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Comparison of forest ecosystem services value evaluation methods: a case study of Sichuan Province, China

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ABSTRACT: *The survival of human and sustainable development of the society both closely rely on forest ecosystem services. Employing two different methods, this paper based on benefit transfer method calculated the forest ecosystem services value of Sichuan province, China. The results showed that the total forest ecosystem services value had a steady rate of increase in Sichuan province from 2008 to 2018, and meanwhile, the different evaluation methods resulted in significant deviation of estimation outcomes. This paper considered the differences of biomass and socioeconomic development which were ignored in prior studies. The Carnegie-Ames-Stanford approach was employed to estimate the net primary productivity of different forest species. Further, the S type R. Pearl growth curve was employed to estimate people's willingness and ability to pay for forest ecosystem services. This paper provided implications to help forest managers and policy makers pay additional attention to the evaluation systems choosing on forest ecosystem services value and the differences of biomass and socioeconomic development by using benefit transfer method method.*

Key words: *forest ecosystem services value, socioeconomic development adjustment factor, biomass adjustment factor, grain equivalent coefficient method, DEG method.*

Comparação de métodos de avaliação de valor de serviços de ecossistemas florestais: um estudo de caso na província de Sichuan, China

RESUMO: *A sobrevivência do homem e o desenvolvimento sustentável da sociedade dependem intimamente dos serviços dos ecossistemas florestais. Com base no método de transferência de benefícios (BTM), empregando dois tipos diferentes de métodos, este artigo calcula o valor dos serviços do ecossistema florestal (FESV) da província de Sichuan, China. Os resultados mostram que o valor dos serviços do ecossistema florestal total tem uma taxa constante de aumento na província de Sichuan de 2008 a 2018, enquanto os diferentes métodos de avaliação resultam em desvios significativos dos resultados da estimativa. Este artigo leva em conta as diferenças de biomassa e desenvolvimento socioeconômico que são ignoradas na estimativa de valor dos serviços do ecossistema florestal usando método de transferência de benefícios. Especificamente, a abordagem Carnegie-Ames-Stanford é empregada para estimar a produtividade primária líquida (NPP) de diferentes espécies florestais como fator de ajuste de biomassa. Além disso, ao usar a curva de crescimento do tipo R. Pérola S, a vontade e a capacidade das pessoas de pagar pelos serviços do ecossistema florestal são consideradas para lidar com as diferenças de desenvolvimento social. Este artigo fornece contribuições para orientar pesquisadores, gestores florestais e formuladores de políticas em pesquisas e práticas futuras para dar mais atenção aos sistemas de avaliação de escolha para valor dos serviços do ecossistema florestal e heterogeneidade regional de biomassa e desenvolvimento socioeconômico.*

Palavras-chave: *valor de serviços ecossistêmicos florestais, análise de comparação, coeficiente de grãos equivalentes, fator de ajuste de desenvolvimento socioeconômico, fator de ajuste de biomassa.*

INTRODUCTION

Forest ecosystem is one of the most vital ecosystems on the earth. Forest ecosystem services value (FESV) means the beneficial values that people can derive from the characteristics and functions of forest ecosystems directly or indirectly, including value of economic service (such as goods of timber, raw material and food), value of ecological service (such as controlling soil erosion and regulating the climates), and value of cultural service (such as landscaping, recreation and sporting) (COSTANZA et al., 1997; DALY et al., 1997; MA, 2005; DE GROOT et al., 2012; SEPUL et al., 2020). The survival of human and sustainable development of the society both intensively rely on the FESV (FARLEY & COSTANZA, 2010). Therefore, estimation of the FESV in monetary units has a critical role to play in demonstrating the importance of forest ecosystem directly and heightening environmental awareness of the public. However, different evaluation methods may result in significant deviation of estimation

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outcomes, and the wide ranges of methods need to be adopted to know the estimation of the FESV better (COSTANZA et al., 2014). As such, this paper takes Sichuan province, China as an example, and employs two different evaluation methods, that is, grain equivalent coefficient method (also named GEC method) proposed by XIE et al. (2003), and the method of DE GROOT et al. (2012) (also named DEG method), to evaluate the monetary estimation outcomes of the FESV. This paper does not intend to display a judgment that the evaluation methods of the FESV are good or bad by comparing the calculation outcomes, but is meant to comb the principles of the two different methods, and provided a direction to make the choice of the FESV evaluation methods receiving further attention.

The neoclassic welfare economics is the first to put forward the theoretical analysis of the estimation of the FESV. The neoclassical welfare economics has proposed that the FESV is the total of individual willingness to pay for the services provided by forest ecosystem, and its economic value evaluation is to measure the degrees of people's preference for those forest ecosystem services (FRANCO et al., 2019). Market price can represent individual preferences for the services of natural resources (LIU et al., 2020). However, most of the services provided by forest ecosystem cannot be traded in market directly, and its market prices cannot be obtained intuitively (NAIME et al., 2020). As such, on the theoretical basis of neoclassical welfare economics, to measure the degree of people's preference for the services provided by forest ecosystem and elicit the FESV, the direct evaluation methods, such as contingent valuation method (CVM), and the indirect evaluation methods, such as benefit transfer method (BTM) appeared (ZHU et al., 2019).

In terms of the CVM, the classical direct evaluation method, it is based on the hypothetical market, employs face-to-face, telephone or mail questionnaire survey to obtain personal quotations for forest ecosystem services, and evaluates the FESV in monetary term (WOODWARD & WUI, 2001). Although, the CVM can obtain the individual preferences for forest ecosystem services directly, the implementation cost is extremely high. The survey process is time-consuming for gathering individual quotations one by one (UTSUNOMIYA, 2018). Therefore, if the acknowledged results which showed individual preferences for forest ecosystem services and were obtained by means of the CVM can be extended to other study cases, it might be highly meaningful. The BTM is such a method. The BTM can transfer the estimated FESV results of one studied area (also referred to study site) to others studied area (also referred to policy site) by means of economic technologies (ZHOU et al., 2020). Compared with employing direct evaluation methods, it is an attractive choice to quickly obtain the FESV via applying the BTM.

