

Article

# Evaluation of the Effects of Land Cover Change on Ecosystem Service Values in the Upper Reaches of the Heihe River Basin, Northwestern China

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**Abstract:** Ecological protection and restoration results in a series of complicated changes in land cover. Lack of research on the historical and potential effects of land cover change on ecosystem service value (ESV) hinders decision-making on trade-offs involved in environmental management. To address this gap, the effects of land cover change on ESV in the upper reaches of the Heihe River Basin in northwestern China were evaluated. First, on the basis of land cover maps for 2001, 2008 and 2015, the land cover map for 2029 was predicted with CA-Markov model. Then, the changes in ESV resulting from land cover change were valued with the benefit transfer method. The results showed that the total ESV increased from \$1207.33 million (USD) in 2001 to \$1479.48 million (USD) in 2015, and the value was expected to reach \$1574.53 million (USD) in 2029. The increase in ESV can be mainly attributed to expansion in areas of wetland. In this study, the elastic index was applied to identify areas that were more sensitive to ecological management, aiding in selecting sites for investment in ecological protection and restoration programs. Furthermore, the potential effects of land cover change on ESV was evaluated. The results are of great importance for guiding future ecological management.

**Keywords:** land cover pattern; ecosystem service function; elasticity indicators; semi-arid mountainous area

## 1. Introduction

Ecosystem services are defined as services and goods that are of fundamental importance to human well-being, livelihoods, health and survival [1]. Estimation of the ecosystem service value (ESV) in terms of monetary units reflects the impacts of human activities on ecosystem structure and function [2], supplies a basis for decisions about ecological compensation [3], and enhances awareness of importance of ESV relative to other contributors to human well-being [4]. Interest in ESVs in both the academia and policy communities around the world has grown rapidly in recent years [5–9].

Together with declining resources and increasing appeals for sustainable development, investment in protecting and restoring natural asset has been enlarged in recent years [10]. Following severe flooding along the Yangze River in 1998, China has implemented some of the world's largest ecological protection and restoration programs. This has not only prevented vegetation destruction due to economic development, but also promoted the conversion of bare land and farmland into grassland and woodland [11]. Such transitions change the landscape pattern and ecosystem structure and function, which influence the delivery of ecosystem services [12–15]. Assessing the effects of land cover change on ESV can generate many benefits for both China and the rest of the world by providing a foundation for reducing natural disaster risk, while alleviating poverty and improving livelihoods [16].

The Heihe River is the second largest inland river in China, originating in the Qilian Mountains and flowing into the Inner Mongolia Plateau. Serving as the water source that supports sustainability of the agricultural ecosystems in the middle reaches and the stability of the ecosystems in the lower reaches, the upper reaches of the Heihe River Basin are an ideal case for ecological protection and restoration in northwestern China [17]. Since 2001, the scale of and investment in protecting and restoring natural asset have been greatly expanded. Accurate evaluation of effects of land cover change on ESV can support the decision-making process regarding the trade-offs involved in ecological management [18].

Land cover change is a complex process with both spatial and temporal dimensions [19–22]. Currently, many models are developed to simulate future land cover change [23,24]. Most of the models, such as LUSD (Land Use Scenario Dynamics) [25], CLUE-S (Conversion of Land Use and its Effects at Small regional extent) [26], are more suitable for application in urban regions, rather than areas that are mostly covered by vegetation. While the CA-Markov (Cellular Automata-Markov) model can be applied in different areas. The hybrid model can simulate the spatial variation of complex systems with the Cellular Automata (CA) [27], and long-term predictions with the Markov Chain [28]. More importantly, the CA-Markov model allows setting goals of ecological protection and restoration programs as constraints, and setting habitats of various vegetation types as factors when producing suitability maps, thereby increasing the simulation accuracy in regions that are mostly covered by vegetation.

To date, theoretical and methodological frameworks have been established for evaluating ESV, including travel cost, market price, productivity and benefit transfer method [29,30]. Among them, the benefit transfer method evaluates ESV by transferring the economic values gathered from one existing study site to new unstudied study site. Actually, the method evaluates ESV by using pre-assigned parameters for each land cover type [31], and it is increasingly popular because of its low demand for data, and simplicity of use at different scales [32]. Meanwhile, most recent advances show that ecosystem services are regulated by various ecological mechanisms exhibiting a dynamic change closely related to ecological structure and function [33,34]. Moreover, the capability and willingness of humans to pay for ecosystem services also vary with economic development [2]. Thus, correcting the pre-assigned parameters is beneficial to accurately reflecting the spatial-temporal dynamics of ESV.

The objectives of this study were to (1) analyze the land cover change from 2001 to 2015; (2) forecast the land cover change from 2015 to 2029; and (3) estimate the effects of land cover change on regional ESV. In this study, the elastic index was adopted to identify areas that were more sensitive to ecological management, aiding in selecting representative sites for investment in ecological protection and restoration programs. Furthermore, the historical and potential effects of land cover change on ESV were evaluated. The results can support the adjustment of current ecological protection and restoration programs, develop more effective ecological management strategies, and provide a basis for the formulation of ecological compensation.

## 2. Materials and Methods

### 2.1. Study Area

Our study site was located in the upper reaches of the Heihe River Basin. The Heihe River is the second largest inland river in China, originating in the Qilian Mountains and flowing into the Inner Mongolia Plateau. The upper reaches of the Heihe River Basin span between 37.7° N–39.1° N and 98.6° E–101.2° E. Total area is nearly  $1 \times 10^6$  ha, with 20% located in Gansu Province, and 80% distributed in Qinghai Province (Figure 1). 98.53% of the study area belongs to unpopulated zone. Elevation in the area ranges from 1991 to 4741 m. The region has a typical continental monsoon climate with an annual average temperature of 2.3 °C and an annual average precipitation of 536 mm [35]. Affected by climate, topography and vegetation, the landscape exhibits vertical

zones, with mountain deserts and grasslands below 2600 m, conifer/broadleaf mixed forest between 2600–2800 m, Qinghai spruce (*Picea crassifolia* Kom) forest and alpine shrub land between 3500–4500 m, and alpine desert and glacier above 4500 m [36]. Soil types also display a vertical distribution, with mountain grey calcic soil at 1900–2300 m, chestnut soil at 2300–2600 m, grey cinnamon and chestnut soil at 2600–3200 m, gray brown and mountain black earth soil at 3200–3600 m, alpine shrub meadow soil and alpine shrub grassland soil at 3600–4000 m, and cold desert soil at >4000 m [37].

