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A *meta*-regression analysis of the economic value of grassland ecosystem services in China

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ABSTRACT

Grasslands provide a variety of ecosystem services (ESs) that contribute to human beings. However, most grassland ESs are public goods with no market value and consequently ignored in private land use decisions. Thus, it is important for grassland conservation to consider the potential economic value of grassland ESs in policymaking. We tried to provide a comprehensive evaluation of the economic value of grassland ESs and the influential factors via a *meta*-regression analysis with 745 observations from 69 studies. The results showed that the total economic value of grasslands in China was 10,876 yuan/ha in constant year 2015, and also revealed large variations in the reported economic values of grassland ESs. Soil fertility (1,899 yuan/ha/yr) and erosion control (1,492 yuan/ha/yr) were the two most valuable services. Further, factors such as valuation methods, research characteristics and study site characteristics all affected the estimates of grassland values. The market price method was most likely to provide higher grassland ES values among all the methods. Lastly, the economic value of grassland ESs showed geographical differences, with eastern China higher than western China. These findings contributed to the literature evaluating the economic value of grassland ESs regarding discrepancies in economic values, thus helping to inform grassland management. Further, these findings are helpful for better accounting for the services provided by grassland ecosystems, which can significantly facilitate land use decision making for sustainable ecosystem management.

1. Introduction

Grasslands play a pivotal role in global ecosystem services (ESs) conservation. They provide a number of valuable ESs that contribute to the well-being of humans (TEEB, 2010). Unfortunately, grasslands are among the most threatened ecosystems in China due to long-term overgrazing, cultivated land extension and overexploitation (Nan, 2005; Liu et al., 2015a; 2015b). Due to the nature of public goods with no market value for most grassland ESs, they are often overlooked in land use strategies. Thus, it is important for grassland conservation to take the potential monetary value of grassland ESs into consideration in policymaking.

Most of the existing monetary valuation studies on ESs conservation have focused on wetlands (Bennett et al., 2018; Wei et al., 2021), forests (Chu et al., 2020; Müller et al., 2020), and urban coastal areas and green spaces (Cetin, 2016; Cetin and Sevik, 2016; Kalayci Onac et al., 2021). However, a relatively small number of studies have quantified the monetary value of ESs associated with grasslands. More importantly, the estimated ES values reported in different studies have large variations, and the substantial information has confused policymakers in land use decisions. First, grasslands provide a variety of ESs, and each of these services can be evaluated from a different dimension. Thus, it is difficult to estimate all grassland ESs using a single method, and the attributes involved in each valuation study also differ (Cao et al., 2017). Second, even for the same grassland ESs, the estimated value can vary based on the valuation method. Currently, a variety of approaches have been applied to estimate grassland ES values, including the market price, equivalent factor, opportunity cost, shadow price, replacement cost and travel cost methods. All of these methods may be reasonable and self-consistent in theory; however, their results vary greatly in terms of welfare measurements, potentially rendering the estimation results incomparable (Xie et al., 2017; Zheng et al., 2018). Given such diverse

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estimations of the value derived from different ESs, valuation methods and valuation regions, it is essential to synthesize the existing valuation results and to identify key factors that may have significant impacts on the economic value of grassland ESs.

A *meta*-regression analysis can provide reliable results by synthesizing a wide range of impact factors from the primary studies. This type of analysis can be used to generate benefit transfer functions that are more reliable and less sensitive to the attributes of individual studies than those obtained with other methods (Folkersen et al., 2018; Acharya et al., 2019). It enables us to better understand the variations in grassland ES value estimates and make the inherent trade-offs in grassland management and economic growth more easily visible (Taye et al., 2021). Such an analysis can also help promote or design financial incentives, for example, the Grassland Ecological Compensation Policy (GECP) in China, which aims to preserve the nonmarketed ESs that grasslands provide. Given these considerations, a *meta*-regression analysis can serve as a feasible alternative.

To the best of our knowledge, few studies using *meta*-regression analyses in relation to grassland ecosystem valuations have been published. These studies were conducted for specific ESs or at the regional level. Huber and Finger (2020) initiated these efforts by focusing only on the cultural services of grasslands and using a *meta*-analysis as the valuation method with samples concentrated mainly in European countries. Furthermore, a *meta*-regression analysis conducted by Ren et al. (2016) highlighted the changes in grassland ESs value before and after restoration in China. However, the authors focused mainly on biodiversity services. Kang et al. (2020) reported *meta*-regression results involving multiple valuation methods and ESs, but the observations concentrated on grasslands in Qinghai Province in China. Given the limitations of these existing studies, it is necessary to expand existing *meta*-regression analyses to cover more aspects of grassland ESs and the determinants in a broader area via different valuation methods.

The main objective of this study is to analyze the economic value of grassland ESs in China and as well as the determinants. We compiled a comprehensive dataset of 69 existing studies involving 745 observations of grassland valuations in China. Based on this dataset, a *meta*-regression analysis was used to explore the drivers of the primary valuation outcomes. We (i) examine variations in the value estimates with respect to different ESs, (ii) identify and explore determinants of the economic value of grassland ESs, and (iii) provide insights for grassland management decisions and policymaking.

2. Meta-analysis dataset

We followed the standard protocols for *meta*-regression analysis proposed by Nelson and Kennedy (2008) and Moher et al. (2015). As shown in Fig. 1, the first step was to construct an original database to include the studies that evaluated grassland ESs in China. We searched the relevant literature published in both English and Chinese before November 2019. The English literature was retrieved from the Web of Science, Scopus and Engineering Village databases based on the following keywords, resulting in 718 English studies. We further searched for Chinese studies through the Chinese National Knowledge Infrastructure (CNKI) database using similar keywords in Chinese, identifying 323 Chinese studies.