The indirect evaluation method of the BTM can be divided into two types, the basic BTM and the adjusted BTM (SU et al., 2020). The basic BTM regards the individual willingness to pay for forest ecosystem services and biomass in study sites and policy sites as the same, and takes the average FESV of one or more study sites as the unit FESV of policy sites (BATKER et al., 2008). Compared with the basic BTM, the adjusted BTM has considered the differences of socioeconomic development and biomass between study sites and policy sites, which has made the transfer of FESV be more accurate. To some extent, per capita GDP can represent people's ability to pay for the FESV. Therefore, the ratio of per capita GDP in study sites and policy sites is frequently used to adjust the differences of socioeconomic development (NAVRUD, 2009). Further, the ratio of forest net primary productivity (NPP) in study site and policy site is regarded as biomass adjustment factor (CAO et al., 2020). NPP is the direct manifestation of biomass. It refers after deducting the autotrophic respiration, the total amount of organic matter accumulated by green plants through photosynthesis in unit area and unit time (BARRAHMOUNE et al., 2019; CHEN et al., 2020).

Two global studies by employing the BTM are the basis of various scales the estimations of FESV. By employing the basic BTM, COSTANZA et al. (1997) transferred the ecosystem value in 100 study sites to the ecosystem services value of globe, and obtained an average value of each ecosystem in globe ($/ha/year). Considering the limited number of study sites and the interdependence among ecosystems, DE GROOT et al. (2012) screened over 665 study sites, constructed spatial statistical models, and presented a revised average value of each ecosystem in globe ($/ha/year). The evaluation of FESV based on the result of DE GROOT et al. (2012) is called DEG method. In the two global studies, the average value of global forest ecosystem and its revised average value have formed the fundamentals for the regional and national FESV evaluations all around the world.

Based on the two studies, the prior literature conducted a FESV transfer. These studies used the average value of global forest ecosystem or its revised average value directly to specific countries or regions to acquire the FESV. However, among these studies, the socioeconomic development and biomass differences are largely ignored (LI et al., 2019). People's willingness to pay needs to be matched by the ability to pay to finalize the payments for forest ecosystem services. To facilitate the calculation, previous studies did consider people's ability to pay for FESV by using the ratio of per capita GDP, but the people's willingness to pay is neglected in the process of FESV transfer (LIU, 2018; YIRSAW et al., 2016). Further, previous study has revised the biomass difference by adopting the ratio of forest NPP of study site and policy site (CAO et al., 2020), and calculated the forest NPP by employing Miami or Thornthwaite Memorial models to simplify the calculation process. Thus, the NPP of different forest species are ignored, such as coniferous forest, broad-leaved forest, and mixed forest, which may make the results be deviated from the actual situation (SU et al., 2020).

To make the FESV estimation be closer to the facts of the policy sites, the average value of global ecosystem calculated by COSTANZA et al. (1997) was improved somewhat by expert opinion method of local condition in China (BATKER, 2008). The GEC method developed by XIE et al. (2003), is the most widely used expert opinion method in Chinese setting to evaluate the services value of ecosystems (SHENG et al., 2017). The GEC method reckons the ecosystem of cultivated land is the most vital ecosystem on the earth. To reflect the contributions of forest ecosystems to the potential capacity of the whole ecosystem services value, the GEC method evaluates the FESV based on the average value of global cultivated land ecosystem. The GEC method divides the average value of global forest ecosystem ($/ha/year) by the average value of global cultivated land ecosystem, 54 ($/ha/year) firstly. The average value of global forest ecosystem and the average value of global cultivated land ecosystem both were accessed in the study of COSTANZA et al. (1997). Accordingly, the standard global FESV equivalent factor ($/ha/year) of the GEC method is obtained. Then, the research team invited 251 experts to score the standard global FESV equivalent factor ($/ha/year) in terms of actual situation of China. After that, combining the experts' scores and the standard global FESV equivalent factor ($/ha/year), the standard FESV equivalent factor of China (yuan/ha/year) is acquired. Lastly, the economic value of a standard FESV equivalent factor of China (yuan/ha/year) is equivalent to the 1/7 market value of annual grain yield of per unit cultivated land (yuan/ha/year) (XIE et al., 2005). It is the reason why the method called "grain equivalent method". Figure 1 displays the summary of the study of COSTANZA et al. (1997), the DEG method, and the GEC method.

In 2008, the GEC method recognized the calculation bias caused by the heterogeneity of biomass of each province in China. The biomass adjustment factors based on the biomass of cultivated land of each province were proposed. For instance, the biomass of cultivated land in Sichuan province approximately is 1.35 times that of the whole country on average. Therefore, the biomass adjustment factor of Sichuan province values 1.35 (XIE et al., 2008). On these grounds, prior study in Chinese setting used the biomass adjustment factors based on cultivated land directly when calculating the FESV (KANG et al., 2019). Although it is indeed desirable to obtain a standard FESV equivalent factor from the perspective of expert opinion method, employing biomass adjustment factors based on cultivated land to evaluate the FESV is inaccurate (LEI et al., 2019). With the advancement of GIS technologies, biomass is no longer as difficult to observe as it used to be. As aforementioned, the NPP of different forest species can be applied to adjust the biomass heterogeneity of study site and policy site.

Since the calculation of the ecosystem service value of a single ecosystem is more accurate than that of multiple ecosystems (DAI et al., 2018), this paper only focused on the forest ecosystem. This study attempts to fill some research gaps in current studies on evaluation of FESV. First, by using time-sensitive official data, this paper used the DEG method based on the global perspective, and GEC method based on local expert opinion, to provide a comprehensive understanding of FESV evaluation methods. Second, the Carnegie-Ames-Stanford approach (CASA) was employed to estimate the NPP of different forest species as biomass adjustment factor to overcome the biomass differences of forest ecosystems in study site and policy site. Third, to address the socioeconomic development differences, the S type R. Pearl growth curve was employed to assess people's willingness and ability to pay for forest ecosystem services.

We organized the remainder of this study as follows, in section 2, we presented the study area, data, and the methods we employed. In section 3, the calculation results were provided. Section 4 included conclusions, and discussions on policy implications.