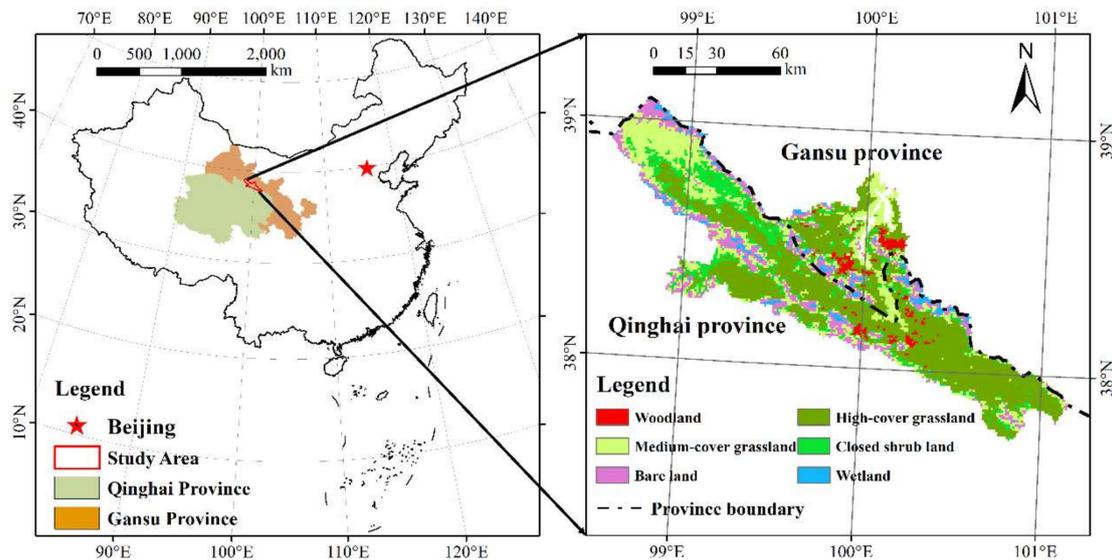


Figure 1. Location and land cover pattern of the study area.

## 2.2. Acquisition of Land Cover Data

### 2.2.1. Historical Land Cover Data

We used 16-day 1000 m MODIS NDIV data (Table 1) to classify land cover types of the study area. First, we transformed the geographic coordinate system to the Universal Transverse Mercator (UTM) projection. While water vapor, bi-directional reflection, aerosol and other factors may affect the accuracy of NDVI data, resulting in difficulties with trend analyses and information extraction [38]. Thus, NDVI data are typically processed to improve classification accuracy. The HANTS smoothing process has the following advantages when dealing with NDVI data: it resolves unequal intervals of time series data, simplifies and compresses time series data, and it detects and replaces invalid data in the time series. In short, the HANTS smoothing process can reconstruct high-quality NDVI timing data [39]. Then we used this method to handle with the obtained MOD13A2 data.

Classification processes include two phases. The first phase involves choosing the classification method. Gu et al. [40] proposed a detailed and effective method to classify land cover types in the Heihe River Basin by analyzing 16-day 1000 m MODIS NDIV data. Thus, we used this classification method to classify land cover types. The second phase involves determination of land cover types. Land cover types in the study area were classified into 6 categories: woodland, closed shrub land, high-cover grassland (cover > 50%), medium-cover grassland (cover between 20% and 50%), wetland and bare land (cover < 20%).

### 2.2.2. Future Land Cover Data

We used the IDRISI 17.2 software to forecast land cover map for 2029 based on the following 6 steps: (1) Preparation of suitability maps. The Multi-Criteria Evaluation (MCE) module was used to produce suitability maps (Appendix A) by combing driving factors based on certain weights (Appendix B). Besides, the woodland and wetland were constrained to convert to other land cover types based on the goals of local ecological protection and restoration programs. (2) Acquisition of

the transition probability matrix through the Markov module in IDRISI 17.2 by inputting land cover maps for 2001 and 2008. (3) Construction of a CA filter. A  $5 \times 5$  contiguity filter was chosen as the neighborhood definition [41]. (4) Simulation of land cover map for 2015. With the suitability maps and transition probability matrix entered into the CA-Markov model, and with the land cover map for 2008 set as the initial year, we simulated the land cover map for 2015 by iterating the module 7 times. (5) Accuracy test. We entered both the simulated and the actual land cover map for 2015 into the VALIDAT module to test the reliability of the CA-Markov model (If the Kappa index  $> 0.80$ , it denotes that the CA-Markov model passed the accuracy test) [42]. (6) Prediction of land cover map for 2029. By setting the land cover map for 2015 as the initial year, the land cover map for 2029 was obtained by iterating the CA-Markov model 14 times.

### 2.3. Estimation of the Total ESV

The benefit transfer method was used to estimate the total ESV; the pre-assigned equivalents were based on Xie et al. [32], who refined the classification of ecosystem services and proposed a set of equivalents applicable to China. The ecosystem was subdivided into 14 sub-types on the basis of the former 6 primary types [43], improving classification of ecosystem services from 9 to 11. The study area is mostly covered by vegetation, and such land cover has 11 types of ecosystem services as proposed by Xie et al. [32]. Moreover, Xie et al. [32] proposed a method for correcting equivalents, which reduced subjectivity of the equivalents derived from expert experience. These corrected equivalents are more suitable for our study area. Data required for correcting equivalents are listed in Table 1.

**Table 1.** Database used for calculating ESV.

Variables	Description	Source
NDVI	Average value for the growing season (from May to October)	Derived from the Atmosphere Archive and Distribution System (LAADS) [44]
Precipitation	Annual average precipitation	Derived from Chinese Academy of Sciences Resource and Environment Science Data Center [45]
Amount of soil retention	Calculated with the universal soil loss equation	Derived from Chinese Academy of Sciences Resource and Environment Science Data Center [46]
Real GDP per capita	Ratio of total GDP to the total population	Zhangye Statistical yearbook for 2001
The Engel coefficient	Proportion of total expenditure for food to the total expenditure for personal consumption	Zhangye Statistical yearbook for 2001
Crop planting area	The planting area of each crop	Zhangye Statistical yearbook for 2001
Net profit of crop	Net profit per ha obtained by planting crop	Compilation of National Agricultural Product Cost and Income Data for 2001

