



# The cost–benefit evaluation based on ecosystem services under different ecological restoration scenarios

Mingqi Li · Shiliang Liu · Yixuan Liu ·  
Yongxiu Sun · Fangfang Wang · Shikui Dong ·  
Yi An

Received: 11 November 2020 / Accepted: 1 June 2021 / Published online: 8 June 2021  
© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2021

**Abstract** The effects of ecological restoration based on ecosystem services (ES) have attracted more and more attention, while the simulation and cost–benefit analysis of ecological restoration scenarios are not well investigated. In this study, four ecological restoration scenarios were simulated at a typical watershed on the Qinghai-Tibetan Plateau (QTP) based on the land use conversion. Scenario 1 was only grassland restoration, Scenario 2 and 3 were mainly farmland to shrub, and Scenario 4 was mainly grassland restoration with bare land converting to forest and shrub. The ecosystem services value (ESV) and the cost-benefits of these scenarios were quantified and compared in 25 years after the restoration investment. The results showed there were significant differences in the ESV under four scenarios, among which Scenario 4 had the largest ESV and Scenario 1 had the smallest ESV. The spatial distribution of ESV was uneven, and high-value regions were concentrated in

the southwest and central regions. There were great variations between original scenario and simulated scenarios, but a little difference between Scenarios 2, 3, and 4. The largest loss of farmland abandonment was regulating service, followed by supporting service, provisioning service, and cultural service. From the perspective of payback period, Scenario 1 was the fastest, and it could obtain net benefits first. From the short- and long-term (6 and 25 years after investment) benefits, Scenarios 1 and 4 had the largest cumulative ESV increase, respectively. The results of this study can provide a basis for the formulation and implementation of ecological policies.

**Keywords** Ecosystem service value · Land use simulation · Grassland restoration · Afforestation · Ecological compensation

**Supplementary information** The online version contains supplementary material available at <https://doi.org/10.1007/s10661-021-09188-7>.

M. Li · S. Liu (✉) · Y. Liu · Y. Sun · F. Wang · Y. An  
School of Environment, State Key Laboratory of Water Environment Simulation, Beijing Normal University,  
Beijing 100875, China  
e-mail: shiliangliu@bnu.edu.cn

S. Dong  
School of Grassland Science, Beijing Forestry University,  
Beijing 100083, China

## Introduction

As a global ecological problem, land degradation has become an important factor restricting regional sustainable development (Wei et al., 2020). Land degradation has been defined as a decline in soil productivity, soil quality, biodiversity, ecosystem services, and standards of living (Batunacun et al., 2019). The FAO assessed that 61.4 million km<sup>2</sup> of land were degraded worldwide, and 26% reached the level of severe degradation (Gang et al., 2018). The QTP is one of the typical ecological fragile zones in China

and one of the most ecologically vulnerable areas in terms of grassland degradation in the world (Li et al., 2019a). As one of the most important indicators of degraded grassland, the area of sandy land has reached  $21.58 \times 10^4 \text{ km}^2$  in Tibet and  $12.46 \times 10^4 \text{ km}^2$  in Qinghai by 2014, ranking the third and fourth largest area at the provincial level in China (State Forestry Administration, 2015). To restore the degraded land, an increasing number of ecological restoration projects have been undertaken in China, such as establishment of natural reserve and revegetation of artificial forest and shrubs (Li et al., 2019a). As one of the important policies of the “Western Regions Development Strategy,” “Grain for Green program” (GFG) is the world’s largest ecological restoration project, and has significantly increased the vegetation coverage in Northwest and Southwest China (Wang et al., 2019). From 1999 to 2014, China’s afforestation area from steep sloping farmland and wasteland was 29.8 million hectares, and another 5.33 million hectares farmland was planned for forestation by 2020 (Fan & Xiao, 2020). Recently, China released the master plan for major projects of national important ecosystem protection and restoration (2021–2035), and the ecological barrier area of the QTP is one of the key areas. However, where and how to carry out the ecological restoration projects are not clear and need to be studied.

The ecological effects of restoration projects must be precisely evaluated, because effective evaluation is essential for any scientific and practical progress in ecological restoration, and also for policy makers and conservationists (Lu et al., 2019; Woodcock et al., 2012). Numerous studies have focused on environmental influence including water and soil quality, biodiversity, and so on (Paillex et al., 2017; Sui et al., 2020; Zhang & Dong, 2010). As one of the main goals of ecological restoration, ecosystem services (ES) have aroused great international attention (Ren et al., 2016) and as an important evaluation indicator. Many studies defined the ES as the benefits directly or indirectly that human acquire from ecosystems (Hasan et al., 2020). The ES often divided into four categories, including supporting services, provisioning services, regulating services, and cultural services (Li et al., 2010). Mao et al. (2019) integrated ecological characteristics, ecological processes, and ES to conduct a comprehensive assessment of wetland restoration in the QTP. Luo et al. (2019) assessed

long-term ES driven by ecological restoration and provided a socio-ecological system for ecosystem services management. However, studies on the dynamic changes of ES in ecological restoration are rare.

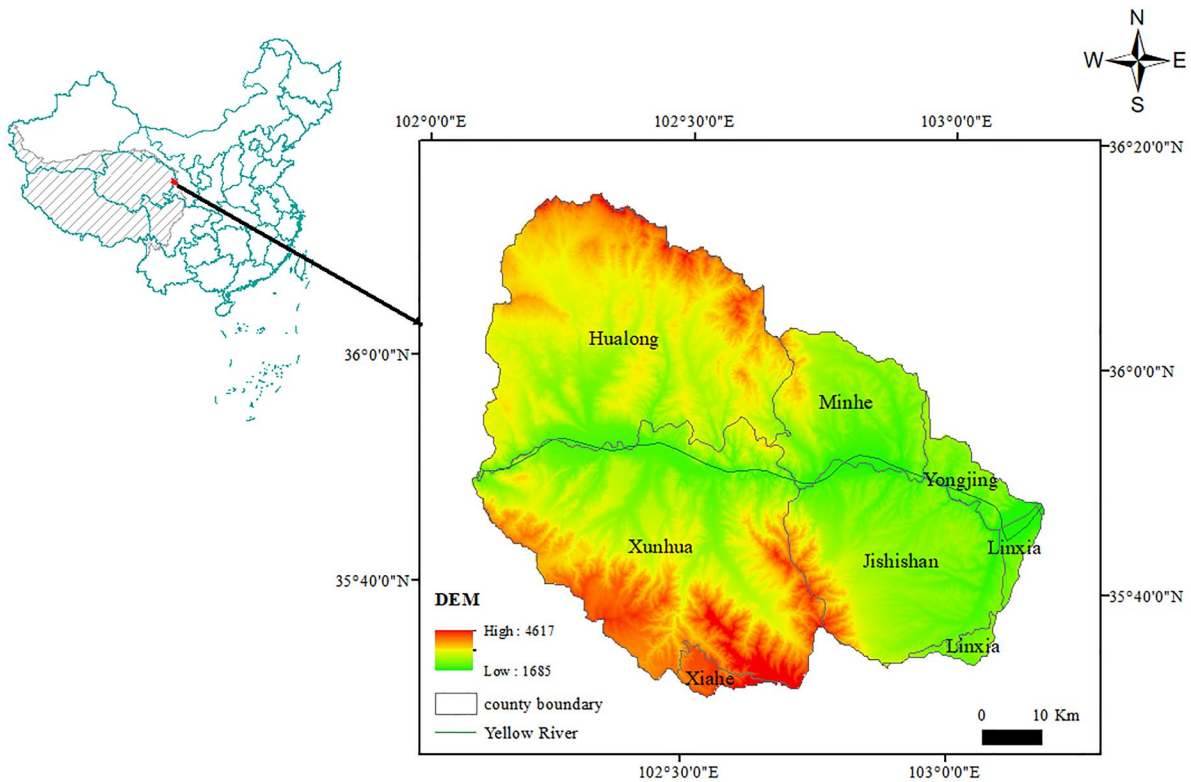
Previous studies have quantified the ecosystem service value and reported ESV changes of restoration projects (Clarke et al., 2015; Jenkins et al., 2010; Tong et al., 2007). However, the restoration costs associated with these ecosystem services have not been adequately considered in previous studies (Xian et al., 2020). Cost–benefit analysis is a commonly applied valuation method used to compare the level of financial investment with the resulting project value (Boyd et al., 2015). Lin et al. (2020) analyzed the costs and environmental benefits of watershed conservation and restoration in Taiwan and found that the total value of environmental benefits exceeded the total cost after 30 years of investment. Xian et al. (2020) conducted a cost–benefit analysis for China’s Grain for Green Program and found the best cost–benefit ratio was acquired through natural forest conservation. The previous research showed a positive correlation between costs and conservation benefits (Naidoo & Ricketts, 2006), but there were a few researches on cost–benefit analysis of ecological restoration in China, especially studies at watershed scale. And there are fewer analyses of the ecological benefits under different scenarios for watershed restoration.