MATERIALS AND METHODS

Study area

Sichuan province between longitude 97°21' and 108°33' E, and latitude 26°03' and

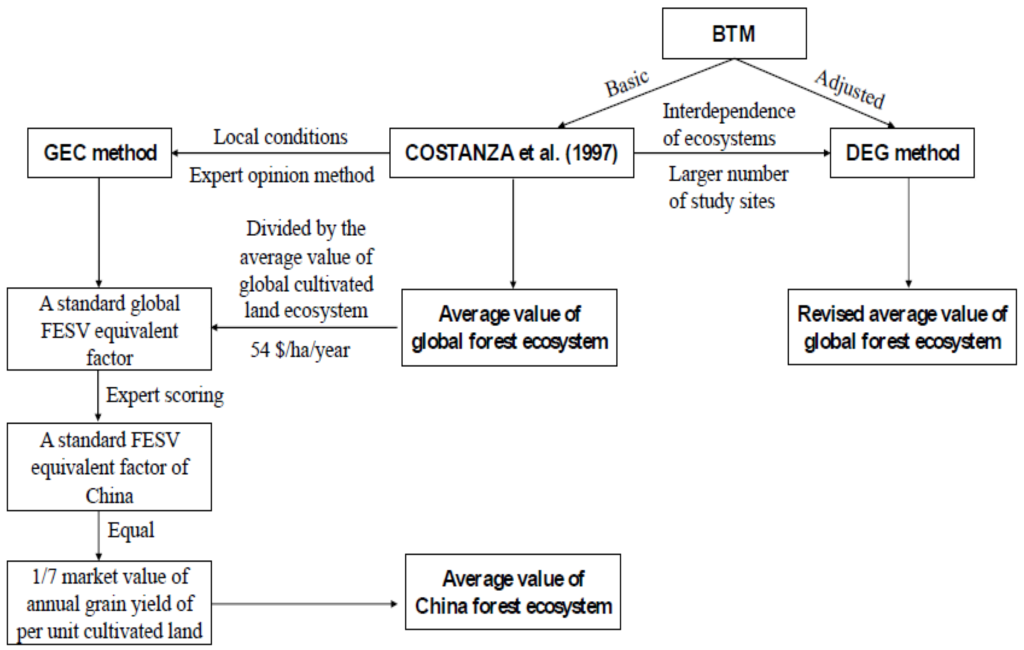

Figure 1 - Summary of the methods.

Notes: FESV means the forest ecosystem services value, and BTM is benefit transfer method.

34°19’ N, is a big province in financial, business and technology, as well as the transportation and communication hub for the southwest of China. It is in a vital position in the layout of China’s regional economic development. Sichuan province covers an area of 486,000 km^2, and ranks as the fifth biggest province in China. Sichuan province shoulders the mission of maintaining national ecological security. It is the upper reaches of many major rivers (e.g., the Yangtze River) in China, and its ecological status is very crucial (Figure 2).

According to the Forest Resources Inventory Report of China, the forested areas of Sichuan province were with coverage of 38.8%, and Sichuan province occupied the third place out of the total 31 provinces in China in the end of 2018 (Data source: National Bureau of Statistics, http://www.stats.gov.cn). Sichuan province is composed of mountains, hills, plains, basins, and plateaus. There are two types of major climates, the subtropical monsoon climate in Sichuan Basin (East) and the mountainous climate in Sichuan Plateau (West). As such, based on the International Geosphere Biosphere Program Scheme, we mainly focus on the four dominant forest categories, that is, coniferous forests, broad-leaved forests, mixed forests, and shrublands (ABELSON, 1986). By employing the ArcGIS software, figure 3 visualizes the land utilization of Sichuan province from 2008 to 2018 (Data source: National Forestry and Grassland Administration, http://www.forestry.gov.cn). Table 1 displays the area of the four dominant forest categories in Sichuan province (Data source: National Forestry and Grassland Administration, http://www.forestry.gov.cn).

Methods

CASA model

The CASA model is a frequently used method to calculate the NPP of vegetation (BAO et al., 2016; YE et al., 2019). It employs the remote sensing technology to obtain the NPP outcomes of vegetation through photosynthetic active radiation (APAR) absorbed by vegetation and the actual light energy utilization rate ε (POTTER et al., 1993). The specific CASA model can be written as follows:

$$NPP(x,t)=APAR(x,t)\times\varepsilon(x,t)$$

where $NPP(x,t)$ is the NPP (gC·m^{-2}·t^{-1}) accumulated by vegetation in pixel x over the period t. $APAR(x,t)$ indicates the photosynthetic active

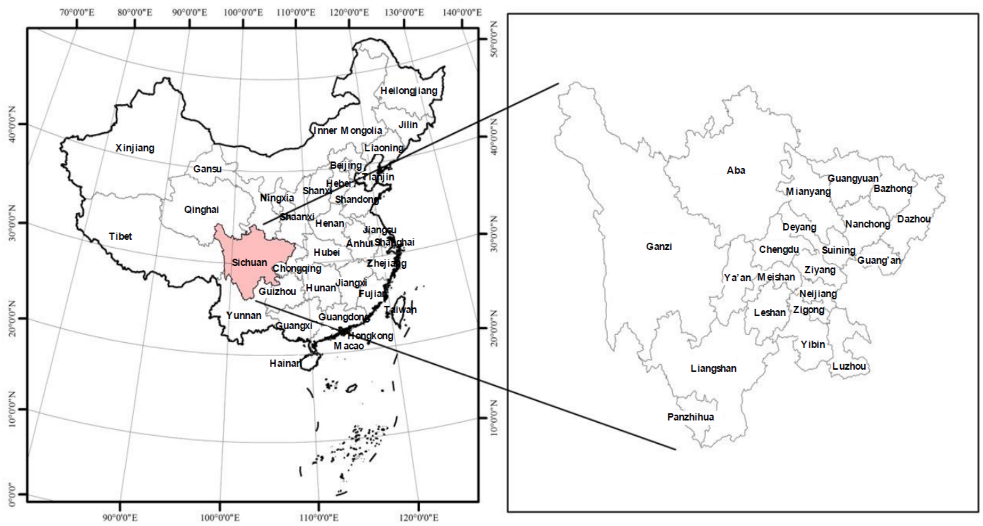

Figure 2 - Location of Sichuan province.

radiation (MJ·m^{-2}·t^{-1}) absorbed by vegetation in pixel *x* over the period *t*. $\varepsilon(x,t)$ represents the actual light energy utilization rate (gC·MJ^{-1}) of vegetation in pixel *x* in the period *t*.