#### 2.3.1. The Economic Value of One Equivalent

The economic value of one equivalent refers to the net profit from farmland food production per ha per year [32]. Based on the Zhangye Statistical yearbook for 2001–2015, corn, wheat, and potatoes were main crops in the study area. Furthermore, Costanza et al. [31] proposed that there were differences in the levels of economic development among different regions, and the levels of inhabitant understanding of ecosystem services were different. Therefore, the capacity and willingness to pay for ecosystem services should be included in the calculation process. Then, the economic value of one equivalent was calculated by using the following formulas [31,32,47,48]:

$$E = \sum_{i=1}^3 P_i \times Q_i \times R \times Y_i \quad i = 1, 2, 3, \quad (1)$$

$$R = \text{GDP}_m / \text{GDP}_n, \quad (2)$$

$$Y = 1 / (1 + e^{-t}), \quad (3)$$

$$t = 1/E_n - 3, \quad (4)$$

where  $E$  is the economic value of one equivalent;  $P_i$  is the percentage of planting area of crop  $i$ ;  $Q_i$  is the net profit for crop  $i$ ;  $R$  is the index of capacity to pay;  $Y$  is the index of willingness to pay;  $GDP_m$  is the real GDP per capita of the study area;  $GDP_n$  is the real GDP per capita of China;  $e$  is the natural logarithm;  $t$  is the socioeconomic development index; and  $E_n$  is the Engel coefficient.

### 2.3.2. Calculation of ESV per ha

We calculated the unit values based on the following formulas, which were proposed by Xie et al. [32].

$$U_{ki} = E \times D_{ki} \times F_{ki} \quad k = 1, 2, \dots, n, \quad (5)$$

$$F_{ki} = \begin{cases} 1) C_k / \bar{C}, \\ 2) W_k / \bar{W}, \\ 3) M_k / \bar{M} \end{cases} \quad (6)$$

where  $U_{ki}$  is the unit value of ecosystem service  $i$  of land cover  $k$ ;  $E$  is the economic value of one equivalent;  $D_{ki}$  is the equivalent per ha of ecosystem service  $i$  of land cover  $k$  [32];  $F_{ki}$  is the functional adjustment index for equivalent of ecosystem service  $i$  of land cover  $k$ ;  $C_k$ ,  $W_k$ , and  $M_k$  refer to the average NDVI of growing season, the annual average precipitation, and annual average amount of soil retention of land cover  $k$  in the study area, respectively;  $\bar{C}$ ,  $\bar{W}$ , and  $\bar{M}$  represent the corresponding average values in China. Specifically, (1) includes the ecosystem services of food production, raw material, atmosphere regulation, climate regulation, waste treatment, nutrient cycling, biodiversity protection and recreation & culture; (2) includes the ecosystem services of water supply and water regulation; and (3) includes the ecosystem service of soil retention.

### 2.3.3. Calculation of Total ESV

$$ESV = \sum_{k=1}^n \sum_{i=1}^m A_k \times U_{ki}, \quad (7)$$

where  $ESV$  is the total ecosystem service value;  $A_k$  is the area of land cover  $k$ ;  $U_{ki}$  is the unit value of ecosystem service  $i$  of land cover  $k$ .

### 2.4. Elasticity in ESV in Response to Land Cover Change

Elasticity is a measure of change in economic variables as a function of another variable. In this study, we aimed to assess the responses of ESV to land cover change. Thus, the elasticity indicator was used to measure the percent change in ESV due to percent change in land cover [29].

$$EEL = |(ESV_{end} - ESV_{start}) / ESV_{start} / LCP|, \quad (8)$$

$$LCP = \sum_{i=1}^6 \Delta LUT_i / \sum_{i=1}^6 LUT_i \times 100\%, \quad (9)$$

where  $EEL$  is the elasticity of ESV in relation to land cover change;  $ESV_{start}$  and  $ESV_{end}$  are the  $ESV_s$  at the start and the end of the study period, respectively;  $LCP$  is the percent of land cover conversion;  $\Delta LUT_i$  is the converted area of land cover  $i$ ; and  $LUT_i$  is the total area of land cover  $i$ . If  $EEL > 1$ , the change in ESV is elastic to land cover change, otherwise, the changes in ESV are considered inelastic to land cover changes.

### 2.5. Contribution Rates of Land Cover Types to ESV

The contribution rate (CR) is calculated to measure the dependency of ESV on certain land cover type [49]. The larger the CR, the higher the contribution rate of a land cover to ESV.

$$CR = U_k \times A_k / \text{ESV}, \quad (10)$$

where CR is the contribution rate;  $U_k$  is the unit values of land cover  $k$ ,  $A_k$  is the area of land cover  $k$ ; ESV is the total ecosystem service value.

## 3. Results

### 3.1. Land Cover Change Analyses

#### 3.1.1. Land Cover Change from 2001 to 2015

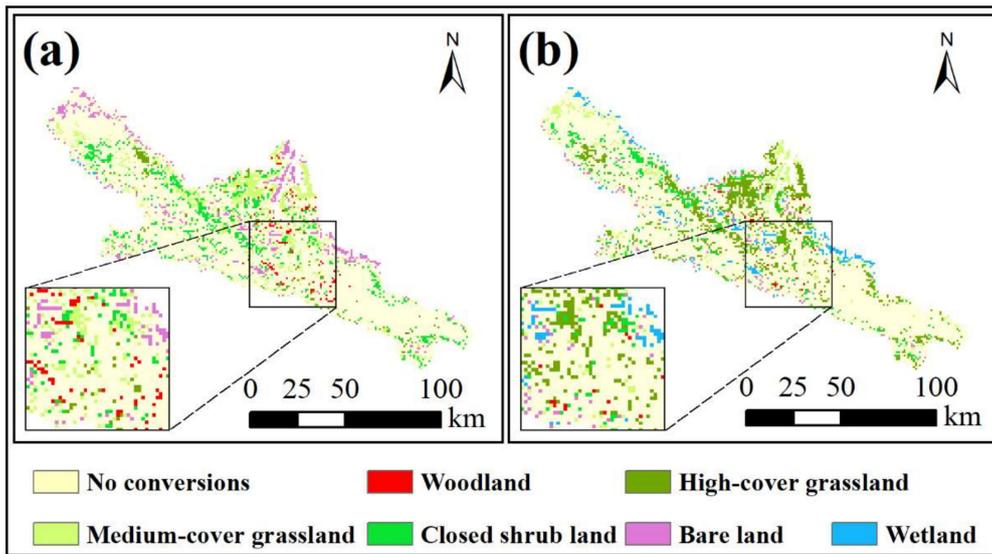
During the period 2001–2015, 25.56% of the total area was converted to other land cover types (Table 2) (Figure 2). The area of high-cover grassland comprised the largest proportion over the period of 2001–2015, at 34.75% in 2001, and at 44.44% in 2015 (Table 3). On the contrary, the area of medium-cover grassland experienced a strongly decreasing trend. Nevertheless, it accounted for the second largest proportion throughout the study period. Next, closed shrub land and bare land exhibited similar quantities. The area of closed shrub land showed a slightly increasing trend over the period of 2001–2008, then decreased rapidly by 18.54% over the second half of the study period. The area of unused land shrank by 24.15% throughout the study period. The least occupied areas were woodland and wetland. The area of woodland experienced a declining trend between 2001 and 2008, but it increased during the subsequent time interval. Wetland expanded substantially from 2001 to 2015 due to the implementation of Wetland Protection Program.