To solve the problem, we calculate the investment costs and environmental benefits based on ESV under four types of ecological restoration scenarios in a typical watershed on the QTP. The objectives of this study were (1) to quantify land use change and the spatial distribution of ESV under different scenarios and (2) to conduct a time series cost–benefit analysis under different ecological restoration scenarios. The results of our study to compare and rank the different ecological restoration scenarios could be utilized to make effective restoration strategies.

## Method

### Study area

The study area is located on the eastern edge of the QTP (Fig. 1), at the junction of Qinghai and Gansu provinces, and is a sub-basin of the Yellow River



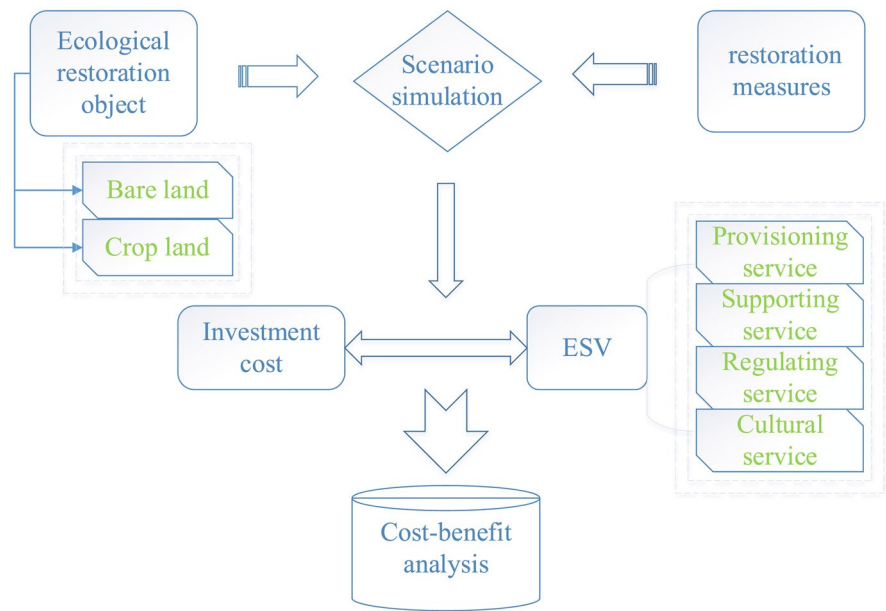
**Fig. 1** The location and DEM of the study area

Basin (102.09~103.18°E, 35.50~36.25°N). More than three-quarters of the study area is located in Haidong City, and about a quarter of the area is located in Linxia Autonomous Prefecture. The study area is traversed by the Yellow River from east to west with the length of 107.6 km, the altitude along both banks in the west is gradually increasing, and the overall altitude in the east is lower. The altitude is ranging from 1685 to 4617 m; and the average annual temperature is about 3.2–8.6 °C. The vegetation types in this area are mainly temperate grasslands and warm temperate deciduous broad-leaved forests. The land use types are diverse, including forests, grasslands, shrubs, farmlands, wetlands, water, impervious, bare land, and snow and ice. The grassland area is the largest, accounting for more than half of the total area of the study area, followed by farmland, accounting for about a quarter. The total population of the area is about 880,000, of which there are many ethnic minorities, and the four largest counties in this area are all ethnic autonomous counties (Fig. 2).

### Simulation scenarios

In the selection of the simulation scenario, the objectives should be first identified for restoration. In this study, agricultural land with a slope of more than 25° and all bare land should be restored; the restoration measures were planted grass, artificial forest, and artificial shrub; and the restoration results were shown as change in land use type. The study identified four simulation scenarios based on the local ecological restoration policies and practices, as well as some local natural and geographical conditions (Zheng et al., 2016). Scenario 1 restores all the bare land and sloping arable land that needs to be returned through artificial grass, which is very simple and common in practice. And the land use type changes are from cropland with slope above 25° and all bare land to grassland. Scenario 2 is a combination of three restoration measures for diversified restoration, with artificial shrub on cropland with slope above 25°, while the restoration of bare land is bounded by

**Fig. 2** The working flow-chart of this study



administrative divisions, which are usually the basic unit in restoration practice. The specific restoration measures are artificial grass planting in the county on the left including Hualong County and Xunhua County, which are areas that grasslands are concentrated. And artificial afforestation is applied in the county on the right including Minhe County, Jishishan County, Yongjing County and Linxia County. Scenario 3 is also a combination of three restoration measures, with artificial shrub on cropland with slope above 25°, and the restoration of bare land rely on water distribution and original vegetation distribution characteristics. On the one hand, in the ecological projects that have been implemented, the two sides of the Yellow River are often planted forests; on the other hand, the forests in the study area are mainly distributed in the range of 3000 to 4000 m above sea level. Therefore, bare land within 1 km of water and in the range of 3000 to 4000 m above sea level is designated for artificial reforestation, and other bare land

for artificial grass. Scenario 4 is also a combination of three restoration measures and a comparison of Scenario 3, with artificial grass on cropland with slope above 25°, artificial forest on bare land within 1 km of the water body and within 3000–4000-m elevations, and artificial shrub forest on bare land in other areas (Table 1).

**Investment program**

All investments during ecological restoration vary according to the restoration measures and actual conditions. In practice, investment projects are generally multi-year processes, usually in 2 years. Therefore, the investment in each restoration, measure is implemented in 2 years. Since grasslands have the shortest growing period, grass will be planted first in various restoration measures. After planting grass, plant shrubs first and then plant forests. The benefits of ecosystem services from different restoration

**Table 1** The land use transfer of four restoration scenarios

Current land use	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Farmland (> 25°)	Grassland	Shrub land	Shrub land	Grassland
Bare land	Grassland	Grassland (counties in the left) Forest (counties in the right)	Forest (1 km around water body and altitude ranging from 3000 to 4000) Grassland (other)	Forest (1 km around water body and altitude ranging from 3000 to 4000) Shrub land (other)

measures are different, and it is gradually increased with the vegetation growth over a period of time. The study assumes that the benefits of ecosystem services increase on an average year-on-year basis and reach the equilibrium after certain years. The ecosystem service benefits of grasslands, shrubs, and forests have been increasing continuously for 3 years, 5 years, and 10 years, respectively. The investment cost is calculated by the area of the restored project and the cost per unit area; the cost per unit area is obtained through the relevant bidding documents. In this study, we refer to the procurement announcement on the Qinghai Provincial Government Procurement Network (<http://www.ccpq-qinghai.gov.cn/>), and try to choose the similar and close cases to the study area. The final prices of artificial grass planting, artificial shrubs, and artificial afforestation were respectively referred to the artificial grass planting project at Henan County in 2019, the shrub plantation project at Ledu County in 2019, and the public welfare forest plantation project at Xining City in 2016 (Qinghai Provincial Government Procurement Network, 2016, 2019a, b).