The APAR (MJ·m^{-2}·t^{1}) absorbed by vegetation in pixel *x* over the period *t* can be written as follows:

$$APAR(x,t)=SOL(x,t)\times FPAR(x,t)\times 0.5$$

where $SOL(x,t)$ represents the total solar radiation is received by pixel *x* in the period *t* (MJ·m^{-2}·t^{-1}). $FPAR(x,t)$ is the absorption ratio of photosynthetic active radiation by vegetation in pixel *x*. The constant 0.5 represents the proportion of solar radiation to total solar radiation in vegetation utilization.

GEC method

GEC method has redrawn the 17 categories of forest ecosystem services in the study of COSTANZA into four ecosystem services, that is, services of provisioning, services of regulation, services of support, and services of culture. Specifically, services of provisioning include food and raw material production; services of regulation contain gas regulation, climate regulation, water regulation, and waste treatment; services of support are composed by soil formation and conservation, and biodiversity maintenance. Further, services of culture are represented by recreation. The nine sub-categories of forest ecosystem services of GEC method and its standard FESV equivalent factor are provided in table 2.

Table 1 - The area of four dominant forest categories in Sichuan province (unit: 10^4 ha).

Year	Coniferous forests	Broad-leaved forests	Mixed forests	Shrublands	Total
2008	705.95	723.38	138.72	40.80	1608.85
2013	715.94	698.08	143.28	57.60	1614.90
2018	823.55	818.88	170.50	52.10	1874.03
Change	117.60	95.50	31.78	11.30	265.18

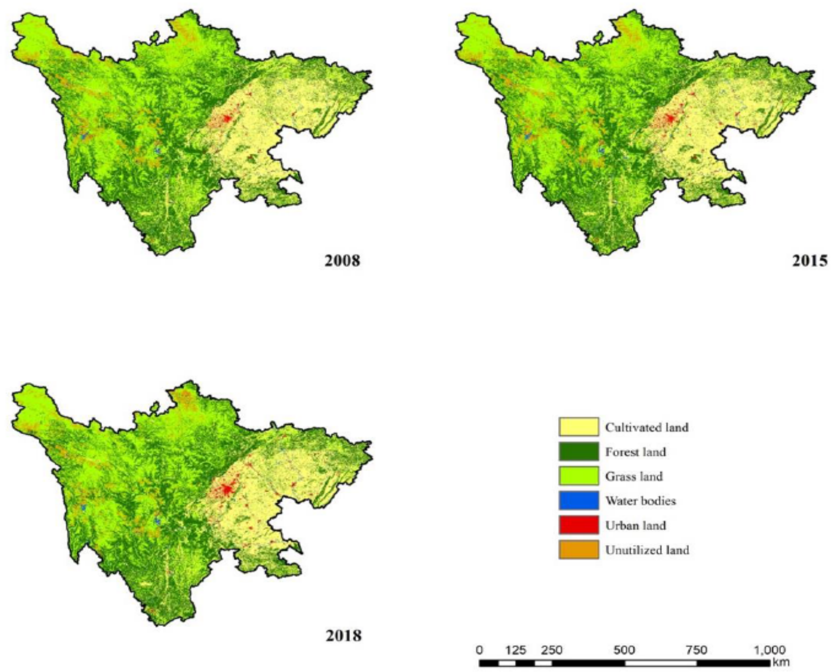

Figure 3 - Land utilization of Sichuan province from 2008 to 2018.

As proposed in the introduction section, in GEC method, the economic value of one standard equivalent factor of FESV in China is equivalent to the 1/7 market value of annual natural grain yield of per unit cultivated land. As such, the economic value of one standard equivalent factor of FESV in China can be written as follows:

$$E=(P\times\frac{Q}{S})\times\frac{1}{7}$$

where E is economic value of one standard equivalent factor of FESV in China (yuan/ha). P is the average market price of grain per unit of Sichuan province in study years (yuan/kg). S is the area of cultivated land of Sichuan province in study years (ha). Q is the total grain yield of Sichuan province in study years (kg).

Referring to the GEC method and the theoretical combing of the adjusted BTM, an assessment model of FESV in Sichuan province can be constructed. The specific FESV calculation equation is written as follows:

$$FESV=A_i\times E\times SE\times B_i\times PI_i$$

where $FESV$ is the forest ecosystem service value (yuan). A_i is area of the i th forest categories (ha). SE is the standard equivalent factor of each forest ecosystem service in table 2. B_i is the biomass adjustment factor, and PI_i is the socioeconomic adjustment factor.

Based on the adjusted BTM, B_i and PI_i can be written as follows:

$$B_i=\frac{NPP_S}{NPP_C}$$

where NPP_s is the NPP (gC·m^{-2}·t^{-1}) of the i th forest categories in Sichuan province, and NPP_c is the NPP (gC·m^{-2}·t^{-1}) of the i th forest categories in China. In this paper, to facilitate evaluation, we adopt the NPP_c results calculated by PIAO et al. (2001) and HE et al. (2005), which employed CASA model and observes the terrestrial NPP of China.

The calculation of socioeconomic adjustment factor is as follows:

$$PI_i=W_t\times A_t$$

where W_t is dictated the people's willingness to pay for the FESV. When the value of W_t becomes larger, people's willingness to pay the FESV is higher. A_t is the people's ability to pay for the FESV, which is calculated based on per capita GDP. The greater A_t, the higher people's ability to pay for the FESV is.

With the development of social economy, people's life quality has increased, and the concern

Table 2 - Standard equivalent factor for forest ecosystem services value.

Ecosystem services	Standard equivalent factor
------------Services of provisioning------------	
Food	0.33
Raw materials	2.98
------------Services of regulation------------	
Gas regulation	4.32
Climate regulation	4.07
Water regulation	4.09
Waste treatment	1.72
------------Services of support------------	
Soil formation and conservation	4.02
Biodiversity maintenance	4.51
------------Services of culture------------	
Recreation	2.08
Total	28.12

for the FESV has become more intense. This process of people's understanding of the FESV is like that of S type R. Pearl growth curve (CHEN & HUANG, 2019). Therefore, the W_t can be calculated by the S type R. Pearl growth curve. The specific equation of the S type R. Pearl growth curve is as follows:

$$l=\frac{L}{1+ae^{-bt}}$$

where *a* and *b* are fitting coefficients. *e* is the base number of natural logarithms. *t* indicates the year. *L* represents the maximum value of *l*. We have drawn the diagram of the S type R. Pearl growth curve, as shown in figure 4.