Study sites: *"China" or "Chinese".*
Ecosystems: *"grassland*" or "rangeland" or "prairie" or "meadow" or "steppe".*
Research topics: *"valu*" or "economic cost" or "economic loss" or "monetary" or "benefit" or "estimat*" or "willingness to pay" or "WTP".*
Research objects: *"eco* service*" or "eco* function" or "eco* goods" or "environmental service*" or "environmental function" or "environmental goods" or "natural capital".*

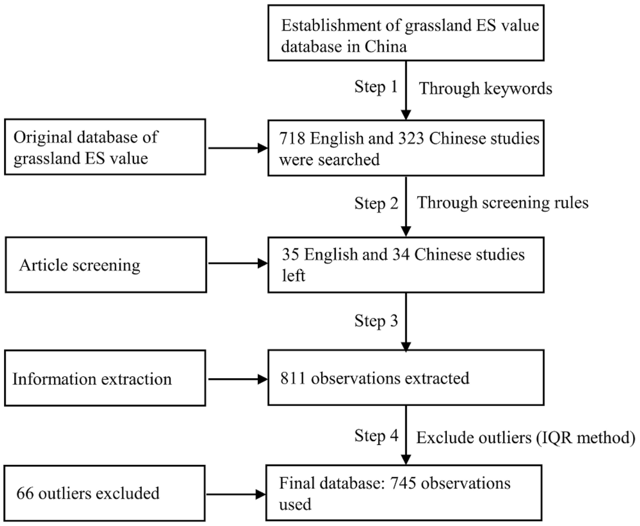

Fig. 1. Flowchart of the construction for grassland ES value database.

The second step was to screen the selected studies based on certain rules by reading the abstract and/or the full text of each study. Specifically, a study included in the dataset must 1) have estimated the value of either a single grassland ES or multiple grassland ESs, 2) have reported the grassland area considered in the study (or this information could be obtained from other external sources); 3) be set in China, and 4) be written in English or Chinese. After screening, a total of 69 primary studies were finally included to form the initial database. A list of these 69 studies is shown in Appendix A.

The third step was to code the economic value of grasslands together with the key explanatory variables. These variables are explained in detail in the Method section (Table 1). As some empirical studies reported multiple value estimates for different ESs, we finally documented 811 observations. The final step was to eliminate outliers (i.e., grassland ES observations). Sixty-six outliers were identified based on the interquartile range (IQR) method (Wan et al., 2014), resulting in a total of 745 observations in our final database.

3. Method

3.1. Dependent variable

Given that grassland ES values were reported in the literature in different forms, we transformed the values into units of thousand yuan per hectare per year. All the studies in our dataset provided either the total value or value per hectare. For the studies that provided the total value, we calculated the value per hectare by dividing the total value by the total study area. The study area was obtained either from the study or the local yearbook.

Furthermore, we converted all economic values per hectare per year into the value of the Chinese yuan in 2015. Following Barrio and Loureiro (2010); Brander et al. (2013); and Chaikumbung et al. (2016), we first converted the values reported in US dollars or other foreign currencies to Chinese yuan using the purchasing power parity (PPP) index provided by the World Bank (2019). For values measured in different years, we used the consumer price index (CPI) given by the National Bureau of Statistics of China to convert the values to constant year 2015 (National Bureau of Statistics, 2019).

3.2. Independent variables

To examine the factors that affect the economic values of grassland ESs, we applied four sets of explanatory variables to the econometric model, including types of grassland ESs, valuation methods, and

Table 1
Definitions and descriptions of the variables used in the *meta*-regression analysis.

Variable name	Variable description	Obs.	Mean	Std.
Dependent variable				
Value	Continuous, annual value per hectare in 2015 thousand yuan	745	1.03	1.15
Independent variables				
Ecosystem Services				
Food supply	Dummy, food supply service is provided (=1). Baseline category	69	0.09	0.29
Raw material	Dummy, raw material service is provided (=1)	72	0.10	0.30
Water supply	Dummy, water supply service is provided (=1)	31	0.04	0.20
Climate regulation	Dummy, climate regulation service is provided (=1)	143	0.19	0.39
Erosion control	Dummy, erosion control service is provided (=1)	19	0.03	0.16
Water regulation	Dummy, water regulation service is provided (=1)	67	0.09	0.29
Soil fertility	Dummy, soil fertility service is provided (=1)	104	0.14	0.35
Waste treatment	Dummy, waste treatment service is provided (=1)	66	0.09	0.28
Genetic diversity	Dummy, genetic diversity service is provided (=1)	59	0.08	0.27
Recreation	Dummy, recreation service is provided (=1)	63	0.08	0.28
Other services	Dummy, other services are provided (=1)	52	0.07	0.25
Value Method				
Equivalent factor method	Dummy, equivalent factor method is used (=1)	555	0.74	0.44
Market price method	Dummy, market price method is used (=1). Baseline category	24	0.03	0.18
Replacement cost method	Dummy, replacement cost method is used (=1)	49	0.07	0.25
Shadow price method	Dummy, shadow price method is used (=1)	82	0.11	0.31
Other methods	Dummy, other methods are used (=1)	35	0.05	0.21
Research Characteristics				
Journal type				
SCI	Dummy, SCI or SSCI listed journals (=1). Baseline category	388	0.52	0.50
CSSCI	Dummy, CSSCI listed journals only (=1)	86	0.12	0.32
Non-SCI/CSSCI	Dummy, not in any SCI/SSCI/CSSCI listed journal (=1)	271	0.36	0.48
Cross-discipline	Dummy, coauthors come from multiple disciplines (=1)	189	0.25	0.44
Research year	Continuous, the year of research	745	2005.21	8.10
Study Site Characteristics				
GDP per capita	Continuous, GDP per capita in thousand yuan in the research year (per province where grassland is located)	745	22.03	14.58
Natural reserve	Dummy, study site is located in a natural reserve (=1)	116	0.16	0.36
Longitude	Continuous, longitude of study area	745	105.50	13.82
Latitude	Continuous, latitude of study area	745	38.97	6.29

characteristics of the study and the study sites.