Calculation of ecosystem service value

The equivalent coefficient of ESV per unit area is usually used as an important method for evaluating the ESV of regional ecosystems, so it is of great significance to choose the appropriate equivalent coefficient of ESV per unit area (Su et al., 2020). Based on the existing ecological service value researches and expert knowledge, an ecosystem

service value equivalent table per unit area was constructed by Xie et al., in which the ecosystem was divided into six primary categories and 14 secondary types, and ecosystem services were divided into four primary categories and 11 secondary types. In this study, on the basis of the equivalent coefficient proposed by Xie et al. (2015), we made some adjustments according to the actual situation of the study area and the results were showed in Table 2. And the land use/cover data we used was from 30 m global land cover dataset with an accuracy of 72.35%, provided by National Earth System Science Data Center, National Science and Technology Infrastructure of China (<http://www.geodata.cn>). This data source has been widely recognized, providing effective technical services and data support for a large number of scientific researches (Yang et al., 2019). The calculation formula is as follows:

$$ESV_t = \sum ESV_j$$

$$ESV_j = \sum_i^n V_{ij} \times A_i$$

$$V_{ij} = F_{ij} \times S$$

where  $ESV_t$  is the total  $ESV$ ,  $ESV_j$  is the  $j$  kind of  $ESV$ ,  $V_{ij}$  is the  $j$  kind of  $ESV$  per unit area of land use type  $i$ , and  $A_i$  is the area of the land use type  $i$ ,  $F_{ij}$  is the equivalent coefficient of the  $j$  kind of  $ES$  of land use type  $i$ , and  $S$  is the economic value of one standard equivalent factor (3406.5 RMB/hm<sup>2</sup>).

**Table 2** Ecosystem service equivalent value per unit area (Xie et al., 2015)

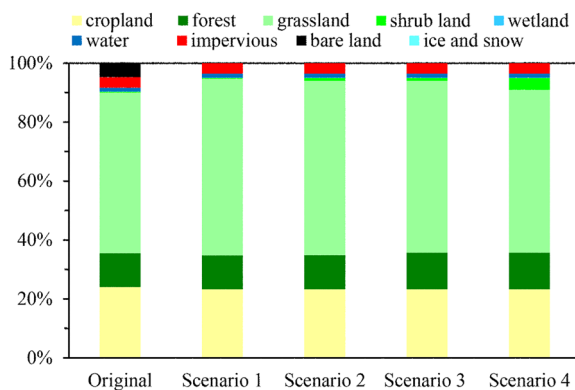
	Provisioning service	Regulating service	Supporting service	Cultural service
Cropland	1.27	1.40	1.28	0.06
Forest	1.23	13.94	5.01	1.01
Grassland	0.77	7.79	2.92	0.59
Shrub land	0.84	10.27	3.42	0.69
Wetland	3.60	33.33	10.36	4.73
Water	9.32	110.85	3.55	1.89
Impervious	0.00	0.00	0.00	0.00
Bare land	0.00	0.15	0.04	0.01
Ice and snow	2.16	8.01	0.01	0.09

## Results

### Land use change under different scenarios

From Fig. 3 we can find that original land use in this basin are mainly grassland, cropland, and forest, accounting for 54.5%, 23.99%, and 11.49% of the total land area, respectively. Bare land, impervious, water, shrub land, and wetland were 4.71%, 3.58%, 1.32%, 0.3%, and 0.1%, respectively, and the area of the ice and snow was extremely small. In Scenario 1, the grassland area increased significantly with a proportion of 59.94%, while the proportion of cropland decreased to 23.26%. Besides, the bare land disappeared, and other land uses remained unchanged. In Scenario 2, the area of grassland, shrub land, and forest all increased. The grassland increased the most, with the proportion reaching 59.10%; shrub land and forest were 1.04% and 11.6%, respectively. The area of cropland decreased to 23.26%. In Scenario 3, grassland, shrub land and forest were increased, with the proportion of 58.26%, 1.04%, and 12.45%, respectively. The area of cropland decreased to 23.26%, and bare land disappeared. In Scenario 4, grassland, forest, and shrub land increased, accounting for 55.23%, 12.45%, and 4.06%, respectively. The cropland decreased to 23.26%, and bare land disappeared.

In terms of the spatial distribution of land uses, the most widely distributed was grassland, concentrated in the southwest, northwest, and northeast (Fig. 4). Farmland was mainly distributed in the southeast and beside the river. It was mainly distributed in small pieces in the mid-west and embedded in the



**Fig. 3** The percentage of nine types of land use

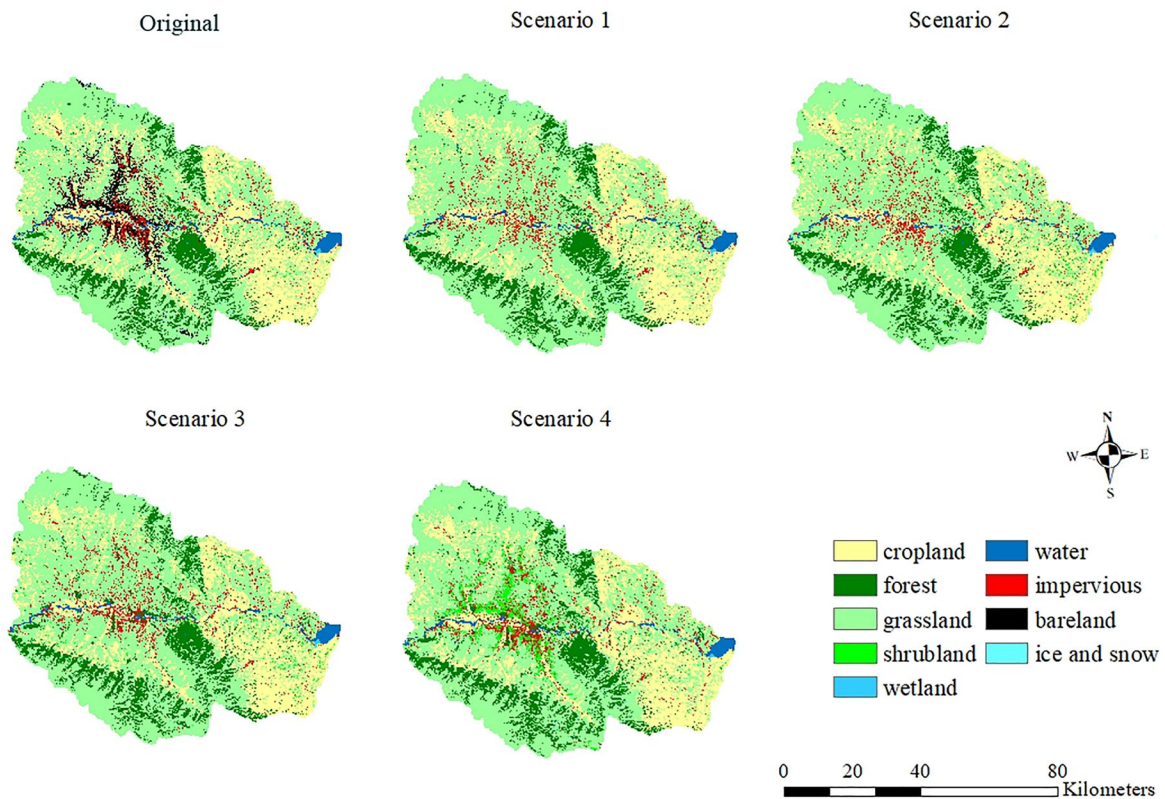
grassland, which may be cultivated from grassland. Farmland in the southeast was more concentrated as the agricultural development in this area was more mature. The forest was located in the southwest and central regions. The forests in the southwest were distributed in strips and were connected to strip farmland, which meant the farmland might be obtained by deforestation and reclamation, and the remained forest was at a higher altitude that was not suitable for reclamation. The small forest in the middle was closed to the river, so the water condition was good. The water body was mainly the Yellow River, which ran east–west and divided the study area into two parts, and the river flowed into a reservoir at the top of the east. The impervious surface was mainly distributed along the banks of the river, indicating that human settlements were mainly distributed along the river, and there were a few sporadic distributions in other places.

### Changes in ESV under different scenarios

In terms of the increase in ESV during four scenarios, Scenario 4 had the largest increase, and Scenario 3 and Scenario 2 were the second, and the third, Scenario 1 had the smallest increase (Table 3). Considering different categories of ESV, the largest increase in ESV was regulating services, followed by supporting services and provisioning services, and finally, the smallest increase was cultural services.