**Table 2.** The LCPs, changes in ESV and EELs of periods of 2001–2015 and 2015–2029(103 ha).

Time Interval	LCP (%)	Changes in ESV (10 <sup>6</sup> \$)	EEL
2001–2015	25.56	272.15	0.88
2015–2029	16.15	95.05	0.40

**Table 3.** Land cover changes between 2001 and 2029 (103 ha).

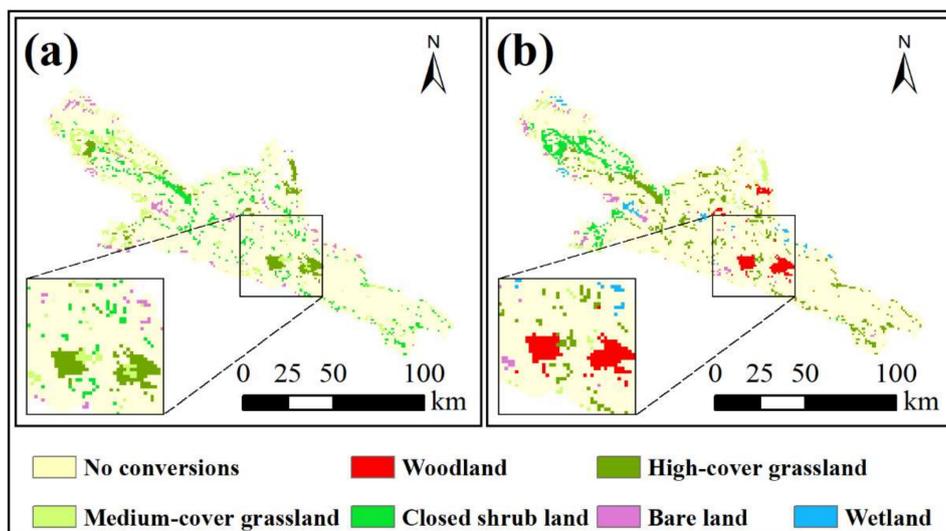
Land Cover Types	2001		2008		2015		2029	
	Area	%	Area	%	Area	%	Area	%
Woodland	32.40	3.30	13.50	1.38	24.70	2.52	46.00	4.69
High-cover grassland	341.10	34.75	380.30	38.74	436.30	44.44	461.50	47.01
Medium-cover grassland	284.60	28.99	275.90	28.10	231.20	23.55	193.40	19.70
Closed shrub land	151.20	15.40	154.80	15.77	126.10	12.85	114.90	11.70
Bare land	162.30	16.53	133.10	13.56	129.40	13.18	123.10	12.54
Wetland	10.10	1.03	24.10	2.45	34.00	3.46	42.80	4.36



**Figure 2.** Land cover change from 2001 to 2015: (a) Land cover pattern in 2001, (b) Land cover pattern in 2015.

### 3.1.2. Land Cover Change from 2015 to 2029

We first tested the simulation accuracy of the CA-Markov model by entering the simulated and actual land cover maps for 2015 into the *VALIDAT* module in IDRISI 17.2. In addition, the Kappa index was above 0.8000 (0.8370), denoting that the CA-Markov model was highly applicable for simulation of land cover maps in the study area. Thus, we forecasted the land cover map for 2029 with this model. The results showed that if current trends persisted, 16.15% of total area was expected to convert to other land cover types during the period of 2015–2029 (Table 2) (Figure 3). The trend in land cover change of the period of 2015–2029 was highly consistent with the period of 2008–2015: the woodland, high-cover grassland, and wetland were expected to continue expanding in varying degrees, especially in woodland, which was expected to increase by 86.23% (mainly due to conversion from high-cover grassland); the medium-cover grassland, closed shrub land, and bare land were expected to decrease by 16.35%, 8.88% and 4.87%, respectively.



**Figure 3.** Land cover change from 2015 to 2029: (a) Land cover pattern in 2015, (b) Land cover pattern in 2029.

### 3.2. Changes in ESV from 2001–2029

The unit values of each ecosystem service for each land cover type are shown in Table 4. Then the ESVs of 2001, 2008, 2015 and 2029 were calculated, respectively. Our results showed that total ESV of the upper reaches of the Heihe River Basin increased from \$1207.33 million (USD) in 2001 to \$1,479.48 million (USD) in 2015, and was expected to peak at \$1574.53 million (USD) in 2029. The spatial distribution of ESV in the study area showed a trend of high in the southeast and low in the northwest (Figure 4). The ESV of high-cover grassland comprised the largest proportion of the total ESV, and the proportions from 2001 to 2029 had similar quantities (44.56–46.58%) (Figure 5). In addition, the ESV of wetland significantly increased, and its proportions increased from 7.95% in 2001 to 20.79% in 2015, and finally 25.84% in 2029. This was followed by medium-cover grassland, which accounted for more than 14.10% of the total ESV over the study period. Similarly, the proportions of ESV of closed shrub land decreased from 12.60% in 2001 to 7.34% in 2029. Finally, both of the ESVs of bare land and woodland represented less than 5% of total ESV throughout the study period.

All of the 11 kinds of ESVs increased over the 14 years to varying degrees (Figure 6). The value of water regulation rose dramatically, from 19.98% in 2001 to 26.43% in 2015, and was expected to reach 28.15% in 2029. Additionally, the value of climate regulation experienced a sharp increase, with the figures climbing from \$304.20 million (USD) in 2001 to \$326.16 million (USD) in 2015, and \$334.07 million (USD) in 2029. The values of soil conservation and biodiversity protection represented similar proportions (10–15%). Proportions of the values of gas regulation and waste treatment remained stable (5–10%). The values of the remaining ecosystem services accounted for less than 5% throughout the study period.