3.2.1. *Types of grassland ESs*

Following the definitions of Costanza et al. (1997), Millennium Ecosystem Assessment (2005) and TEEB (2010), we classified grassland ESs into 11 categories under four major types. Specifically, the grassland ESs that we considered included food supply, raw material and water supply under provisioning services; climate regulation, erosion control, water regulation, soil fertility and waste treatment under regulating services; genetic diversity under habitat services; and recreation under cultural services. Services that had very few observations and did not belong to any of the above services were classified as ’other services’. Detailed definitions of these ES types are presented in Appendix B.

3.2.2. *Valuation method*

A number of valuation methods were applied to evaluate grassland ESs. We classified them into three categories following De Groot et al. (2012) and Zhou et al. (2020). The first was the market-based method, including the market price method (MP) and shadow price method (SP). When grassland products or services are traded directly on the market, we can use prices to reveal human preferences for grassland services. The shadow price method is an alternative market approach that uses existing prices for marketed goods to parameterize the value of nonmarket goods. For example, Li et al. (2018) used the prices of N, P and K in fertilizer to estimate the economic value of maintaining soil fertility services. Similarly, the price of the carbon tax was used to calculate the capacity of grassland carbon sequestration by Ouyang et al. (1999). The second method is the replacement cost method (RC), which is a cost-based method. The replacement cost method refers to the scenario in which a certain amount is spent to establish a substitute service after a certain ES is damaged (Liu, 2009). The third is the equivalent factor method (EF), which represents a unit value-based approach (Costanza et al., 1997) and was proposed by Xie et al. (2008; 2017) based on a survey of 500 Chinese ecology experts. Specifically, all the ESs of each ecosystem were scored by 500 Chinese ecological experts and reweighted by importance, generating an equivalent coefficient for all the ESs of each ecosystem. The equivalent coefficient reflects the relative weight of the corresponding ES’s economic value for a certain ecosystem in comparison to that in a standard ecosystem (e.g., farmland). The estimates of the ES values change along with the equivalent factors. This is a very commonly used method to evaluate ESs in China. The fourth group, other methods, was less common in our database and included methods such as the avoidance cost method, energy analysis method, mitigation and restoration method, travel cost method and conditional value method.

3.2.3. *Research characteristics*

Three indicators were used to classify the characteristics of the empirical research (Chaikumbung et al., 2016), including the journal type (*SCI, CSSCI* and *non-SCI/CSSCI*), multi-disciplinarity of the authors (*cross-discipline*) and the year of the research (*research year*). The journal type consisted of three categories based on which database the study was published in: SCI (Science Citation Index journals), CSSCI (Chinese Social Sciences Citation Index) and non-SCI/CSSCI. English-language articles belonging to both the SCI and SSCI categories were classified into the SCI category. The *cross-discipline* variable was equal to 1 if the coauthors’ institutions covered more than one discipline category and otherwise equal to 0. Twelve common major discipline categories in China were used. The variable *research year* was also included in the meta dataset to capture possible changes in preferences over time.

3.2.4. *Characteristics of study sites*

We used three indicators to describe the study sites. First, the per capita GDP of the province where the study site was located (*GDP per capita*) was used to reflect the economic development level. These data were collected from the National Bureau of Statistics of China (2019). Second, whether the study site was located in a natural reserve *(natural reserve*) was used to reflect ecological protection efforts. This information was often given in the articles. For a few articles that did not provide this information, we manually checked the People’s Republic of China website (2019). Third, the latitude and longitude of the study site (*latitude, longitude*). These data were collected directly if they were reported in the primary studies; otherwise, we searched for the information in external yearbooks.

3.3. Econometric model

We first established the following model for the *meta*-regression analysis (Stanley et al. (2008); Fan et al. (2018)). The basic ordinary least square (OLS) regression model can be specified as:

$$y_{ij} = \beta + \sum_{i=1}^{I} \alpha_i X_{ij} + e_{ij} (i = 1, 2, \cdots\cdots I, j = 1, 2, \cdots\cdots J) \qquad (1)$$

where y_{ij} is the grassland ES value in thousand yuan/ha/yr for the i th observation in the j th primary study, X_{ij} is a vector including all independent variables, j is the number of independent variables, α_i represents the estimated coefficients, and e_{ij} is the error term, which is normally distributed.

Multicollinearity, publication bias and heteroskedasticity are three common issues when estimating the above model for a *meta*-regression analysis (Stanley et al., 2008; Fan et al., 2018). In regard to the first issue, variance inflation factors (VIFs) are commonly used to test for potential multicollinearity problems. The VIFs for this set of independent variables ranged from 1.54 to 7.21 (less than 10), indicating that multicollinearity was not an issue.