From the perspective of spatial distribution in total ESV (Fig. 5), the highest-value area was where the river located, roughly at the mid-axis location of the basin. Besides, the high-value areas were mainly located in the southwest and central regions, while the low-value areas were located in the mid-west. In the Original status, the distribution of low-value areas was relatively concentrated, showing a radial distribution. However, in the four simulated scenarios, the distribution of low-value areas were more scattered, and most of them were distributed near the banks of the river. In Scenario 4, the high-value areas increased and located in the mid-west along the banks of the river. The spatial distribution of total ESV in other scenarios had no obvious characteristics. From the perspective of different service categories (Figs. A.1, A.2, A.3 and A.4 in the Supplementary material), the value of provisioning services was generally low and the value of most





**Fig. 4** Land use of different scenarios

regions was low; the value of regulating services was generally high, but the value of most regions was in the lower middle range; the overall value of supporting services was low, but most regions were in the upper middle range; the overall value of cultural services was low, but most regions were in the upper middle range.

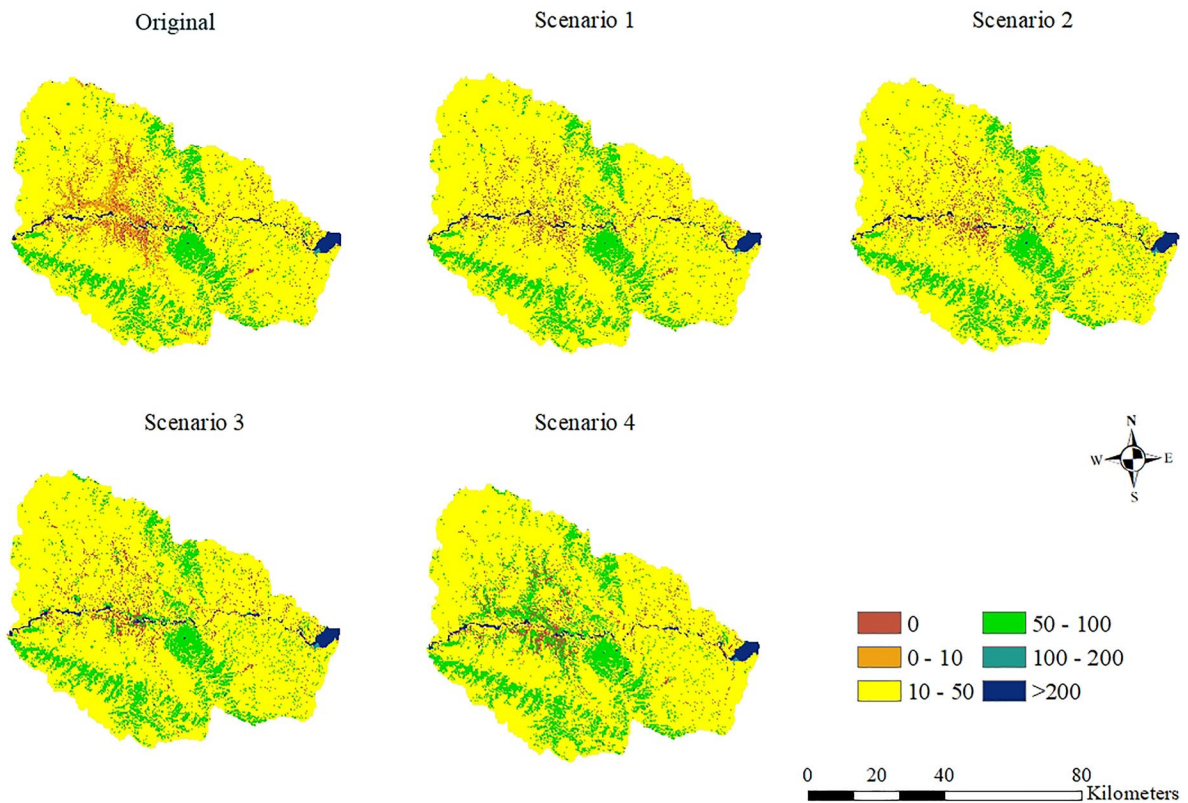
Returning farmland to forest or grass had caused significant economic losses to farmers, and in terms of ecosystem services, the reduction of farmland also led to a significant reduction in ESV (Fig. 6). In this study, the reduced area of cropland was 3688.114 hm<sup>2</sup>, causing a loss of 15.869 million RMB·year<sup>-1</sup>

in provisioning service, 17.494 million RMB·year<sup>-1</sup> in regulating service, 15.994 million RMB·year<sup>-1</sup> in supporting service, 750,000 RMB·year<sup>-1</sup> in cultural service, and a total ESV loss of 50.107 million RMB·year<sup>-1</sup>.

In terms of the spatial distribution, the distribution of converted cropland was relatively scattered, mostly in small blocks, and mainly distributed in the east and mid-west. The loss of different types of ecosystem services in farmland varied greatly. The largest loss of ESV was regulating service with a loss of 4769.1 RMB·hm<sup>-2</sup>·year<sup>-1</sup>, followed by supporting service and provisioning service with the

**Table 3** Increase in ESV per year of different scenarios after land use transfer

$\Delta$ ESV/10 <sup>4</sup> RMB·yr <sup>-1</sup>	Provisioning service	Regulating service	Supporting service	Cultural service	Total ESV
Scenario 1	5526.72	69,296.08	25,173.10	5319.14	105,315.04
Scenario 2	5706.12	73,567.00	26,194.92	5523.12	110,991.16
Scenario 3	6370.89	82,395.63	29,198.37	6120.94	124,085.83
Scenario 4	6748.76	95,191.73	31,774.77	6636.22	140,351.48



**Fig. 5** The spatial distribution of total ESV ( $1000 \text{ RMB} \cdot \text{year}^{-1}$ ) under different scenarios

losses of  $4360.32 \text{ RMB} \cdot \text{hm}^{-2} \cdot \text{year}^{-1}$  and  $4326.26 \text{ RMB} \cdot \text{hm}^{-2} \cdot \text{year}^{-1}$ , respectively. And the smallest loss of ESV was cultural service with a loss of  $204.39 \text{ RMB} \cdot \text{hm}^{-2} \cdot \text{year}^{-1}$ . The total ESV loss of cropland was  $13,660.07 \text{ RMB} \cdot \text{hm}^{-2} \cdot \text{year}^{-1}$ .

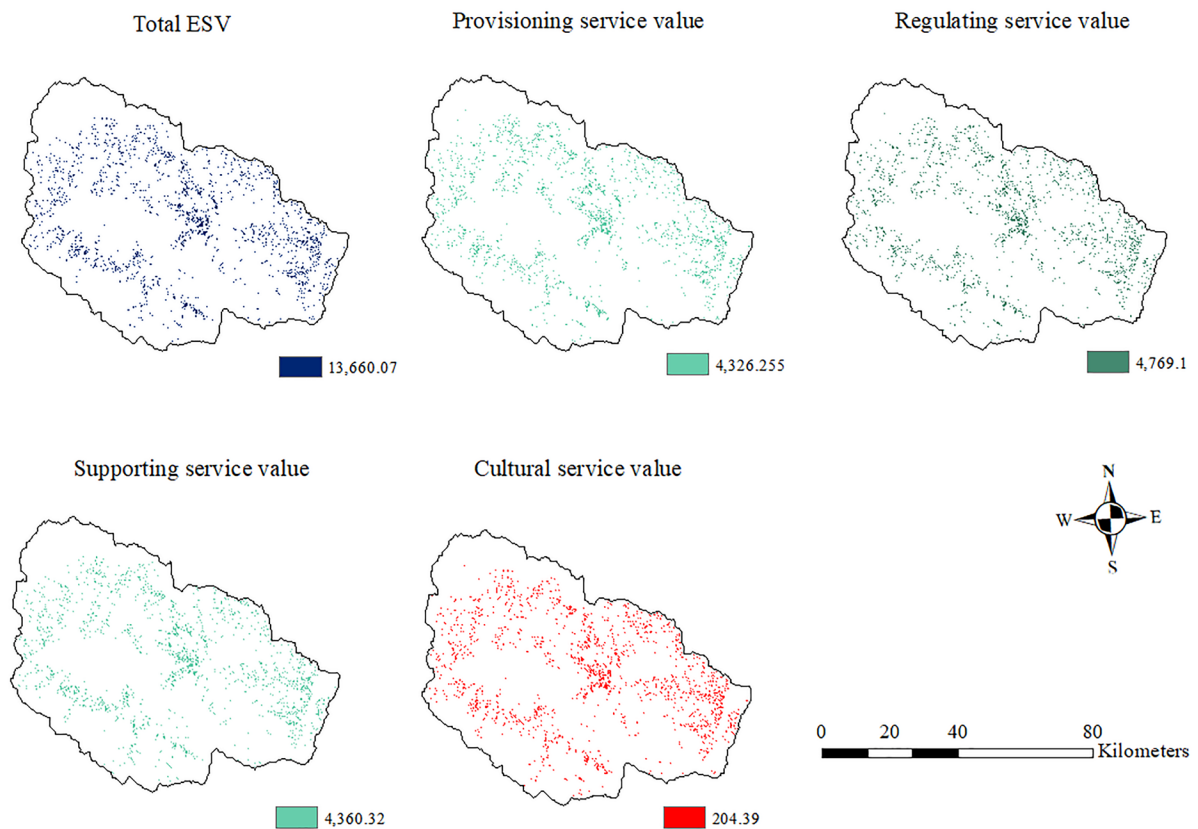
The comparison of temporal variations between different scenarios