It can be seen from figure 4 that when *t* goes to negative infinity (-∞), *l* equals 0. It can be indicated that when the level of social development (*t*) is extremely low, people's willingness to pay

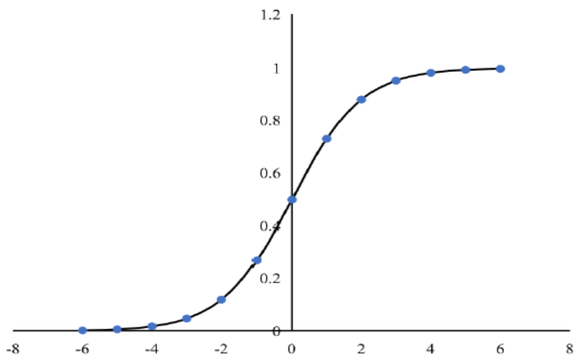

Figure 4 - The S type R. Pearl growth curve.

Notes: Level of social development is on the abscissa of the curve (*t*), and people's willingness to pay for forest ecosystem services value is on the ordinate of the curve (*l*).

for the FESV basically is zero. In contrast, when t towards positive infinity (+∞), l is equal to 1. That represents when the level of social development (t) is extremely high, the maximum value of people's willingness to FESV reaches 100%. It means that people's willingness to pay for the FESV is equivalent to the actual FESV. Therefore, no matter from the change trend or the range, the S type R. Pearl growth curve can represent the relationship between people's willingness to pay for the FESV and the level of social and economic development.

For the social development level, this paper defines the social development stages by obtaining the Engel coefficient (*En*, %) of study years. As the S type R. Pearl growth curve in figure 4 is positive, 1/*En* should be used to replace the abscissa of the curve rather than *En*.

Considering the reality of China's rapid economic development, in this paper we slightly adjusted the *En* proposed by the Food and Agriculture Organization, to determine the stage of social development. Specifically, the value of *En* is greater than 50% or the value of 1/*En* is less than 0.5, which is defined as poor life. When the value of *En* is between 50% to 25%, it represents well-off life. Likewise, the value of 1/*En* is between 0.5 to 4, which is also means well-off life. If the value of *En* is less than 25% or the value of 1/*En* greater than 4, it indicates a wealthy life. The specific social development stages are presented in table 3.

1/*En* is a non-negative number. When the S type R. Pearl's growth curve shifts four units to the right side, the curve just covers almost all stages of social development, that is, all possible values of 1/*En*. The relationship of the S type R. Pearl's growth curve and 1/*En* was presented in figure 5.

In figure 5, the origin in the x-axis has shifted 4 units to the right compares figure 4. The abscissa of the S type R. Pearl's growth curve is 1/*En*, which means the social development stage. The ordinate of the S type R. Pearl's growth curve represents people's willingness to pay for FESV. Once *En* is known, the W_t can be calculated.

$$A_t = \frac{GDP_S}{GDP_C}$$

where GDP_s and GDP_c are denoted the per capita GDP of Sichuan province and the per capita GDP of China in study years, respectively.

DEG method

The DEG method is an amendment of COSTANZA calculation system, and it extended the number of case study sites and considered the symbiosis of various ecosystems. DEG method contained 11 categories forest ecosystem services according to the ecosystem services classification scheme from the Economics of Ecosystems and Biodiversity Foundation Report (DE GROOT et al., 2010). Table 4 provides the specific categories forest ecosystem services and its revised average value of global forest ecosystem.

When using the DEG method to evaluate the FESV of a provincial scale of China, the adjusted BTM must be employed to facilitate the international transfer. Therefore, this study constructed the assessment model of the FESV suitable for the DEG method. The specific calculation equation is as follows:

$$FESV = A_i \times RAV \times B_{ic} \times PI_{ic} \times R_{ic} \times B_i \times PI_i$$

where *FESV* is the forest ecosystem service value (yuan). A_i is area of the *i* th forest categories in Sichuan province (ha). and *RAV* indicates the revised average value of forest ecosystem in globe in table 4 ($/ha/year, 2007 price level). B_{ic} and PI_{ic} are biomass and socioeconomic factor adjustment factors respectively, which are employed to overcome the biomass and socioeconomic differences between globe and China. R_{ic} indicates the official average exchange rate of US dollar to RMB in 2007. The definitions and

Table 3 - Judgment on social development stages.

Development stage	Poor life	Well-off life	Wealthy life
En	>50%	50%~25%	<25%
1/*En*	<0.5	0.5~4	>4

Note: *En* is the Engle index of Sichuan province.

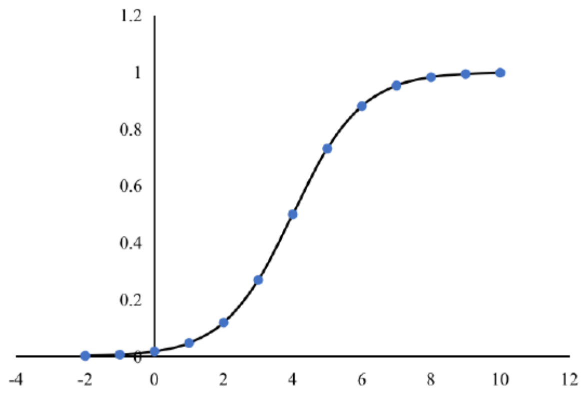

Figure 5 - The shifted S type R. Pearl's growth curve.

Notes: *1/En* is on the abscissa of the curve, and people's willingness to pay for forest ecosystem services value is on the ordinate of the curve.

calculations of B_i and PI_i are the same as those in the GEC method, which are used to address the biomass and socioeconomic differences between China and Sichuan province.

$$B_{ic}=\frac{B_c}{B_g}=1$$

where B_c is the biomass in China, while B_g is the biomass of globe. In this paper, we have assumed the biomass of globe and China are same, therefore, B_{ic} equals 1.

The calculation principle of PI_{ic} is the same as the GEC method, and PI_{ic} can be written as follows:

$$PI_{ic}=W_{ic}\times A_{ic}$$

where W_{ic} indicates the coefficient of people's willingness to pay for the FESV in China. In this paper, we have assumed the payment preferences of China and globe are with no differences, thus, W_{ic} equals 1. A_{ic} is the coefficient of people's ability to pay for the FESV in China.

$$A_{ic}=\frac{GDP_c}{GDP_g}$$

where GDP_c is per capita GDP ($/year) of China in study year, and GDP_g is global per capita GDP ($/year) in study year which is calculated according to purchasing power parity of each country.