On the second issue, publication selection bias, which refers to the fact that statistically significant results are essentially more likely to be published, can be another important concern in *meta*-regression analyses (Stanley, 2005; Hirsch, 2018). As the standard errors were not available for each grassland ES value included in our analysis, the square root of sample size in each study was used as the weight in weighted least squares (WLS) to measure publication bias. As showed in Appendix C, we used a t test to test the coefficient of the square root of the sample size in the *meta*-regression analysis to check the effect of publication bias (Stern, 2012; Chaikumbung et al., 2016; Fan et al., 2018). The coefficient corresponding to the square root of sample size was nonsignificant, implying that the observed effects varied randomly around the “true” effect, i.e., that there was no publication bias in our study selection (Stern, 2012; Fan et al., 2018). The details are as follows:

First, the square root of the sample size was employed in Eq. (1) to test for publication selection bias according to Stern (2012); Chaikumbung et al. (2016); Fan et al. (2018). The updated OLS regression model can be specified as follows:

$$y_{ij} = \beta + \sum_{i=1}^{I} \alpha_i X_{ij} + \beta_0 \frac{1}{\sqrt{n_j}} + e_{ij} (i = 1, 2, \cdots\cdots I) \qquad (1\quad '\quad)$$

where y_{ij} is the i th observation on grassland ES value from the j th study, β is the “true” effect when no publication selection and misspecification biases are presented, and n_j is the number of observations in the j^{th} empirical study.

Second, due to obvious heteroskedasticity, equation (1’) is rarely estimated directly. Rather, its WLS version, where the equation is divided by $\frac{1}{\sqrt{n_j}}$, is the obvious method of obtaining efficient estimates. The regression results of equation (2) showed that there was no publication bias in our study (Appendix C):

$$y^n_{ij} = \beta_0 + \beta\sqrt{n_j} + \sum_{i=1}^{I} \sqrt{n_j}\alpha_i X_{ij} + v_{ij} (i = 1, 2, \cdots\cdots I) \qquad (2)$$

where β_0 is the new intercept tested with a t test to account for a publication bias effect, the estimate coefficient β represents the authentic effect, i.e., correction for publication selection bias (Stanley, 2005), $y^n_{ij} = \sqrt{n_j} y_{ij}$ is the weighted grassland ES value estimate, and $v_{ij} = \sqrt{n_j} e_{ij}$ is the new error term with a normal distribution.

For the third issue, we used the White test to test for heteroskedasticity and confirmed its presence. OLS with White’s standard errors (Quintas-Soriano et al., 2016) in equation (1) was applied to the *meta*-regression analysis to address heteroskedasticity.

Alternatively, the disturbance variance derived from the OLS model in equation (1) was used as the weight in the WLS model to correct for the heteroskedasticity problem (Greene, 2005; Stanley et al., 2008). Following equation (1), the WLS model can be expressed as follows:

$$y^{sd}_{ij} = \frac{\beta}{\widehat{\sigma}^2_{ij}} + \sum_{i=1}^{I} \alpha_i \frac{X_{ij}}{\widehat{\sigma}^2_{ij}} + \mu_{ij} (i = 1, 2, \cdots\cdots I) \qquad (3)$$

where $\widehat{\sigma}^2_{ij}$ is the estimated disturbance variance σ^2_{ij}, $y^{sd}_{ij} = \frac{y_{ij}}{\widehat{\sigma}^2_{ij}}$ is the weighted grassland ES value, and μ_{ij} is the new error term with a normal distribution.

To confirm the robustness of the regression results, two models (the robust OLS model and WLS model) illustrated and compared with the results from basic OLS model. Data analysis was conducted using Stata 16.0 (StataCorp, USA). The map of the sampling sites was plotted with ESRI ArcGIS 10.3 (ESRI, USA).

4. Results

4.1. Statistical description

A total of 745 grassland valuation observations were extracted from 69 articles. The locations corresponding to these observations were distributed throughout most provinces in China (Fig. 2.), covering 91% of the grassland areas in the country. Inner Mongolia ranked first, with 114 observations, accounting for 15.3% of all observations, followed by Xinjiang, with a proportion of 14.9% (111 observations). These two provinces are the main grassland provinces, covering 35% of the total grassland area of China (Li and Wang, 2016). Sichuan, Gansu and Jilin Provinces each had approximately 70 observations. Shaanxi Province ranked last with only 11 observations.

Among all the valuation methods, the equivalent factor method was the most popular method, with over 74% of the obtained observations (Table 2). Approximately 11% and 7% of the observations were obtained through application of the shadow price method and replacement cost method, respectively. The market price method was less used, with the fewest observations, accounting for approximately 3%. Furthermore, the equivalent factor method was used to assess all types of services provided by grasslands in our database, while the other methods were used for certain ES types. For example, the market price method was mainly applied to estimate the values of raw material and food supply services; the shadow price method was mainly used to value erosion control, soil fertility, and sometimes climate regulation services; and the replacement cost method was mainly applied to estimate the value of climate regulation, water regulation and waste treatment services.

A summary of the economic value of each ES is presented in Table 3. Almost 20% of the observations were associated with climate regulation services, which ranked first among all the services assessed. Soil fertility ranked second, with a proportion of 14% of the observations. Water supply services had the fewest observations, accounting for only 4% of the total number. Among all grassland service values, on average, soil fertility was the highest valued (mean = 1,912 yuan/ha/yr), followed by genetic diversity (mean = 1,483yuan/ha/yr) and erosion control (mean = 1,459 yuan/ha/yr). In contrast, the services that carried the lowest economic value estimates were raw material (mean = 230 yuan/ha/yr) and other services (146 yuan/ha/yr). Furthermore, based on the average value of each ES, we calculated that the total average economic value of grassland ESs in China was 10,781 yuan/ha/yr. More specifically, the total economic values of soil fertility, erosion control, climate regulation, waste treatment and water regulation under regulation services accounted for 67% of the total average grassland ES value. This showed that grassland regulation services were the most valuable services. This