From Fig. 7, we can find that in Scenario 1, the investment was concentrated in the first 2 years, the amount of investment decreased rapidly; the ESV increased rapidly, and the growth rate of the ESV increased first and then decreased; the cumulative increase of ESV in the second year began to outweigh the investment. In Scenario 2, the investment was concentrated in the first six years, and the amount of investment decreased rapidly; the ESV increased quickly in the first 5 years and slowly in the later years; the cumulative increase of ESV in the second year began to be greater than

the investment. In Scenario 3, the investment was concentrated in the first 6 years, the investment amount first decreased gently, and then rapidly decreased; the ESV increased rapidly, but the increase rate in the first 6 years was faster than later years; the cumulative increase in the ESV in the third year began to be greater than the investment. In Scenario 4, the investment was concentrated in the first six years, the first 2 years decreased slowly, and the next two 2 decreased rapidly; the growth trend of ESV was slow first, then fast then slow; the cumulative increase of ESV in the fifth year will begin to outweigh the investment.

From the balance point (Fig. 7), the balance points of Scenario 1 and Scenario 2 were in the second year, the balance point of Scenario 3 was the third year, and the balance point of Scenario 4 was the fifth year. If the fastest return was used as the criterion, the best to worst solution was ordered by Scenario 1, Scenario 2, Scenario 3, and Scenario 4. So, the Scenario 4 was the best restored mode.





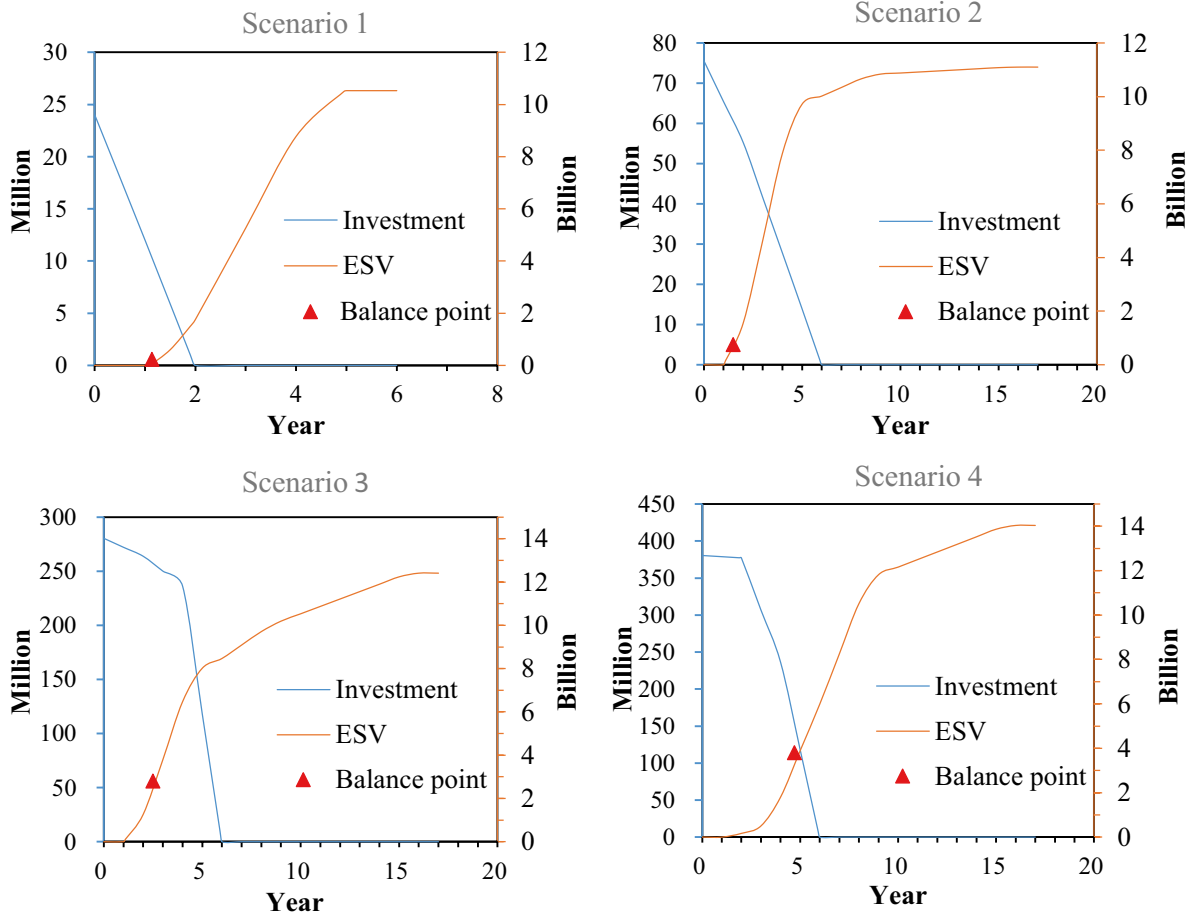
**Fig. 6** The losses of ESV (1 RMB/hm<sup>2</sup>/a) in cropland

From the perspective of the cumulative increase of ESV (Fig. 8), four scenarios were different at long-term and short-term scale. We chose 6 years as the short-term period because the restoration investment were constrained in 6 years. It can be found that Scenario 1 had the largest cumulative ESV increase of 368,600 RMB; followed by Scenario 2 and Scenario 3, the cumulative ESV increase were 338,200 RMB and 280,100 RMB respectively; and the least was Scenario 4, the cumulative ESV increase was 123,500 RMB. If the short-term cumulative ESV increase was the criterion, then Scenario 1 was the optimal solution.

We defined 25 years as the long-term period, as after 25 years, the difference in cumulative ESV increase of each scenario was very significant. It can be found from the figure that Scenario 4 had the largest cumulative ESV increase of 2,135,500 RMB; followed by Scenario 2 and Scenario 2, the

cumulative ESV increase was 2,944,000 RMB and 2,245,200 RMB; finally, in Scenario 1, the cumulative ESV increase was 2,369,600 RMB. If the long-term cumulative ESV increase was used as a criterion, then Scenario 4 was the optimal solution.

Scenario comparison under different standards has different results due to the different growth cycle and ESV of different vegetation types. Herbs have the shortest growth cycle, followed by shrubs, and trees are the longest. Therefore, the benefits of grassland restoration come the fastest, while benefits of afforestation come the slowest. On the contrary, the ESV of forest is the largest, and grassland is the smallest. So, the more artificial grass planting, the shorter the payback period, and the greater the short-term benefits; the more trees planted, the longer the payback period, and the greater the long-term benefits.