**Table 4.** The unit values of each ecosystem service for each land cover type of the Heihe River Basin (\$).

Ecosystem Service Types	Woodland	High-Cover Grassland	Medium-Cover Grassland	Closed Shrub Land	Bare Land	Wetland
Food production	17.73	32.13	21.05	14.40	2.22	46.53
Raw material	42.10	47.64	32.13	33.24	7.76	46.53
Water supply	9.97	18.83	17.73	8.86	7.76	651.45
Atmosphere regulation	138.49	166.19	110.79	108.57	26.59	175.05
Climate regulation	414.35	440.94	294.70	326.83	24.37	331.26
Waste treatment	121.87	146.24	97.50	98.60	74.23	331.26
Water regulation	129.62	238.20	213.82	136.27	79.77	6091.23
Soil retention	198.31	216.04	170.62	94.17	31.02	655.88
Nutrient cycling	13.29	15.51	11.08	9.97	2.22	16.62
Biodiversity protection	154.00	185.02	124.08	120.76	28.81	725.67
Recreation & culture	66.47	81.98	54.29	53.18	12.19	435.40

Note: a- 1\$(USD) = 6.64Yuan (CNY) in 2016.

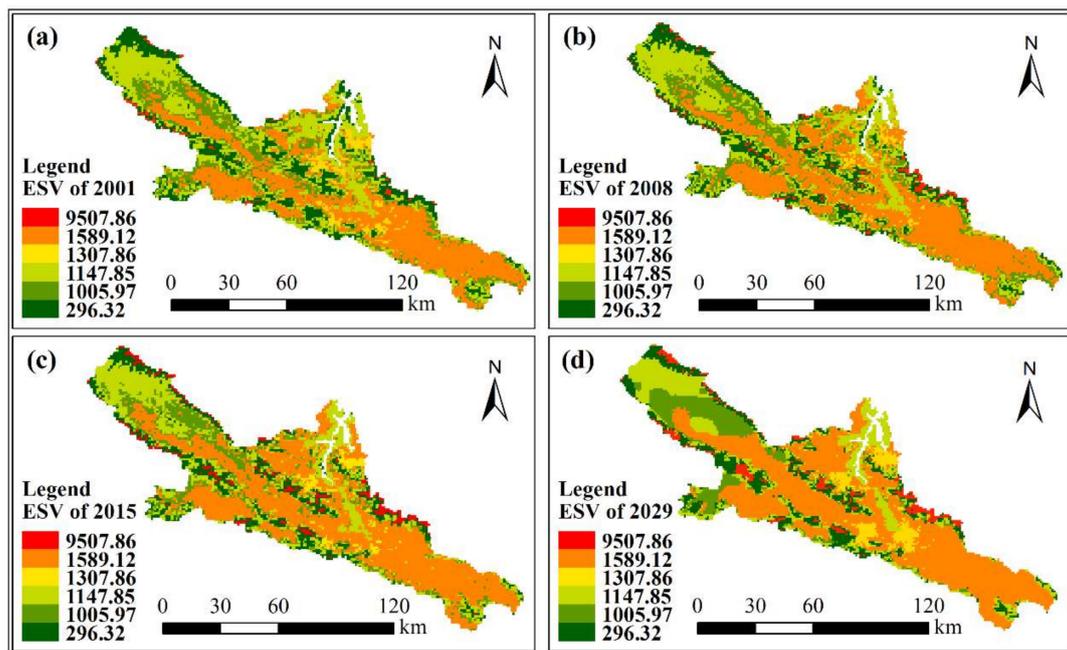


Figure 4. Changes in ESV (\$) in the upper reaches of the Heihe River Basin from 2001 to 2029: (a) ESV in 2001, (b) ESV in 2008, (c) ESV in 2015, (d) ESV in 2029.

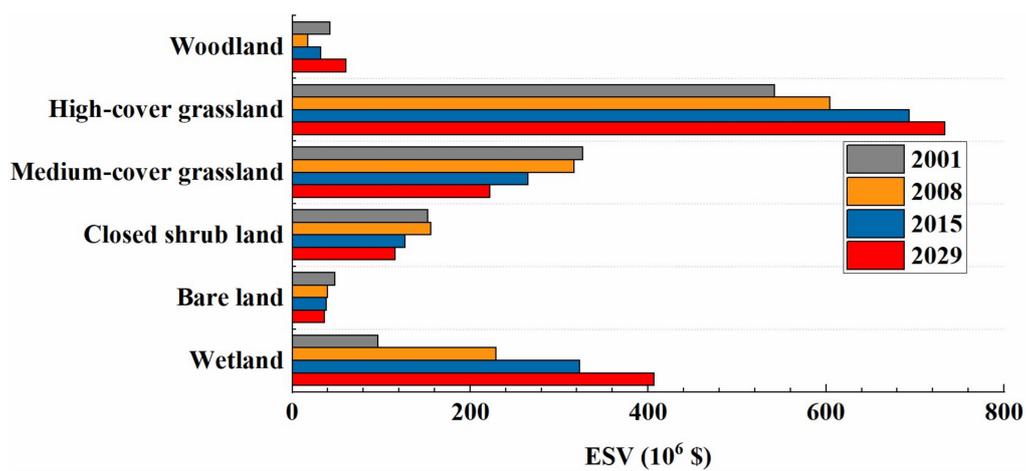
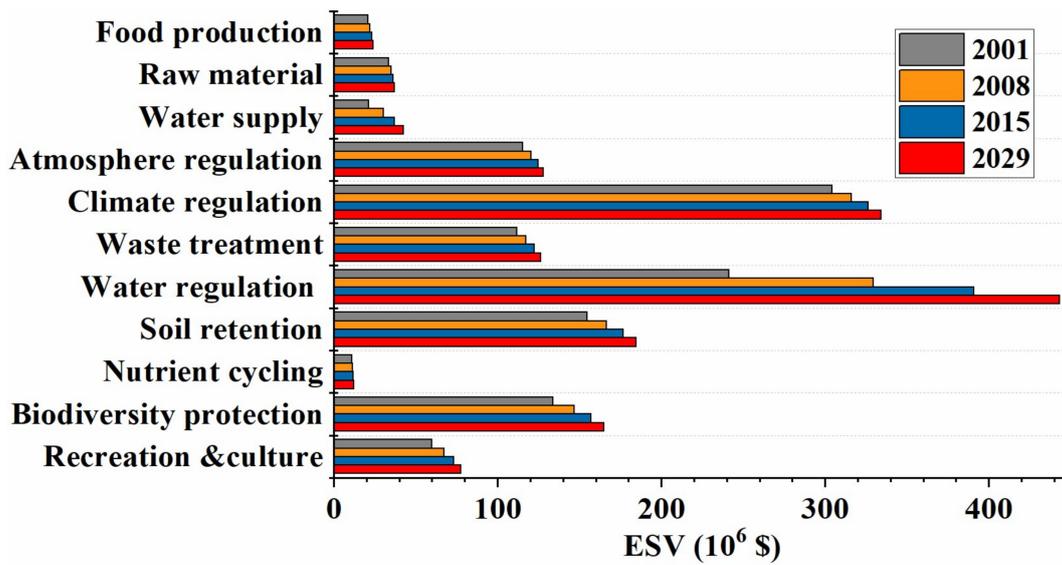


Figure 5. The ESV for each land cover type in the upper reaches of the Heihe River Basin from 2001 to 2029 (10<sup>6</sup>\$).