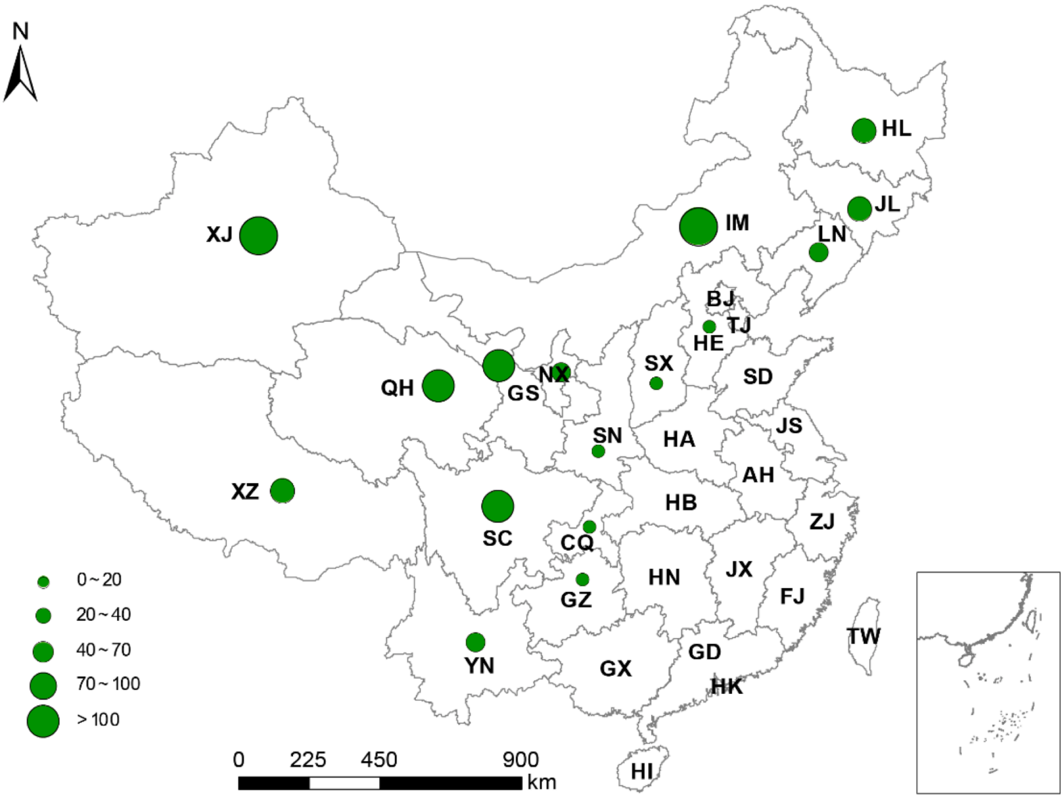

Fig. 2. Geographical distribution of the observations.

Table 2
Number of observations representing different grassland ES and valuation methods.

Grassland ES	Valuation Methods				
	EF	MP	SP	RC	Other
Food supply	61	6	0	0	2
Water supply	23	2	5	1	0
Raw material	62	8	1	0	1
Climate regulation	119	1	4	17	2
Water regulation	42	0	6	18	1
Waste treatment	55	0	8	2	1
Erosion control	2	0	10	2	5
Soil fertility	67	5	22	5	5
Genetic diversity	56	0	0	1	2
Recreation	53	1	1	0	8
Other services	15	1	25	3	8
Total	555	24	82	49	35

Note: EF = equivalent factor method; MP = market price method; SP = shadow price method; RC = replacement cost method.

ES type was followed by provisioning services (e.g., food supply, raw material and water supply) and habitat services, each with almost the same proportion of 13%. Cultural services ranked last.

4.2. Meta-regression analysis

To verify the robustness of the WLS model (Model 3), we added two more regressions: the basic OLS regression (Model 1, baseline model), robust OLS regression with robust standard errors (Model 2). As shown in Table 4, the regression results of Model 2 and Model 3 were consistent with each other, confirming the robustness of the WLS regression. Furthermore, we also calculated the Akaike's information criterions (AICs) for all the models to evaluate the performance of the models (Akaike, 1974). The WLS model had the lowest AIC among the three models, indicating a better fit for the data than the other two models. Besides, since the observations from the same paper may correlated with each other, we also tried to cluster the standard errors by paper in the WLS model (Wooldridge, 2015). The estimation results for all key variables were consistent between the two models with and without clustering. Here we present the results without clustering. Based on the above three points, the results obtained from Model 3 are reported. For all dummy variables, the coefficient of the explanatory variable in the model was interpreted as the difference of ES value in thousand yuan/ha/year between this variable and the category used as base for comparison. For the continuous variables such as GDP per capita, the estimated coefficient was marginal value of ES.The adjusted R^2 values ranged from 0.37 to 0.54, which were close to the adjusted R^2 values in

Table 3
Summary of the economic value for each ES. Values are expressed in thousand yuan/ha/yr at constant year 2015.

	N	Average value (thousand yuan in 2015/ha/yr)	SD
Provisioning services			
Food supply	69	0.423	0.199
Raw material	72	0.231	0.295
Water supply	31	1.001	0.781
Regulating services			
Climate regulation	143	1.343	1.060
Erosion control	19	1.460	1.850
Water regulation	67	1.049	0.948
Soil fertility	104	1.912	1.724
Waste treatment	66	1.355	0.811
Habitat services			
Genetic diversity	59	1.483	0.883
Cultural services			
Recreation	63	0.288	0.452
Other services	52	0.146	0.148
Total average economic value		10.781	

Note: N = number of estimates; SD = standard deviation.

Table 4
Estimates of the *meta*-regression analysis models with ordinary least squares (OLS) and weighted least squares (WLS) models.