**Fig. 7** The changes of investment and ESV per year under different scenarios. The left axis is the remaining investment/¥ 1 million, and the right axis is the annual value added of ESV/¥ 1 billion. The balance point is the year when the cumulative

increase in ESV equals the total investment, indicating the investment payback period, which are usually used to analyze the benefits of the projects, including economic and environmental benefits

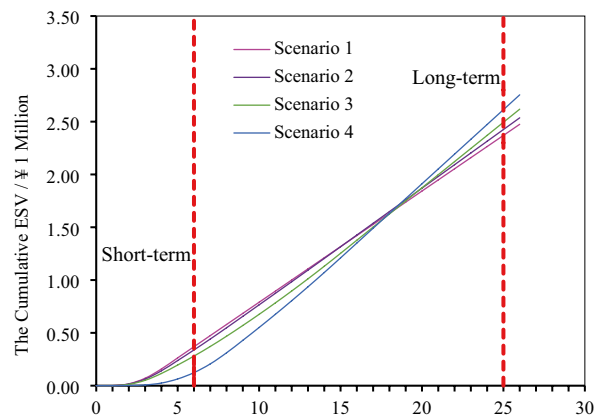
**Discussion**

Eco-compensation for returning farmland to forests or grass

In order to change the deteriorating ecological environment, the Chinese government launched the project of returning farmland to forests or grass at the end of the twentieth century. The project of returning farmland to forests is an important measure to promote the harmonious development of human and nature as well as the coordinated development of economic society and the natural environment (Zhang et al., 2016). On the one hand, we can increase the forest coverage rate by reducing the area of farmland, which

contributes to improving the ecological environment; on the other hand, returning farmland to forests project has changed the rural economic structure to a certain degree and promoted the development of regional characteristic industries (Liu & Zheng, 2020). Although returning farmland to forests reduces the productive income of farmers, subsidies for returning farmland based on opportunity cost can make up for this part of income, and the transfer of agricultural labor force increases labor income. And we usually call the subsidies as ecological compensation, which is a payment for ecological/environmental services. Ecological compensation is one of ways to balance the relationship between ecosystem services and human needs, and usually used as a policy tool to

**Fig. 8** The cumulative increase of ESV with restoration years of different scenarios



maintain or improve ecological conditions by various incentives in China (Fu et al., 2021; Zhong et al., 2020). Ecological compensation is an important way to increase farmers’ participation and consolidate the achievements of returning farmland to forest (Guo & Wang, 2020). And quantifying the value of ecosystem services is a prerequisite for successfully achieving ecological compensation. Therefore, the ESV assessment is generally as the basis for formulating ecological compensation standards (Fu et al., 2021). At present, there have been many studies on ecological compensation standards at all stages of the “returning farmland to forest” project (Wang et al., 2020a). In the primary stage of returning farmland to forests, scholars are mainly concerned about the incentives of returning farmland to forest subsidies to farmers, so the subsidies should be greater than the opportunity cost of farmers giving up farmland cultivation; thus, farmers think that returning farmland to forests is profitable, so as to increase their participation (Xu et al., 2004). In the stable stage during returning farmland to forest, the focus is on the calculation of subsidy standards to avoid farmers returning to farming. There are generally three types of methods for determining the compensation standards for returning farmland to forest, based on the economic loss during the process of returning farmland to forest, the economic value of the ecological effects of returning farmland to forest, and the optimal amount of economic analysis (Zhang, 2013). Under normal circumstances, the ecosystem services value is the upper limit of compensation standards, or based on a certain service function to determine compensation standards. For example, Yu and Yao (2012) determined the optimal subsidy standard for returning farmland

to forest based on the carbon sink perspective; Sheng et al. (2017) proposed three different types of ecological compensation standards based on ecosystem service value and location diversity indicators. The cumulative ecosystem service value in the short-term and long-term in this study can provide a basis for the formulation of regional ecological compensation standards.

#### Land use scenario simulation

As a critical of research related to global environmental change and sustainable development, the researches regarding land use and land cover change have increased significantly in recent years (Pocewicz et al., 2008). The CLUE-S model, proposed by Verburg et al. (2002), consisted of two distinct modules including non-spatial demand module and spatially explicit allocation model, is often used for simulating land use change and for deriving scenario analyses (Liu et al., 2017). In addition, the CLUE-S model is based on probabilistic analysis, and can simulate the impact of natural geographical factors, location factors, and socio-economic factors on land use change (Huang et al., 2019). However, the CLUE-S model simulation is based on a probability distribution, which is less accurate than the real situation (Huang et al., 2019). Besides, in ecological restoration, engineering implementation is usually carried out in a specific area, so some type of transformation is planned and inevitable in this area, contradicting the probability distribution of CLUE-S model. And as the latest development based on a series of models of the CLUE model, CLUMondo model is usually used to simulate land use change under restoration scenarios, which can

simulate changes in land cover and land use intensity driven by the demands for external goods and services. But the parameters of this model are highly subjective and require repeated adjustments to obtain better simulation results. Therefore, instead of using these models, we have designed artificial scenarios based on the local conditions.

Our principles when designing simulation scenarios are realistic and easy to operate. Scenario 1 is very convenient for practical operation. Scenario 2 is divided according to administrative regions, which is consistent with ecological restoration policies in China. China's ecological restoration projects are top-down, and finally implemented by smaller administrative units in order. Scenario 3 and Scenario 4, according to the water body and altitude, consider both policy factors and natural factors. From the information of ecological plantation project in Qinghai Province, it can be found that afforestation on both banks of the Yellow River and afforestation in mountainous areas are very common. During our field investigation, we also can find that most of the upper reaches of the Yellow River are planted with forests, and some mountainous areas with forested areas also have concentrated plantations.

However, the simulated scenario design of this study also has some shortcomings. We did not consider the impacts of other human activities and climate change on land use change. The four main counties in the study area, Xunhua County, withdrew from poor counties in 2018, and Hualong County, Minhe County, and Jishishan County all withdrew from poor counties in 2020. Studies have shown that poverty can retard regional development, so poverty reduction is conducive to regional economic development and urbanization (Cobbinah et al., 2015). Poverty reduction in these counties will inevitably affect their level of urbanization, thus land use. In the era of climate change, the types and composition of vegetation have changed, which will affect land use change. Dong et al. (2020) found that climate change could affect the plant productivity and diversity on the QTP. Wang et al. (2020b) analyzed the stability of QTP ecosystem to climate change, found that temperature significantly affected the stability of steppe and meadow and precipitation played a vital role on stability of coniferous and hylaea forests and shrubs.

The limitations of cost–benefit analysis in the study

The ecological restoration investment in this study is just the construction cost, without considering the maintenance cost. Insect damage and drought are common problems in returning farmland to forest or grass, and can cause serious harm to the results of returning farmland to forest and grass. In planted forests, the types of forest trees are relatively single, which is very likely to cause pest outbreaks, and extreme climates are also susceptible to degradation of forests and grasslands, requiring proper maintenance and management. Only scientific and effective forest and grass industry management can achieve sustainable forest and grass industry development. Therefore, the maintenance cost is very important in the investment.

The restoration measures in this study are relatively simple and not comprehensive as only considering land use transformation. Previous study showed that natural vegetation restoration is a potentially effective measure for improving soil quality, plant and ecosystem health in arid and semiarid ecosystems (Li et al., 2019b). Closing land for plantation and fences are useful options for natural vegetation restoration and the costs of them are much lower. In the study, there are a lot of small patches of slope farmland and degraded land, which can be restored naturally by sealing mountains and fencing, which can effectively reduce costs and achieve better restoration results. Hu et al. (2020) found that natural vegetation restoration has a greater potential to increase soil fertility, and is better to maintain multiple ecosystem functions than managed vegetation restoration in a relatively short period in the karst regions. The study of Lan et al. (2020) showed that natural vegetation restoration of abandoned farmland plays a positive role in the improvement of soil structure, the coupling accumulation of soil carbon and nitrogen, and the conversion and utilization of soil nitrogen. In addition, the effect of ecological progress is not considered in this study. In further study, the Resource Investment Optimization System (RIOS) tool that focuses on impacts of landscape changes on multi-annual time scales can be used to target investments in ecological restoration that achieves the greatest return on ecosystem services.

The calculation of ecosystem service value in the research is also relatively rough. In further research,

some NPP adjustment factors, precipitation adjustment factors, and soil conservation adjustment factors can be combined to adjust the model, so as to obtain more accurate research results. In addition, we can conduct some sensitivity analysis to test the reliability of the results.