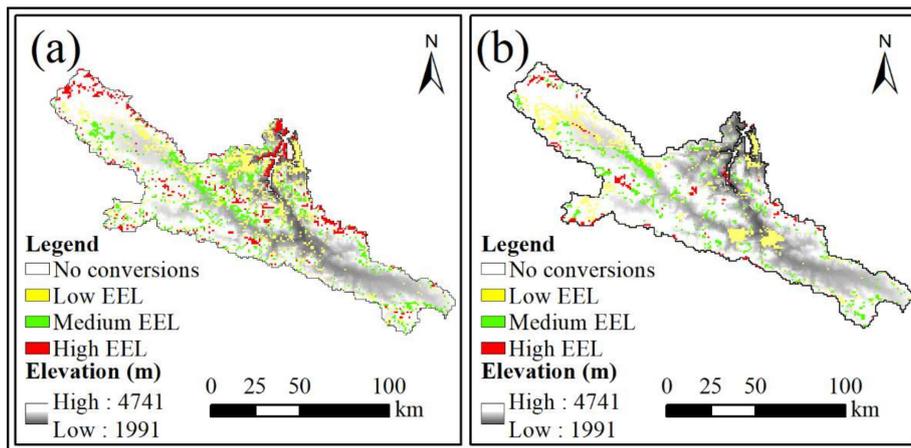


**Figure 6.** The ESV for each ecosystem service type in the upper reaches of the Heihe River Basin from 2001 to 2029 (10<sup>6</sup>\$).

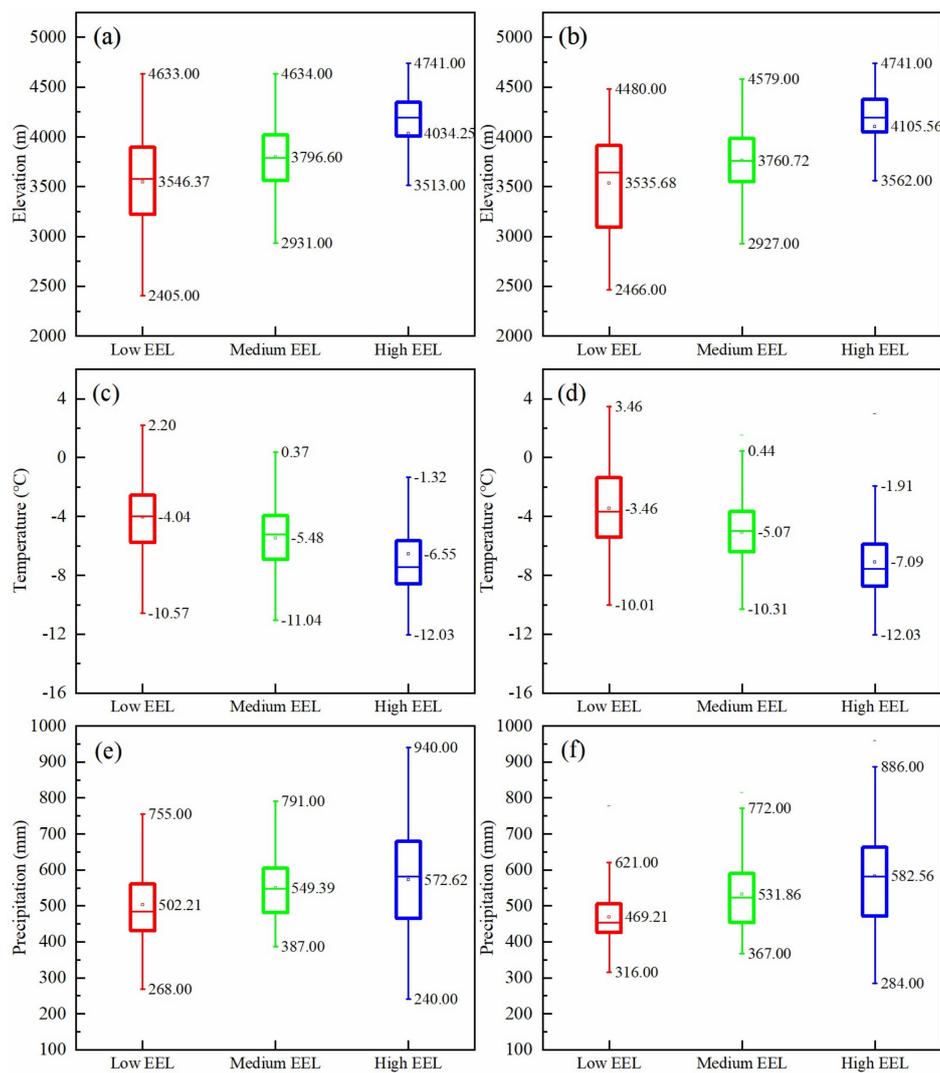
3.3. Elasticity of Change in ESV with Respect to Land Cover Chang.

The EELs were categorized into three groups based on their distributions in the study area:  $EEL \geq 1$  was classified as high,  $0.5 < EEL < 1$  was classified as medium,  $0 < EEL \leq 0.5$  was classified as low. The results showed that the EELs during the periods of 2001–2015 and 2015–2029 were 0.88 and 0.40, respectively (Figure 7), indicating that conversion of 1% of land cover area would result in 0.88% and 0.40% changes in ESV. Responses of ESV to land cover change were not very marked.

Distribution of EELs exhibited noticeable zonality (Figure 8). Namely, the higher the elevation, the higher the EEL. With an increase in elevation in the alpine area, the temperature decreased, while precipitation increased to varying degrees. Consequently, the distribution of EELs was negatively correlated with temperature, and positively with precipitation.



**Figure 7.** Changes in EELs in the upper reaches of the Heihe River Basin from 2001 to 2029: (a) EELs of 2001–2015, (b) EELs of 2015–2029.