VARIABLES	Model 1: OLS		Model 2: Robust OLS		Model 3: WLS	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
Intercept	6.155	12.927	6.155	14.075	16.183**	6.873
Ecosystem Services (baseline = Food supply)						
Raw material	−0.198	0.156	−0.198***	0.058	−0.231***	0.053
Water supply	0.504**	0.202	0.504***	0.128	0.485***	0.074
Climate regulation	0.898***	0.137	0.898***	0.086	0.771***	0.074
Erosion control	1.301***	0.256	1.301***	0.409	1.251***	0.325
Water regulation	0.627***	0.165	0.627***	0.131	0.677***	0.100
Soil fertility	1.571***	0.146	1.571***	0.157	1.283***	0.141
Waste treatment	1.026***	0.161	1.026***	0.099	1.004***	0.091
Genetic diversity	1.078***	0.165	1.078***	0.107	1.052***	0.097
Recreation	−0.091	0.162	−0.091	0.072	−0.149**	0.078
Other services	0.117	0.188	0.117	0.111	−0.041	0.065
Valuation Method (baseline = Market price method)						
Equivalent factor method	−0.395*	0.208	−0.395**	0.160	−0.334***	0.089
Shadow price method	−0.759***	0.229	−0.759***	0.219	−0.558***	0.108
Other methods	−0.374	0.254	−0.374*	0.217	−0.373***	0.100
Replacement cost method	0.123	0.243	0.123	0.299	−0.007	0.245
Research Characteristics						
Journal type (baseline = SCI)						
CSSCI	−0.473***	0.139	−0.473***	0.129	−0.204***	0.070
Non-SCI/CSSCI	−0.186*	0.105	−0.186*	0.110	−0.061	0.052
Cross-discipline	0.314***	0.087	0.314***	0.087	0.176***	0.048
Research year	−0.003	0.006	−0.003	0.007	−0.008**	0.003
Study Site Characteristics						
GDP per capita	0.009**	0.004	0.009**	0.004	0.012***	0.003
Natural reserve	−0.036	0.118	−0.036	0.139	0.013	0.066
Latitude	−0.012*	0.007	−0.012**	0.005	−0.008**	0.003
Longitude	0.011***	0.003	0.011***	0.002	0.006***	0.002
Observations	745		745		745	
R-squared	0.373		0.373		0.536	
AIC	2016.539		2016.539		971.767	
Mean VIF	2.32		2.32		2.04	
F	19.53		33.67		37.88	
p value	0.000		0.000		0.000	

Note: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

previous *meta*-regression studies by Quintas-Soriano et al. (2016) and Zhou et al. (2020). The mean VIFs were 2.32, 2.32 and 2.04 for Model 1, Model 2 and Model 3, respectively, which indicated no concerns over multicollinearity.

4.2.1. Analysis of ESs and methods

All types of services provided by grasslands had different values (Table 4, Model 3). Compared to food supply services, only raw material and recreation services supplied a lower value (by 231 fewer yuan/ha/yr and 149 fewer yuan/ha/yr, respectively), while all other types of services had higher values. Soil fertility ranked the highest, with a value 1,283 yuan/ha/yr higher than that of food supply, followed by erosion control, with a value 1,251 yuan/ha/yr greater.

The application of different methods had great impacts on the monetary results of ESs. The market price method and replacement cost method provided the highest grassland ES estimation values, followed by the equivalent factor method. Other methods and the shadow price method were associated with the lowest values reported among all the studied methods. Specifically, the overall grassland ES value estimated by the equivalent factor method was 334 yuan/ha/yr lower than that estimated by the market price method. Other methods and the shadow price method provided values 373 yuan/ha/yr and 558 yuan/ha/yr lower, respectively, than those estimated by the market price method.

4.2.2. Analysis of research and study site characteristics

We also found that studies published in different types of journals provided different estimated values. The studies published in SCI journals provided higher grassland ES values than CSSCI publications. The grassland ES values reported were 204 yuan/ha/yr lower in CSSCI than in SCI publications. More interestingly, we found that coauthors with multidisciplinary backgrounds were more likely to provide higher values than those reported in publications by coauthors with the same area of study. The grassland ES value estimated in multidisciplinary papers was 176 yuan higher than that reported in studies by coauthors from the same field. The negative significance of the research year indicated that the estimated value of grassland ESs decreased by 8 yuan/ha/yr.

In terms of study site characteristics, the economic development level indicated by per capita GDP showed a significant and positive association with the grassland value. An increase of 1000 yuan in per capita income was found to increase the economic value of grasslands by 12 yuan/ha/yr, according to Model 3. We also added the natural reserve variable to describe the type of grassland (natural reserve versus nonnatural reserve). The corresponding coefficient was positive but nonsignificant. The latitude and longitude information of each study site were included in the *meta*-regression analysis to deduce the geographical distribution trends of the economic value of ESs. The results of Model 3 showed that the economic value of grassland ESs decreased with increasing latitude and increased with increasing longitude.

4.2.3. Analysis of interactions between ESs and methods

We further explored the relative magnitudes of the economic value of each ES provided by different methods. Four interactions between the ESs and methods were introduced to explore whether the use of a certain method causes different estimated grassland ES values. We correlated each method variable (except that for the ’other methods’ category) with all the types of grassland ESs; the interaction results are shown in the columns for Model 4, Model 5, Model 6 and Model 7 (Table 5). The adjusted R^2 values of the interactive models shown in Table 5 ranged from 0.354 to 0.378.

Table 5
Estimation results of the *meta*-regression analysis models with interactions.