## Conclusion

This study calculated the cost–benefit based on ESV of the four ecological restoration scenarios in a typically degraded river basin in the Upper Yellow River Valley on the QTP. We found that the increases of ESV varied in different scenarios, as Scenario 4 had more forest and shrub lands, it had the biggest increase in ESV. At the same time, the spatial variation of ESV within each scenario was significant, but it was different between scenarios. The Scenario 2, Scenario 3, and Scenario 4 showed a similar spatial distribution. The cost–benefit analysis showed the obvious difference in trends of cost and benefits under four scenarios. The choice of the optimal scenario differs depending on the evaluation criteria. From the balance point, Scenario 1 is the best and has the shortest investment return time; from the short-term benefit, Scenario 1 is the best and has the largest increase in ESV over the 6 years after investment; and from the long-term benefit, Scenario 4 is the best and has the largest increase in ESV at a long-time scale. The ESV can be used to determine the subsidy standard for returning farmland to forest, and is generally used as the upper limit of the standard. If the maintenance cost, diversified restoration models, and more realistic ESV calculations are considered, the research results can provide a better scientific basis for the selection of regional ecological restoration mode and ecological compensation for returning farmland to ecological land.

**Funding** The work was supported by the second scientific expedition to the Qinghai-Tibet Plateau (No. 2019QZKK0405-05), National Natural Sciences Foundation of China (No. 41571173), and National Key Research and Development Project (No. 2016YFC0502103).

**Data availability** All data generated or analyzed during this study are included in this published article (and its supplementary information files).

## Declarations

**Conflict of interest** The authors declare no competing interests.

## References

- Batunacun, Wieland, R., Lakes, T., Hu, Y., Nendel, C. (2019). Identifying drivers of land degradation in Xilingol, China between 1975 and 2015. *Land Use Policy*, 83, 543–559. <https://doi.org/10.1016/j.landusepol.2019.02.013>
- Boyd, J., Epanchin-Niell, R., Siikamäki, J. (2015). Conservation Planning: A Review of Return on Investment Analysis. *Review of Environmental Economics and Policy* 9(1), 23–42. <https://doi.org/10.1093/reep/reu014>
- Clarke, S. J., Harlow, J., Scott, A., & Phillips, M. (2015). Valuing the ecosystem service changes from catchment restoration: A practical example from upland England. *Ecosystem Services*, 15, 93–102. <https://doi.org/10.1016/j.ecoser.2015.08.004>
- Cobbinah, P. B., Erdiaw-Kwasie, M. O., & Amoateng, P. (2015). Rethinking sustainable development within the framework of poverty and urbanisation in developing countries. *Environmental Development*, 13, 18–32. <https://doi.org/10.1016/j.envdev.2014.11.001>
- Dong, S., Shang, Z., Gao, J., Boone, R. B. (2020). Enhancing sustainability of grassland ecosystems through ecological restoration and grazing management in an era of climate change on Qinghai-Tibetan. *Plateau Agriculture, Ecosystems & Environment*, 287, 106684. <https://doi.org/10.1016/j.agee.2019.106684>
- Fan, M., Xiao, Y. (2020). Impacts of the grain for Green Program on the spatial pattern of land uses and ecosystem services in mountainous settlements in southwest China. *Global Ecology and Conservation*, 21, e806. <https://doi.org/10.1016/j.gecco.2019.e00806>
- Fu, Y., Xiong, K., Zhang, Z. (2021). Ecosystem services and ecological compensation of world heritage: A literature review. *Journal for Nature Conservation*, 60, 125968. <https://doi.org/10.1016/j.jnc.2021.125968>
- Gang, C., Zhao, W., Zhao, T., Zhang, Y., Gao, X., & Wen, Z. (2018). The impacts of land conversion and management measures on the grassland net primary productivity over the Loess Plateau, Northern China. *Science of the Total Environment*, 645, 827–836. <https://doi.org/10.1016/j.scitotenv.2018.07.161>
- Guo, Z., & Wang, R. (2020). Analysis on farmers' satisfaction with the construction and management of the grain for green project—Based on the survey data of farmers in typical demonstration areas before and after the implementation of the grain for green project (1980–2017). *Journal of Social Sciences*, 3, 53–67. (in Chinese) <https://doi.org/10.13644/j.cnki.cn31-1112.2020.03.013>
- Hasan, S. S., Zhen, L., Miah, M. G., Ahamed, T., Samie, A. (2020). Impact of land use change on ecosystem services: A review *Environmental Development*, 34, 100527. <https://doi.org/10.1016/j.envdev.2020.100527>



- Hu, P., Xiao, J., Zhang, W., Xiao, L., Yang, R., Xiao, D., Zhao, J., Wang, K. (2020). Response of soil microbial communities to natural and managed vegetation restoration in a subtropical karst region. *CATENA*, 195. <https://doi.org/10.1016/j.catena.2020.104849>
- Huang, D., Huang, J., & Liu, T. (2019). Delimiting urban growth boundaries using the CLUE-S model with village administrative boundaries. *Land Use Policy*, 82, 422–435. <https://doi.org/10.1016/j.landusepol.2018.12.028>
- Jenkins, W. A., Murray, B. C., Kramer, R. A., & Faulkner, S. P. (2010). Valuing ecosystem services from wetlands restoration in the Mississippi Alluvial Valley. *Ecological Economics*, 69, 1051–1061. <https://doi.org/10.1016/j.ecolecon.2009.11.022>
- Lan, J., Hu, N., Fu, W. (2020). Soil carbon-nitrogen coupled accumulation following the natural vegetation restoration of abandoned farmlands in a karst rocky desertification region. *Ecological Engineering*, 158. <https://doi.org/10.1016/j.ecoleng.2020.106033>
- Li, H., Gao, J., Hu, Q., Li, Y., Tian, J., Liao, C., Ma, W., & Xu, Y. (2019a). Assessing revegetation effectiveness on an extremely degraded grassland, southern Qinghai-Tibetan Plateau, using terrestrial LiDAR and field data. *Agriculture, Ecosystems & Environment*, 282, 13–22. <https://doi.org/10.1016/j.agee.2019.05.013>
- Li, J., Liu, Y., Hai, X., Shanguan, Z., Deng, L. (2019b). Dynamics of soil microbial C:N: P stoichiometry and its driving mechanisms following natural vegetation restoration after farmland abandonment. *Science of the Total Environment*, 693, 133613. <https://doi.org/10.1016/j.scitotenv.2019.133613>
- Li, Y., Zhu, X., Sun, X., & Wang, F. (2010). Landscape effects of environmental impact on bay-area wetlands under rapid urban expansion and development policy: A case study of Lianyungang, China. *Landscape Urban Plan*, 94, 218–227. <https://doi.org/10.1016/j.landurbplan.2009.10.006>
- Lin, J., Chen, Y., Chang, C. (2020). Costs and environmental benefits of watershed conservation and restoration in Taiwan. *Ecological Engineering*, 142, 105633. <https://doi.org/10.1016/j.ecoleng.2019.105633>
- Liu, G., Jin, Q., Li, J., Li, L., He, C., Huang, Y., & Yao, Y. (2017). Policy factors impact analysis based on remote sensing data and the CLUE-S model in the Lijiang River Basin, China. *CATENA*, 158, 286–297. <https://doi.org/10.1016/j.catena.2017.07.003>
- Liu, T., & Zheng, Y. (2020). Analysis of ecological compensation for returning farmland to forests in China. *Issues of Forestry Economics*, 1, 21–28. (in Chinese) <https://doi.org/10.16832/j.cnki.1005-9709.2020.01.004>
- Lu, W., Xu, C., Wu, J., & Cheng, S. (2019). Ecological effect assessment based on the DPSIR model of a polluted urban river during restoration: A case study of the Nanfei River, China. *Ecological Indicators*, 96, 146–152. <https://doi.org/10.1016/j.ecolind.2018.08.054>
- Luo, Y., Lü, Y., Fu, B., Zhang, Q., Li, T., Hu, W., & Comber, A. (2019). Half century change of interactions among ecosystem services driven by ecological restoration: Quantification and policy implications at a watershed scale in the Chinese Loess Plateau. *Science of the Total Environment*, 651, 2546–2557. <https://doi.org/10.1016/j.scitotenv.2018.10.116>
- Mao, X., Wei, X., Jin, X., Tao, Y., Zhang, Z., & Wang, W. (2019). Monitoring urban wetlands restoration in Qinghai Plateau: Integrated performance from ecological characters, ecological processes to ecosystem services. *Ecological Indicators*, 101, 623–631. <https://doi.org/10.1016/j.ecolind.2019.01.066>
- Naidoo, R., & Ricketts, T. H. (2006). Mapping the economic costs and benefits of conservation. *PLOS Biology*, 4, 2153–2164. <https://doi.org/10.1371/journal.pbio.0040360>
- Paillex, A., Schuwirth, N., Lorenz, A. W., Januschke, K., Peter, A., & Reichert, P. (2017). Integrating and extending ecological river assessment: Concept and test with two restoration projects. *Ecological Indicators*, 72, 131–141. <https://doi.org/10.1016/j.ecolind.2016.07.048>
- Pocewicz, A., Nielsen-Pincus, M., Goldberg, C. S., Johnson, M. H., Morgan, P., Force, J. E., Waits, L. P., & Vierling, L. (2008). Predicting land use change: Comparison of models based on landowner surveys and historical land cover trends. *Landscape Ecology*, 23, 195–210. <https://doi.org/10.1007/s10980-007-9159-6>
- Qinghai Provincial Government Procurement Network. (2016). 2016 afforestation (public welfare forest afforestation) project in the northern part of the third phase of the greening project of the southern and northern mountains in Xining area. [http://www.cccp-qinghai.gov.cn/ZcyAnnouncement/ZcyAnnouncement4/ZcyAnnouncement3004/621488.html?utm=sites\\_group\\_front.f27d48a.0.0.fa8e1930d0211ea89bd4555841557ee](http://www.cccp-qinghai.gov.cn/ZcyAnnouncement/ZcyAnnouncement4/ZcyAnnouncement3004/621488.html?utm=sites_group_front.f27d48a.0.0.fa8e1930d0211ea89bd4555841557ee) (July 27, 2020).
- Qinghai Provincial Government Procurement Network. (2019a). The first batch of forestry reform and development fund afforestation subsidy pilot shrub afforestation projects in Ledu District, Haidong City in 2019. <https://zcy-gov-open-doc.oss-cn-north-2-gov-1.aliyuncs.com/1014AN/339900/1000532559/20196/98690cb0-2b7e-4da5-881e-ad975b00c2ff> (July 27, 2020).
- Qinghai Provincial Government Procurement Network. (2019b). Pilot project for artificial grass planting ecological restoration of degraded grasslands in Henan County in 2019. <https://zcy-gov-open-doc.oss-cn-north-2-gov-1.aliyuncs.com/1014AN/630105/10006211645/201910/c4643872-953c-478e-b376-7340d6da4443> (July 27, 2020).
- Ren, Y., Lü, Y., & Fu, B. (2016). Quantifying the impacts of grassland restoration on biodiversity and ecosystem services in China: A meta-analysis. *Ecological Engineering*, 95, 542–550. <https://doi.org/10.1016/j.ecoleng.2016.06.082>
- Sheng, W., Zhen, L., Xie, G., & Xiao, Y. (2017). Determining eco-compensation standards based on the ecosystem services value of the mountain ecological forests in Beijing, China. *Ecosystem Services*, 26, 422–430. <https://doi.org/10.1016/j.ecoser.2017.04.016>
- State Forestry Administration, P.R.C. (2015). The Bulletin of Desertification and Sandification State of China. 2–7.
- Su, K., Wei, D., Lin, W. (2020). Evaluation of ecosystem services value and its implications for policy making in China - A case study of Fujian province. *Ecological Indicators*, 108, 105752. <https://doi.org/10.1016/j.ecolind.2019.105752>
- Sui, H., Wang, J., Li, Z., Zeng, Q., Liu, X., Ren, L., Liu, C., Zhu, Y., Lv, L., Che, Q., Liu, X. (2020). Screening of ecological impact assessment indicators in urban water