**Figure 8.** The environmental factors corresponding to EEL categories in the upper reaches of the Heihe River Basin from 2001 to 2029: (a) Average elevations of 2001–2015, (b) Average elevations of 2015–2029, (c) Annual average temperatures of 2001–2015, (d) Annual average temperatures of 2015–2029, (e) Annual average precipitations of 2001–2015, (f) Annual average precipitations of 2015–2029.

#### 3.4. Analyses of Contribution Rates of Land Cover Types to ESV

CRs (Figure 9) were calculated to measure the contribution rate of a land cover type to ESV. The results showed that CRs of high-cover grassland and wetland were relatively higher than those of other land cover types, partly because the area of high-cover grassland represented the largest proportion, and partly because its unit values were higher than those of other land cover types. Wetland CRs were expected to increase from 0.08 in 2001 to 0.26 in 2029 along with expansion of its area. Though the CR of medium-cover grassland was 0.27 in 2001, its value was expected to decrease to 0.14 in 2029. The CRs of other land cover types were close to zero. These results demonstrated that an accurate correction of coefficients of high-cover grassland and wetland were critical for the estimation of the total ESV in the upper reaches of the Heihe River Basin.

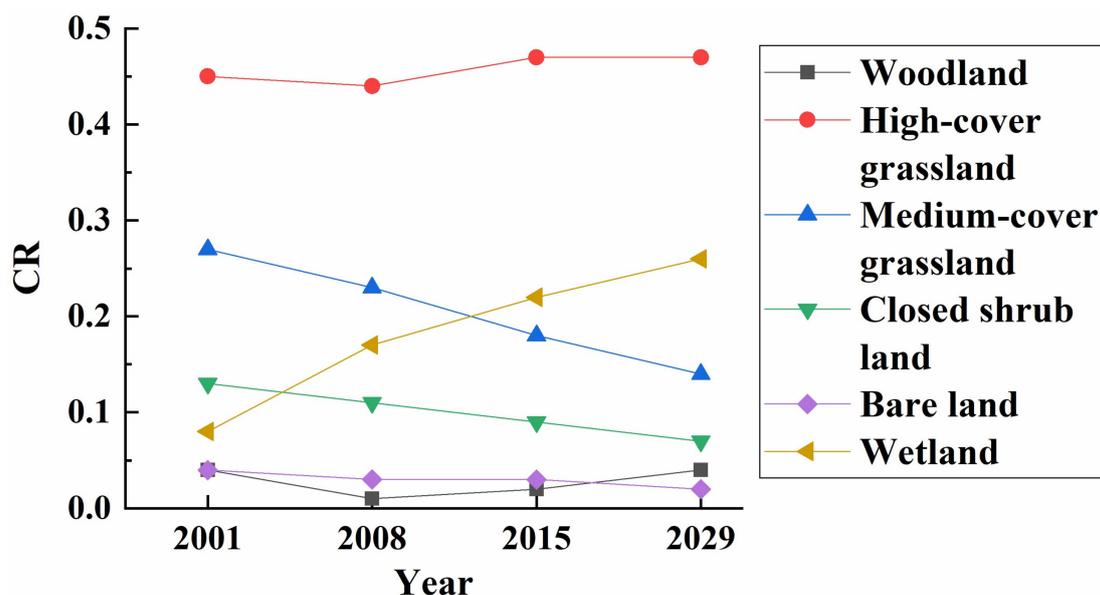


Figure 9. The CRs of different land cover types from 2001 to 2029.

## 4. Discussion

### 4.1. Effects of Land Cover Change on ESV

Presently, ecological protection and restoration is more and more relevant than ever since appeals for sustainable development is increasing. Considerable investments in these programs have changed the landscape pattern. The cumulative land cover changes alter ecosystem structure and function [50]. In our study, area, the land cover pattern from 2001 to 2015 was also optimized due to implantation of ecological protection and restoration programs, and the total ESV increased by \$272.15 million (USD). Conversion from bare land to wetland added ESV of \$233.97 million (USD). Besides, conversions from closed shrub land and medium-cover grassland to high-cover grassland increased ESV by \$53.83 million (USD). Nevertheless, conversions from wetland and medium-cover grassland to bare land still existed, leading to an ESV losses of \$31.65 million (USD).

In the near future, the total ESV of the study area was expected to increase by \$95.05 million (USD) from 2015 to 2029. Similar to the previous time interval (2001–2015), the increase in ESV was expected to mainly result from wetland expansion. Conversion from bare land to wetland was expected to increase ESV of \$82.90 million (USD). In addition, closed shrub land and medium-cover grassland were expected to convert to high-cover grassland, resulting in an ESV increase of \$32.09 million (USD). In addition, vegetation degradation was expected to be main cause for loss of ESV. Conversions of high-cover grassland to other vegetation types were expected to account for the largesse loss of ESV, \$13.55 million (USD). Degradation of medium-cover grassland to bare land was expected to lead to an ESV loss of \$10.39 million (USD).

In all, due to the implementation of ecological protection programs, land cover types with lower unit values (e.g., medium-cover grassland, bare land) were converted to those with higher unit values (e.g., high-cover grassland, wetland). In particular, the conversion of bare land to wetland contributed most to the increase of ESV. While vegetation degradation (e.g., high-cover grassland to medium-cover grassland, medium-cover grassland to bare land) was main cause for loss of ESV. This issue should be taken seriously to prevent further loss of ESV.

### 4.2. Comparisons with Other Results

Comparison with published results was a feasible way to assess the reasonableness of our approach. It was worth noting that because we calculated the comparable value relative to 2001, we chose the year 2001 as the base year for compared to other studies. Research on the ESV

in China reached its peak in 2010 [32]. Presently, most Chinese studies are restricted to certain ecosystem types [51], certain areas [52], or including China as a whole [53]. Though several studies are conducted on the ESV of the Heihe River Basin, their focus is the middle [54], and the lower reaches [55], which have a higher intensity of human activity. Even though there are already a small number of studies on the upper reaches, research has focused on specific ecosystem services, not on total ESV [56]. Therefore, we only compared our results with those of Zhang et al. [57]. The results of Zhang et al. [57] showed that the ESV in the upper reaches of the Heihe River Basin in 2000 was \$339.20 million (USD), which was 28.20% of that for our study. The main reasons for the differences were: Zhang et al. [57] calculated ESV based on the unit values of Costanza et al. [31]. However, the unit values in Costanza et al. [31] were not applicable to the study area. The adjusted unit values in our study were higher than those of Costanza et al. [31], partly because we calculated the ESVs of 11 ecosystem services, rather than 9 in Costanza et al. [31], partly because the equivalents from Xie et al. [32] were higher than those from Costanza et al. [31].