Variables	Model 4 ES#MP		Model 5 ES#EF		Model 6 ES#SP		Model 7 ES#RC	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
Interactional Characteristics								
Food supply #Method	0.328*	0.175	−0.279*	0.155	–	–	–	–
Raw material #Method	0.437***	0.146	−0.340**	0.138	−0.266**	0.136	–	–
Water supply #Method	0.120	0.455	−0.039	0.308	−0.185	0.409	0.400**	0.182
Climate regulation #Method	0.376**	0.163	−0.812**	0.354	−0.878*	0.473	1.329***	0.428
Erosion control #Method	–	–	−1.374***	0.452	0.085	0.763	0.248	1.263
Water regulation #Method	–	–	0.228	0.271	−1.100***	0.159	0.198	0.320
Soil fertility #Method	0.452	0.528	0.514	0.393	−0.805*	0.455	0.761	1.314
Waste treatment #Method	–	–	0.318	0.318	−0.466	0.390	−0.381	0.514
Genetic diversity #Method	–	–	−0.627	0.762	–	–	−0.857***	0.179
Recreation #Method	1.357***	0.145	−0.321*	0.182	−0.078	0.143	–	–
Other services #Method	−0.337***	0.173	0.103	0.110	−0.114	0.089	−0.252	0.225
Intercept	10.155	14.300	10.201	13.883	13.868	13.885	10.675	13.850
Observations	745		745		745		745	
R-squared	0.354		0.377		0.370		0.378	
AIC	2039.339		2026.128		2026.082		2014.983	
F	15.730		27.150		15.600		16.760	
p value	0.000		0.000		0.000		0.000	

Note: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.
We deleted the regression results in this table for which the coefficients were consistent with those listed in Table 4.
Missing values indicate that the coefficients could not be estimated owing to a lack of observations representing this type of variable interaction.

Compared to the nonmarket price method, the market price method provided higher values for evaluations of climate regulation, food supply, raw material and recreation services (in Model 4). Specifically, for recreation services, the market price method provided a value 1,357 yuan/ha/yr higher than that provided by the other methods. However, the effects of the market price method on the valuation of the remaining grassland ESs, such as soil fertility and water supply, were the same as those of the other methods category. In contrast, the equivalent factor method provided lower values in assessments of food supply, raw material, climate regulation, erosion control and recreation services (Model 5). Similarly, the estimated values were negatively determined when the shadow price method was used to assess raw material, climate regulation, water regulation and soil fertility services (Model 6). Additionally, the values of the climate and water supply services were positively determined and genetic diversity services negatively determined when the replacement cost method was used in the studied articles (Model 7).

4.2.4. *Predicted monetary values of ESs*

We estimated the monetary value of each grassland ES after the *meta*-regression and all the estimates were significance at 1%. As shown in Table 6, the total estimated grassland monetary value was 10,876 yuan/ha/yr. The grassland regulating services were the most valuable, with a total of economic value of 7,162 yuan/ha/yr, accounting for two-thirds of the total monetary value of grassland. Among the regulating services, the two most valuable services were soil fertility service and erosion control service. Surprisingly, the economic value of genetic diversity was relatively high (1,437 yuan/ha/yr), demonstrating the contribution of grassland to genetic diversity.

Table 6
Predicted monetary value of individual ESs per thousand yuan per hectare in constant year 2015.

Ecosystem service	Predicted value	Std. Err.	*t*	P > *t*	[95% Conf.	Interval]
Food supply	0.343	0.055	6.300	0.000	0.236	0.450
Raw material	0.157	0.059	2.640	0.008	0.040	0.273
Water supply	0.799	0.155	5.170	0.000	0.496	1.103
Climate regulation	1.228	0.070	17.530	0.000	1.090	1.365
Erosion control	1.492	0.324	4.610	0.000	0.856	2.127
Water regulation	1.100	0.102	10.840	0.000	0.901	1.299
Soil fertility	1.899	0.124	15.270	0.000	1.654	2.143
Waste treatment	1.443	0.081	17.880	0.000	1.285	1.602
Genetic diversity	1.437	0.075	19.110	0.000	1.289	1.585
Recreation	0.260	0.076	3.440	0.001	0.112	0.409
Other services	0.718	0.119	6.020	0.000	0.484	0.952

5. Discussion

This study tried to provide a synthetic evaluation of the monetary value of grassland ESs. The *meta*-regression analysis was conducted with 745 observations, covering a variety of grassland ESs and other characteristics. The findings provide useful perspective to the multiple economic values of grassland ESs and the influential determinants related to variations in such evaluations, as reported in the evaluation literature. We believe that econometric modeling provides a rigorous assessment of the factors of the ES values, and illustrates a substantial advance on previous studies based on smaller databases or site-specific cases (De Groot et al., 2012).

The most synthetic assessment of ES values reported by De Groot et al. (2012) provided an overview of the economic value of 10 biomes including grasslands, and represented a useful comparison to our results. As shown in Appendix D, more primary studies and grassland ESs were incorporated in our study than were available to De Groot et al. in 2012. The mean estimated values varied greatly between the two studies. For example, the value estimates for water supply, climate regulation, erosion control, waste treatment and recreation were noticeable lower in De Groot et al. (2012), while those for food supply and genetic diversity were higher in contrast to our results.

The estimated values per individual ES varied vastly. The economic value of soil fertility and erosion control service were higher than those for other services. This is in line with previous findings by Kang et al. (2020). Soil plays a crucial role in ecological functions and is the foundation for the whole food web in grassland ecosystems (Lal, 2004). The destruction of soil fertility service not only results in a reduction in grass yield output but also further reduces the subsequent meat and milk supplies (Liu et al., 2015a; 2015b). Thus, taking the potential monetary value of grassland regulating services into consideration in land use decisions is important for improving the provision of grassland ESs and the allocation of grassland resources.