Data

The forest data including forest area and forest land cover types were extracted from the National Forestry and Grassland Administration (Data source: National Forestry and Grassland Administration, http://www.forestry.gov.cn), China Statistical Yearbook 2008-2018 (Data source: National Bureau of Statistics, http://www.stats.gov.cn), and Sichuan Province Statistical Yearbook 2008-2018 (Data source: Sichuan Provincial Bureau of Statistic, http://tjj.sc.gov.cn).

The data sources of the related socioeconomic indices are as follows: the area of cultivated land, the per-capita GDP of Sichuan province and China, the official average exchange rate, and the Engle index of Sichuan province were obtained from the China Statistical Yearbook 2008-2018 (Data source: National Bureau of Statistics, http://www.stats.gov.cn), and Sichuan Province Statistical Yearbook 2008-2018 (Data source: Sichuan Provincial Bureau of Statistic, http://tjj.sc.gov.cn). The average market price of grain per unit of Sichuan province in study years were acquired from the Sichuan Provincial Development and Reform Commission (Data source: Sichuan Provincial Development and Reform Commission, http://fgw.sc.gov.cn). The yearly grain yield of Sichuan province in study years were obtained from People's Government of Sichuan Province (Data source: People's Government of Sichuan Province, http://www.sc.gov.cn). Further, the per-capita GDP of globe in study years were obtained from the World Bank (Data source: World Bank, https://www.worldbank.org/en/understanding-poverty).

Table 4 - Revised average value of forest ecosystem in globe ($/ha/year, 2007 price level).

Ecosystem services	Revised average value
-----Services of provisioning-----	
Food	299
Water	191
Raw materials	181
-----Services of regulation-----	
Climate regulation	152
Waste treatment	7
Erosion prevention	5
Nutrient cycling	93
Biological control	235
-----Services of habitat-----	
Genetic diversity	862
-----Cultural services-----	
Esthetic information	989
Cognitive development	1
Total	3013

Notes: The forests in Sichuan province are temperate forests, so the revised average value of global forest ecosystem is referred to the value of temperate forests in the study of DE GROOT et al. (2012).

To calculate the NPP of the four forest species, MODIS data and geo-spatial meteorological data were chosen as input parameters to CASA. MODIS-derived 16-day composite vegetation indices (MOD13A1) of atmospherically corrected maximal values at 500m resolution were downloaded from EOS data gateway (Data source: http://edcimswww.cr.usgs.gov/pub/imswelcome/). Additionally, the meteorological data of Sichuan province (including monthly mean temperatures, monthly total precipitation, and monthly total solar radiation data) was obtained from China Meteorological Data Sharing Service System (Data source: China Meteorological Data Sharing Service System, http://cdc.nmic.cn/).

RESULTS

Results of biomass adjustment factor

The mean values NPP of the four dominant forest categories in China and Sichuan province 2008, 2013 and 2018 are listed in table 5. Specifically, in 2008, the yearly mean value of NPP of the coniferous forests of Sichuan province is 622.78 ($gC\cdot m^{-2}\cdot t^{-1}$), the broad-leaved forests is 697.37 ($gC\cdot m^{-2}\cdot t^{-1}$), the mixed forests is 811.56 ($gC\cdot m^{-2}\cdot t^{-1}$), and the shrublands is 465.54 ($gC\cdot m^{-2}\cdot t^{-1}$). In 2013, the yearly mean value of NPP of the coniferous forests of Sichuan province is 558.88 ($gC\cdot m^{-2}\cdot t^{-1}$), the broad-leaved forests is 618.66 ($gC\cdot m^{-2}\cdot t^{-1}$), the mixed forests is 707.98 ($gC\cdot m^{-2}\cdot t^{-1}$), and the shrublands is 433.59 ($gC\cdot m^{-2}\cdot t^{-1}$). In 2018, the yearly mean value of NPP of the coniferous forests of Sichuan province is 622.88 ($gC\cdot m^{-2}\cdot t^{-1}$), the broad-leaved forests is 693.58 ($gC\cdot m^{-2}\cdot t^{-1}$), the mixed forests is 764.97 ($gC\cdot m^{-2}\cdot t^{-1}$), and the shrublands is 460.66 ($gC\cdot m^{-2}\cdot t^{-1}$).

Results of socioeconomic development adjustment factor

The W_t, A_t, PI_t, A_{ic} and PI_{ic} are listed in table 6. Specifically, En (%) of Sichuan province in 2008, 2013 and 2018 were 52.0%, 43.5% and 35.2%, respectively. Therefore, W_t are 0.11, 0.15 and 0.24 in 2008, 2013 and 2018, correspondingly. According to GDP_s and GDP_c in 2008, 2013 and 2018, A_t equals 0.643, 0.743 and 0.741 respectively. As such, PI_i is obtained.

Further, R_{ic} were 7.5215, that is, one dollar equals 7.5215 yuan in 2007. Based on the per capita GDP of globe and per capita GDP of China in study

Table 5 - Mean value NPP of four dominant forest categories in Sichuan province and China.

Forest types	NPP of China ($gC·m^{-2}·t^{-1}$)	------NPP of Sichuan province ($gC·m^{-2}·t^{-1}$)------			--------------B_i--------------		
		2008	2013	2018	2008	2013	2018
Coniferous forests	525	622.78	558.88	622.88	1.186	1.065	1.186
Broad-leaved forests	354	697.37	618.66	693.58	1.970	1.748	1.959
Mixed forests	330	811.56	707.98	764.97	2.459	2.145	2.318
Shrublands	283	465.54	433.59	460.66	1.645	1.532	1.628

Note: B_i is the biomass adjustment factor of Sichuan province. NPP is net primary productivity.

years, A_{ic} is 0.335, 0.705 and 0.883 in 2008, 2013 and 2018, respectively. Since this paper assumes that people's payment preferences of China and globe are with no differences, the W_{ic} is equal to 1. Therefore, the value of A_{ic} equivalents to PI_{ic} .

It can be seen from table 6, with advancement of the socioeconomic across the ten years, the Engle index shows a downward trend, and people's willingness and ability to pay for FESV are increased.

