On the contrary, Gibbon et al. (2010) quantified the carbon stores in a 49,300 ha scale of landscape centered on the cloud forest–grassland transition of the high Andes in Manu National Park. They did not find the relationships between carbon densities and slope, altitude or fire disturbance history. However, our result revealed that the EV of carbon fixation and oxygen release is negatively related to altitude ($r = -0.457$, $P < 0.05$) and slope gradient ($r = -0.504$, $P < 0.01$) for economic forest in CCFP (Table 1), and these significant correlations are not found in the ecological forest and shrubbery (Tables 2, 3). We hypothesize the forest type may result in the differences.

Our study also identified the consistency of biotope indicators involved in the paper working on the water conservation EV and T_{ev} to some extent. Higher annual average temperature and more average annual rainfall usually make the water conservation EV and T_{ev} higher. Higher latitude and longer annual sunshine duration always make the water conservation EV and T_{ev} lower. It is not completely consistent for all the involved indicators acting on the species conservation, water conservation EV and T_{ev} . However, the influences of annual average temperature, average annual rainfall, latitude and annual sunshine duration on above three EV categories are coincident (Tables 1, 2, 3).

Consideration of $T_{ev,s}$ and direct economic returns

The services of ecosystems contribute to human welfare both directly and indirectly (Constanza et al. 1997; Sun et al. 2006, 2007). Although the CCFP has also formed large ecological benefit of forest ecosystems, the program was always less effective than the expected (Cao et al. 2011). There was still EV potential by adopting some targeted measures for forestation in CCFP, thinking about the aspects involved in this study. In addition, the direct economic returns of ecological and economic forest, 1455 RMBs $\text{hm}^{-2} \text{a}^{-1}$ and 12,135 RMBs $\text{hm}^{-2} \text{a}^{-1}$ (Yang and Dai 2011), were obviously low comparing with their $T_{ev,s}$ (3.8–8.0 e^4 RMBs $\text{hm}^{-2} \text{a}^{-1}$ and 3.3–6.3 e^4 RMBs $\text{hm}^{-2} \text{a}^{-1}$) in CCFP. The low direct economic returns were far from meeting the basic needs of the local farmers. This will be a main problem to keep the program sustainable. To consolidate the achievements of CCFP, the farmers' direct economic returns must be taken into account to maintain the existing formed area. Otherwise, there will be a possibility of area degradation. Furthermore, successful forestation should be simultaneously able to achieve socio-economic, ecological and environmental effects. Hence, it is critical to increase the ways of utilization, improve the corresponding policies and management measures for the formed forest in CCFP.

Limitations

There are many ecological service values for the forest should be taken into the analyses. Such as noise reduction, landscape value and so on. We did not include them for lack of the detailed materials of these aspects. Moreover, linguistic factors might limit our ability to present our work clearly. Even so, we are still willing to communicate with our peers to improve our research.

Conclusions

The Conversion of Cropland to Forest Program has produced obvious and unbalanced ecological benefits among different regions and different forest types in China. Comparing with the ecological benefit of national wide forest, 4.0–5.0 e^4 RMBs $\text{hm}^{-2} \text{a}^{-1}$ (Wang et al. 2011a, b), the T_{ev} of CCFP varies in the range of 2.6–8.0 e^4 RMBs $\text{hm}^{-2} \text{a}^{-1}$. This indicates the ecological benefit in CCFP can remarkably exceed that of general forest. There are great EV potentials in many regions through reasonable forestation according to the biotope conditions, such as the $T_{ev,s}$ of economic forest and Shrubbery in the regions of NTAS and NTSH.

Water conservation EV plays the leading role among all the EV categories in CCFP. As another leading function, soil conservation EV (SFA 2014) should be paid more attention

in some regions, such as ecological forest in CHSH and economic forest in SMTS.

There are widespread correlations between EV categories and biotope indicators. In general, the forest ecological values are significantly affected by some of the habitat indicators and they vary with the forest types. It is coincident for the indicators affecting T_{ev} and water conservation EV. For the economic forest and shrubbery, annual average temperature and average annual rainfall are main impact factors to promote T_{ev} and water conservation EV; the higher latitude and longer annual sunshine duration always strangle the water conservation EV and T_{ev} . However, as to the ecological forest, slope gradient and altitude are commonly the main promoting indicators to increase T_{ev} and water conservation EV.

Knowing about the EV responding features of different forest types to biotopes could be useful for making the forestation more efficient in the future. To produce maximal EV, the approach (including the selection of forest types) of EV-based forestation must refer to the concrete feature of biotope rather than the overall feature. Ecological forest should be more developed in the areas with higher altitude and steeper slope. Economic forest and shrubbery should be more planted in the areas with abundant rainfall and higher temperature, and avoid developing in high latitude and long sunshine area.

The low direct economic return is a main problem to keep the program sustainable. To consolidate the achievements of CCFP, the farmers' direct economic returns must be taken into account to maintain the existing formed area. It is critical to increase the ways of utilization, improve the corresponding policies and management measures for the formed forest in CCFP.

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Data Availability We declare that the materials described in the manuscript, including all relevant raw data, are freely available, without breaching participant confidentiality.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests. Both at the time of conducting this research as well as at present, none declared by others.

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Ethics approval and consent to participate This manuscript does not report on or involve the use of any animal or human data or tissue.

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