As expected, the economic value of raw material services was relatively lower than that of food supply services. This may be due to the varying degrees of grassland degradation in China, which leads to declines in forage quality and quantity (Zhou et al., 2005; Harris, 2010). Overgrazing is an important factor related to degradation (Yan et al., 2021). With population increases, the ruminant livestock population grows synchronously, further reducing the productivity of grasslands and increasing the gap between the food supply service and raw material service. The lower economic value of recreation services than that of most other ESs is consistent with the findings of Kang et al. (2020). Many natural grassland areas are either not associated with the tourism industry or the tourism industry is constrained in these regions by seasonal changes. The consequences are higher travel costs, inconvenient traffic, short travel seasons and relatively low value estimations (Jiang et al., 2014).

In terms of the valuation methods, we found that the market price method produced higher economic estimates than that of others. This is consistent with the findings of Taye et al. (2021) and Chaikumbung et al. (2016), who noted higher grassland ES values produced by the market price method. More specifically, higher economic values tended to be reported for provisioning services, climate regulating services and recreation services when the market price method was used. One explanation for this result is that provisioning services and recreation services have more direct impacts on their corresponding market than other ESs do, leading to greater concerns and higher valuations. The lower ES values found to be associated with the equivalent factor method match the results of Zhou et al. (2020). Interestingly, the values of all grassland ESs estimated using the equivalent factor method were lower than those valued by the other methods. This may be related to the low weights of grassland ES values for the equivalent factor method. Therefore, selecting the appropriate valuation method for different services is key to account for the economic value of grassland ESs.

We included the latitude and longitude as a proxy for geographical factors, finding that grassland ES values decrease in latitude but increase in longitude. Previous studies, e.g., Sun et al. (2018) reported the significance of geographical coordinates in influencing the monetary value of ESs. This was associated with the climate characteristics of China, i.e., rainfall and sunshine increase gradually as longitude increases and latitude decreases (Wang et al., 2014). Further, spatial differences in grassland ES monetary values might provide insights for grassland conservation policymaking. The results also revealed that per capita GDP has a significant and positive effect on grassland ES values, which has been confirmed in similar studies (Brander et al., 2012; Sun et al., 2018; Bockarjova et al., 2020). That is, grasslands are a normal good, and grassland values are inelastic in income.

Our study also provided the empirical evidence on the significance of *journal types* and *coauthor disciplines* on the evaluation of the monetary value of grassland services, which has been supported in previous studies (Chaikumbung et al., 2016). SCI studies tended to report higher values than CSSCI studies. This may be related to the fact that estimates published in SCI journals are subject to more professional peer review compared to the national wide reviewers for CSSCI studies, resulting in more positive valuations. Coauthors from different disciplines appeared to produce higher value than those from the same discipline. This could attribute to the advantage of cross-disciplinary approaches, which integrate a knowledge from broader areas to measure the benefits that grassland ESs provided to humans (Lawton and Rudd, 2013); thus, authors with interdisciplinary backgrounds can take more aspects of grassland ESs into account during the evaluation.

Although encouraging results were obtained from this study, we admit that the paper also has some limitations specifically associated with the classification of grassland types. Comparing the economic value of ESs based on different grassland types is challenging, as the primary studies are often conducted on general grassland with less classification. The direction of future studies will involve covering more refined grassland classification types, wider geographical ranges and varieties of grassland characteristics to improve the accuracy of the results. Furthermore, a *meta*-regression analysis only provides a general assessment of the influential factors of ESs in monetary units including primary study characteristics and national level variables, without considering local contexts properly at a more micro or site-specific scale.

6. Conclusions and policy implications

This study attempts to systematically analyze the primary studies that provide estimates of the economic value of grassland ESs, including the valuation methods and other study characteristics. Four main results were derived through the *meta*-regression analysis by using a total of 745 observations from 69 studies. First, the total monetary value of grassland was 10,876 yuan/ha/yr. Second, soil fertility and erosion control were the two most valued services, with values estimated 1,899 yuan/ha/yr and 1,492 yuan/ha/yr, respectively. Third, the market price method was the likeliest to provide higher grassland ES values. Fourth, the economic value of grasslands in eastern China was higher than that in western China.

Even through grassland regulating services such as soil fertility service and erosion control play important roles in grassland ES functions, they are often neglected in private land use decisions due to the perception that they are public goods with no market value (Taye et al., 2021). Thus, designing better grassland conservation strategies for local communities by emphasizing the monetary values of grasslands and combining conservation efforts with market-based mechanisms, for instance, involving GECPs, might be a possible strategy to address this situation. Our analysis of the determinants of ES economic values can help identify policy interventions in grassland conservation efforts by providing information on the relevant influencing factors.

Attention should be paid to the selection of the evaluation method, especially when accounting for grassland ES values. Our study determined that the evaluation method was an important factor that could affect the evaluation results and that the market price method was the likeliest to estimate higher values. An appropriate evaluation method should be considered according to the target grassland services when evaluating the monetary value of grassland ESs. The monetary value of grassland ecosystems showed geographical distribution differences that decreased with increasing latitude and increased with increasing longitude, indicating that grasslands in eastern China were more valuable than those in western China. These findings contribute to the literature evaluating the economic value of grassland ESs regarding the discrepancies in economic value, thus helping to inform grassland management (Grammatikopoulou and Vačkářová, 2021). Further, these results are helpful for better accounting for the services provided by grassland ecosystems, which is significant for improving land use decision making for sustainable ecosystem management.

CRediT authorship contribution statement

Huifang Liu: Methodology, Data curation, Writing – original draft, Writing – review & editing. **Lingling Hou:** Conceptualization, Methodology, Writing – review & editing. **Nannan Kang:** Data curation, Writing – review & editing. **Zhibiao Nan:** Conceptualization, Writing – review & editing, Supervision, Funding acquisition, Project administration. **Jikun Huang:** Conceptualization, Methodology, Writing – review & editing, Supervision, Funding acquisition, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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