Results of FESV by employing GEC method

The grain yield per unit area of Sichuan province was 4854.1, 5320.7, and 5575.6 kg/ha in 2008, 2013 and 2018, respectively. Simultaneously, the average market price of grain in Sichuan province was 3, 3.2, and 3.5 yuan/kg in study years. As such, economic value of one equivalent factor of FESV, E (yuan/ha) is calculated to be 2080.33, 2432.34 and 2787.82 in Sichuan province 2008, 2013 and 2018, respectively. On the basis of the A_i, the area of the each forest categories (ha), B_i, the biomass adjustment factor, Pi_i, the socioeconomic development adjustment factor, and E, economic value of one equivalent factor of FESV (yuan/ha) that we have obtained, the results of FESV by employing the GEC method are presented in table 7. Further, the FESV of the four dominant forest categories in Sichuan province are displayed in figure 6.

It can be observed from table 7 that by using the GEC method, the total FESV of Sichuan province is 109.364, 152.377 and 315.740 billion yuan in 2008, 2013 and 2018, respectively. Specifically, across the ten years, the forest ecosystem service of biodiversity

Table 6 - Socioeconomic development adjustment factor.

Year	En	W_t	A_t	PI_i	W_{ic}
2008	0.520	0.110	0.643	0.070	1
2013	0.435	0.150	0.743	0.110	1
2018	0.352	0.240	0.741	0.180	1

Notes: En is the Engle index of Sichuan province; W_t is dictated the people's willingness to pay for the FESV of Sichuan province; A_t is the people's ability to pay for FESV of Sichuan province. PI_i is the socioeconomic factor adjustment coefficient of Sichuan province; W_{ic} indicates the coefficient of people's willingness to pay for the forest ecosystem services value (FESV) of China.

Table 7 - The Evaluation results of forest ecosystem services value (FESV) by employing GEC method (billion yuan).

Ecosystem services	---FESV---			
	2008	2013	2018	Change
---Services of provisioning---				
Food	1.283	1.788	3.705	2.422
Raw materials	11.590	16.148	33.460	21.871
---Services of regulation---				
Gas regulation	16.801	23.409	48.506	31.705
Climate regulation	15.829	22.055	45.699	29.870
Water regulation	15.907	22.163	45.924	30.017
Waste treatment	6.689	9.320	19.313	12.623
---Services of support---				
Soil formation and conservation	15.635	21.784	45.138	29.503
Biodiversity maintenance	17.540	24.439	50.640	33.099
---Services of culture---				
Recreation	8.090	11.271	23.355	15.265
Total	109.364	152.377	315.740	206.376

Note: US$1 = 6.317 yuan as of March 8, 2022.

maintenance, gas regulation, water regulation are constant top three contributors to the FESV of Sichuan province, while the forest ecosystem service of food, waste treatment and recreation are the three least contributors. In terms of change trend of the FESV of Sichuan province from 2008 to 2018, the total FESV shows an upward trend, increasing from 109.364 to 315.740 billion yuan. Likewise, values of the nine sub-categories of forest ecosystem services are also increased (Table 7). The area of Sichuan province has increased 265.18 (10^4 ha) from 2008 to 2018, thus, the going up FESV can be attributed to the rising area of the forest to a large extent. Among the nine sub-categories of forest ecosystem services, across the ten years, the value of gas regulation shows the biggest rise, while the value of food observes the smallest.

Concerning the FESV of different forest types, figure 6 illustrates that across the ten years, the coniferous forests and broad-leaved forests have the higher FESV, compared with the mixed forests and shrublands. Since the area of coniferous forests and broad-leaved forests are the two largest forests in Sichuan province, and meanwhile, its NPP are relatively high than other forests.

Results of FESV by employing DEG method

The results of the total FESV of Sichuan province by employing the DEG method are presented in table 8, and the FESV of the four dominant forest categories are provided in figure 7. Table 8 shows that with employing the DEG method, the total FESV of Sichuan province is 14.203, 41.644, and 108.077 billion yuan in 2008, 2013 and 2018, respectively. Additionally, among the calculated FESV results of the 11 types of ecosystem services, all of them are on the increase. Across the ten years, genetic diversity, esthetic information, and food occupy the three biggest contributors to the total FESV, while waste treatment, erosion prevention and cognitive development are the smallest contributors. Regarding the FESV of the four dominant forest categories in Sichuan province evaluated by the DEG method in figure 7, the FESV of the four dominant forest categories all have increasing trends for the ten years. Being similar to the results estimated in figure 6, the

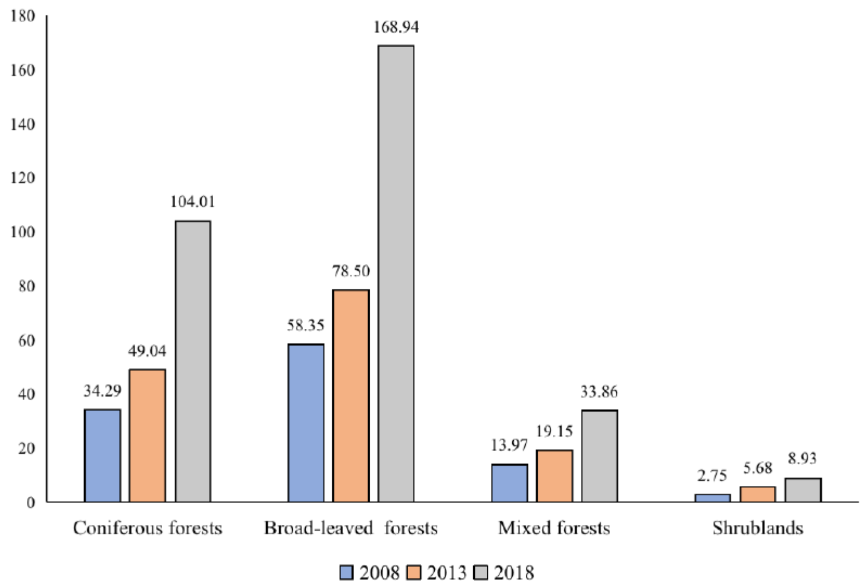

Figure 6 - Forest ecosystem services value (FESV) of the four dominant forest categories in Sichuan province evaluated by GEC method (billion yuan).

Note: US$1 = 6.317 yuan as of March 8, 2022.

coniferous forests and broad-leaved forests have the higher FESV than mixed forests and shrublands.