- body restoration process title. *Ecological Indicators*, 113, 106198. <https://doi.org/10.1016/j.ecolind.2020.106198>
- Tong, C., Feagin, R. A., Lu, J., Zhang, X., Zhu, X., Wang, W., & He, W. (2007). Ecosystem service values and restoration in the urban Sanyang wetland of Wenzhou, China. *Ecological Engineering*, 29, 249–258. <https://doi.org/10.1016/j.ecoleng.2006.03.002>
- Verburg, P. H., Soepboer, W., Veldkamp, A., Limpiada, R., Espaldon, V., & Mastura, S. S. A. (2002). Modeling the spatial dynamics of regional land use: The CLUE-S model. *Environmental Management*, 30, 391–405. <https://doi.org/10.1007/s00267-002-2630-x>
- Wang, H., Chen, K., & Wang, L. (2020a). Eco-compensation standard of sloping land conversion program based on opportunity cost method—Taking ecological vulnerable region of northwestern Liaoning as an example. *Journal of Shenyang University (Social Science)*, 22, 176–181. (in Chinese) <https://doi.org/10.16103/j.cnki.21-1582/c.2020.02.010>
- Wang, J., Liu, Y., Li, Y. (2019). Ecological restoration under rural restructuring: A case study of Yan’an in China’s loess plateau. *Land Use Policy*, 87, 104087. <https://doi.org/10.1016/j.landusepol.2019.104087>
- Wang, S., Guo, L., He, B., Lyu, Y., Li, T. (2020b). The stability of Qinghai-Tibet Plateau ecosystem to climate change. *Physics and Chemistry of the Earth, Parts A/b/c*, 115, 102827. <https://doi.org/10.1016/j.pce.2019.102827>
- Wei, W., Gao, Y., Huang, J., Gao, J. (2020). Exploring the effect of basin land degradation on lake and reservoir water quality in China. *Journal of Cleaner Production*, 268, 122249. <https://doi.org/10.1016/j.jclepro.2020.122249>
- Woodcock, B. A., Bullock, J. M., Mortimer, S. R., Brereton, T., Redhead, J. W., Thomas, J. A., & Pywell, R. F. (2012). Identifying time lags in the restoration of grassland butterfly communities: A multi-site assessment. *Biological Conservation*, 155, 50–58. <https://doi.org/10.1016/j.biocon.2012.05.013>
- Xian, J., Xia, C., Cao, S. (2020). Cost–benefit analysis for China’s Grain for Green Program. *Ecological Engineering*, 151, 105850. <https://doi.org/10.1016/j.ecoleng.2020.105850>
- Xie, G., Zhang, C., Zhang, C., Xiao, Y., & Lu, C. (2015). The value of ecosystem services in China. *Resources Science*, 9, 1740–1746. (in Chinese).
- Xu, J., Tao, R., & Xu, Z. (2004). Sloping land conversion program: Cost-effectiveness, structural effect and economic sustainability. *China Economic Quarterly*, 4, 139–162. (in Chinese).
- Yang, Y., Wang, Y., Bai, Y., Yue, X., Du, J., Bai, Y., Sun, J. (2019). Development and practice of the National Earth System Science Data Center in China. *Journal of Agricultural Big Data*, 1, 5–13. (in Chinese) <https://doi.org/10.19788/j.issn.2096-6369.190401>
- Yu, J., & Yao, S. (2012). Optimal subsidy of SLCP in China from the perspective of carbon sequestration benefit. *China Population, Resources and Environment*, 34–39. (in Chinese).
- Zhang, J., & Dong, Y. (2010). Factors affecting species diversity of plant communities and the restoration process in the loess area of China. *Ecological Engineering*, 36, 345–350. <https://doi.org/10.1016/j.ecoleng.2009.04.001>
- Zhang, K., Xie, C., Peng, W., & Wang, J. (2016). A new round of returning farmland to forest policy problems that exist in the implementation and policy recommendations. *Forestry Economics*, 3, 52–58. (in Chinese) <https://doi.org/10.13843/j.cnki.lyjj.2016.03.010>
- Zhang, N. (2013). Study on the compensation standards of Grain for Green Project in the Loess Hilly Region-- in a case of Ansai County. (Master Thesis) Northwest A&F University, Yangling, Shaanxi, China.
- Zheng, H., Li, Y., Robinson, B. E., Liu, G., Ma, D., Wang, F., Lu, F., Ouyang, Z., & Daily, G. C. (2016). Using ecosystem service trade-offs to inform water conservation policies and management practices. *Frontiers in Ecology and the Environment*, 14, 527–532. <https://doi.org/10.1002/fee.1432>
- Zhong, S., Geng, Y., Huang, B., Zhu, Q., Cui, X., Wu, F. (2020). Quantitative assessment of eco-compensation standard from the perspective of ecosystem services: A case study of Erhai in China. *Journal of Cleaner Production*, 263. <https://doi.org/10.1016/j.jclepro.2020.121530>

**Publisher’s Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.