CONCLUSION

This paper based on the BTM, employing two different methods (the GEC method and DEG method) calculated the FESV of a provincial area, Sichuan province, China. The results showed that, by using the GEC method, the total FESV of Sichuan province increased 206.376 billion yuan (from 109.364 to 315.740) from 2008 to 2018. By adopting the DEG method, the total FESV of Sichuan province has changed 93.875 billion yuan (from 14.203 to 108.077). The results displayed the total FESV has a steady rate of increase in Sichuan province. Different from the previous studies, this paper neither directly employed the standard equivalent factor for the FESV, nor the revised average value for the global FESV. To adjust the standard equivalent factor and the revised average value, the biomass adjustment factors for different categories forest type were calculated through employing MODIS dataset. The socioeconomic adjustment factor basing on people's willingness and ability to pay for FESV was considered. This paper provided contribution to help researchers, forest managers, and policy makers pay additional attention to evaluation systems of the FESV, and regional heterogeneities of forest biomass and socioeconomic development.

For the total FESV, the results of the two methods were a long way from each other. The FESV in 2008 calculated by the GEC method was almost eight times than it calculated by the DEG method. In terms of the tremendous difference between the two different methods, the policy maker or restoration manager should propose the official and authoritative concept and estimation system of the FESV to achieve green social economic development. With the concept of green GDP put forward, the FESV will be calculated in national green GDP, and the great difference in different calculation systems should be considered circumspectly.

For the division of forest ecosystem services categories, the GEC method defined nine sub-categories (food production, raw material production, gas regulation, climate regulation, water regulation, waste treatment, soil formation and conservation, biodiversity maintenance, and recreation). The DEG method contained 11 sub-categories forest ecosystem services (food, water, raw materials, climate regulation, waste treatment, erosion prevention,

Table 8 - The Evaluation results of forest ecosystem services value (FESV) by employing DEG method (billion yuan).

Ecosystem services	FESV			
	2008	2013	2018	Change
Services of provisioning				
Food	1.408	4.130	10.718	9.310
Water	0.900	2.638	6.847	5.947
Raw materials	0.853	2.500	6.488	5.636
Services of regulation				
Climate regulation	0.716	2.099	5.449	4.733
Waste treatment	0.033	0.097	0.251	0.218
Erosion prevention	0.024	0.069	0.179	0.156
Nutrient cycling	0.438	1.285	3.334	2.896
Biological control	1.107	3.246	8.424	7.317
Services of habitat				
Genetic diversity	4.061	11.906	30.900	26.839
Services of culture				
Esthetic information	4.659	13.660	35.452	30.793
Cognitive development	0.005	0.014	0.036	0.031
Total	14.203	41.644	108.077	93.875

Note: US$1 = 6.317 yuan as of March 8, 2022.

nutrient cycling, biological control, genetic diversity, esthetic information, and cognitive development). Obviously, the DEG method extended the regulation and culture ecosystem services of forest, while in the GEC calculation system they were slightly weakened. Therefore, the DEG method might be more suitable for evaluating the value of forest ecosystem providing significance on the regional regulation and culture services.

Regarding the average value (equivalent) of forest ecosystem, after converting revised average value for global FESV (US dollar) into RMB (yuan), the average equivalent in the GEC method was lower than it in the DEG method, while the estimated total FESV showed an opposite result. It was likely that the GEC method overestimated the average equivalent of forest ecosystem service by employing the market value of grain production. Although, the FESV of the DEG method was smaller, the DEG method studied large number of ecosystems, different types of landscapes, definitions of services, scale, area, time, and complexity (LEE & BROWN, 2021). It can be argued that the results of DEG might be closer to the actual situation.

Regarding the adjustment factors, the biomass factors and socioeconomic development adjustment factor showed increase trends, which indicated the advantage of forest biomass and socioeconomic development in Sichuan province relative to the average value of national’s biomass and socioeconomic development increase continuously. This study showed that no matter what kind of calculation system was used to obtain FESV, the adjustment factor must be used to obtain a relatively accurate result.

This study also has some limitations, first, on the biomass adjustment factor, since the

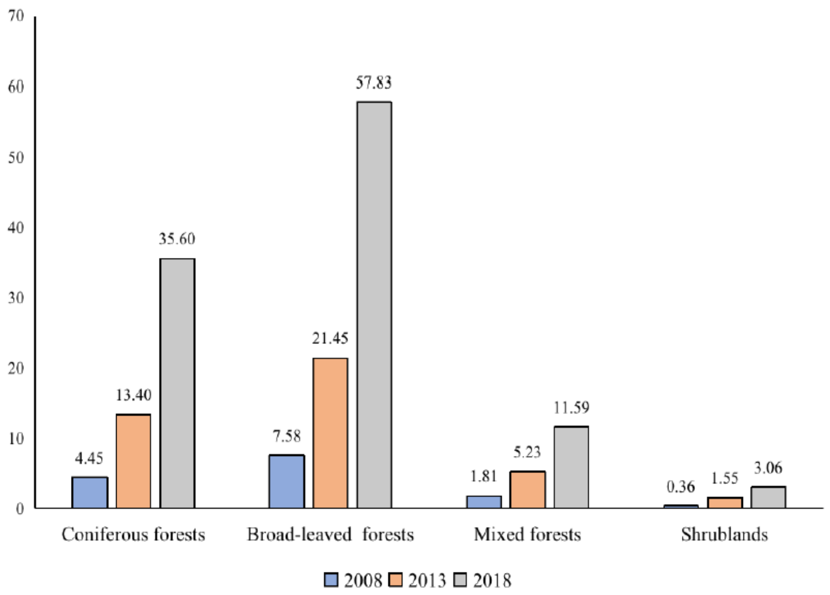

Figure 7 - Forest ecosystem services value (FESV) of the four dominant forest categories in Sichuan province evaluated by DEG method (billion yuan).

Note: US$1 = 6.317 yuan as of March 8, 2022.

huge amount of data needed to calculate the NPP of different types of forest in China, we did not re-calculate it. This paper used the calculation results of previous acknowledged studies directly. Second, on the divisions of forest types, Sichuan is a big province which abounds with natural forest resources. In this paper, for the data availability, we only calculated the FESV of the main four types of forest. Once the data are available in the future, the later research can attempt to complete these two potential directions.

DECLARATION OF CONFLICT OF INTEREST

The authors do not have any conflicts of interests.

AUTHORS' CONTRIBUTIONS

All authors have made contributions to the present research. Yao Jiang was fully engaged in the paper writing and revision. Fan Yang edited the whole paper.

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