Furthermore, we compared our results with Shi et al. [53], who estimated the ESV of China based on the 1999 unit values. Overall, the unit values in our study were similar to those of Shi et al. [53]. Specifically, the unit values of woodland in our study were lower than the value from Shi et al. [53], which was due to forest type in the study area were coniferous forest and closed shrub, with lower unit values than that of broad-leaved forest and coniferous and broad-leaved mixed forest in other regions of China [32]. In contrast, the unit values of high-cover and medium-cover grassland were higher than that of the average level of China. This was principally because the main type of grassland in our study area was meadow, and its unit values were higher than steppe [32]. Finally, the unit values of wetland were significantly higher than those of other studies. This was due to the fact that in recent years scholars had attached importance to ESV of wetland in recent years, resulting in high equivalents of wetland [32,58,59]. Last, the unit values of unused land were higher, mainly because we incorporated low cover meadow into unused land, enhancing the ability of unused land to provide ecosystem services.

Our results can also be verified by comparing them with areas in the world where ecological protection and restoration programs have been implemented. Adusumilli [59] found that the Wetlands Mitigation Program in the United States was very beneficial for improvements in regional ESV. Chazdon's [60] findings suggested that the woodland can enhance biodiversity conservation and improve ecosystem services. Namely, after implementing ecological protection and restoration programs, ecological land, such as wetland and woodland, usually expanded, and then improved the regional ESV. On the contrary, the ESVs declined in areas where ecological management measures were lacking [58,61,62]. Economic development was always the dominant factor in land use/cover change in those areas [63], and the lack of alternative economic measures has become an important cause of land degradation and ecosystem service reduction. Thus, provisions of effective ecological management, and establishment of a compensation mechanism were considered as essential measures in optimizing land use/cover pattern, and maintaining ecosystem services [64,65].

#### *4.3. Application in Planning for Ecological Management*

Assessments of ESV are always applied in spatial planning [66]. The results in this study can be used to support spatial planning and decision-making. Since the study area is belong to the Qilian Mountain Nature Reserve, 98.53% of the total areas are unpopulated. Planning in the study area involves only ecological management. Therefore, the ESV can only be used to adjust the existing ecological management measures and provide suggestions for future ecological management.

First, the ESV can be used as an information source for evaluating impacts of proposed planning decisions [67]. In the Qilian Mountain Nature Reserve, a series of ecological protection and restoration programs are implemented simultaneously, including the Wetland Protection Program, and the Natural Forest Conservation Program. Based on our results, remarkable achievements had been gained of the Wetland Protection Program as the area of wetland increased from 101 ha in 2001 to 340 ha in 2015.

In addition, wetland expansion contributed most to the growth of ESV. Obviously, investment in Wetland Protection Program has the highest yield to ESV. In the future, the Wetland Protection Program should still be implemented in accordance with present measures. Contrarily, the Natural Forest Conservation Program was not very effective in protecting forest. The woodland shrunk by 23.77% from 2001 to 2015. Specifically, the area of woodland first decreased (2001–2008) and then increased (2008–2015). Obviously, the measures for woodland protection in 2008–2015 were more effective than the former time interval, which was of reference for the Natural Forest Conservation Program.

Second, the EELs can help identify areas of particular environmental sensitivity, and provide strategies for further ecological management [67]. With increasing elevation, increasing precipitation and decreasing temperature, the EELs increased significantly, indicating that the ESVs of those areas were more sensitive to land cover change resulting from these programs. As a result of the Wetland Protection Program, wetland expansion mainly contributed to high EELs. Though current ecological protection and restoration programs had achieved success in the region, further attention should be given to those areas because of the responses they have shown [29]. While the medium EEL was mainly caused by vegetation degradation (medium-grassland converting to bare land), the focus of ecological management in these regions should be to prevent further deterioration of medium-cover grassland. In summary, the focus of ecological management in the study area is to support the current protection measures, and prevent vegetation degeneration in ecologically fragile areas.

#### 4.4. Limitations of ESV Evaluation

In this study, we applied the benefit transfer method to assess the effects of land cover change on ESV, which is popular with decision makers in virtue of fast evaluation and low demand for data when assessing ESV at broad geographical scales [29]. Nevertheless, limitations of the benefit transfer method still exist. First, we applied pre-assigned parameters that were previously reported for assessing ESV. Although we adjusted them in the application process, the results were still an estimation and simulation of the real situations. Additionally, terrestrial ecosystem supplies not only positive services, but also negative ones [53]. Taking artificial ecosystems as an example, construction land supplies the ecosystem services of recreation & culture and waste treatment, meanwhile, it changes the original natural landscape, and obstructs the original ecological process [68]. Therefore, neglecting negative ecosystem services may cause deviations in the evaluation of ESV [69]. Regarding further research on ESV, the empirical parameters should be determined more accurately based on local conditions. In addition, a greater effort should be made to incorporate the positive and negative ecosystem services into the accounting method of ESV to measure ESV accurately and comprehensively.

## 5. Conclusions

The effects of land cover change on ESV in the upper reaches of the Heihe River Basin were assessed in northwestern China. The results showed that from 2001 to 2015, the land cover types with lower unit values (e.g., medium-cover grassland, bare land) were converted to those with higher unit values (e.g., high-cover grassland, wetland). In addition, the trend of land cover change from 2015 to 2029 is expected to be similar to that of 2001–2015.

Due to land cover change, the total ESV of the study area increased from \$1207.33 million (USD) in 2001 to \$1479.48 million (USD) in 2015, and the value was expected to reach \$1574.53 million (USD) in 2029. Along with those, the ESVs of 11 types of ecosystem services showed increasing trends to varying degrees, especially those of water and climate regulation due to expansions of wetland and high-cover grassland.

The EEL was also adopted to assess the response of ESV to land cover change, and the results showed that the values were 0.88% and 0.40% during 2001–2015 and 2015–2029, respectively. Moreover, high EELs were distributed in regions with higher elevation, more precipitation and lower temperature.

In this study, areas sensitive to ecological protection and restoration are identified. This will aid in selecting representative sites from the alpine zones for further ecological management. Furthermore, the results of changes in ESV will support decision-making in trade-offs involved in environmental management. However, only the positive ecosystem service values were evaluated. In the future, efforts should be paid to incorporate the negative and positive ecosystem services into the accounting method for ESVs.

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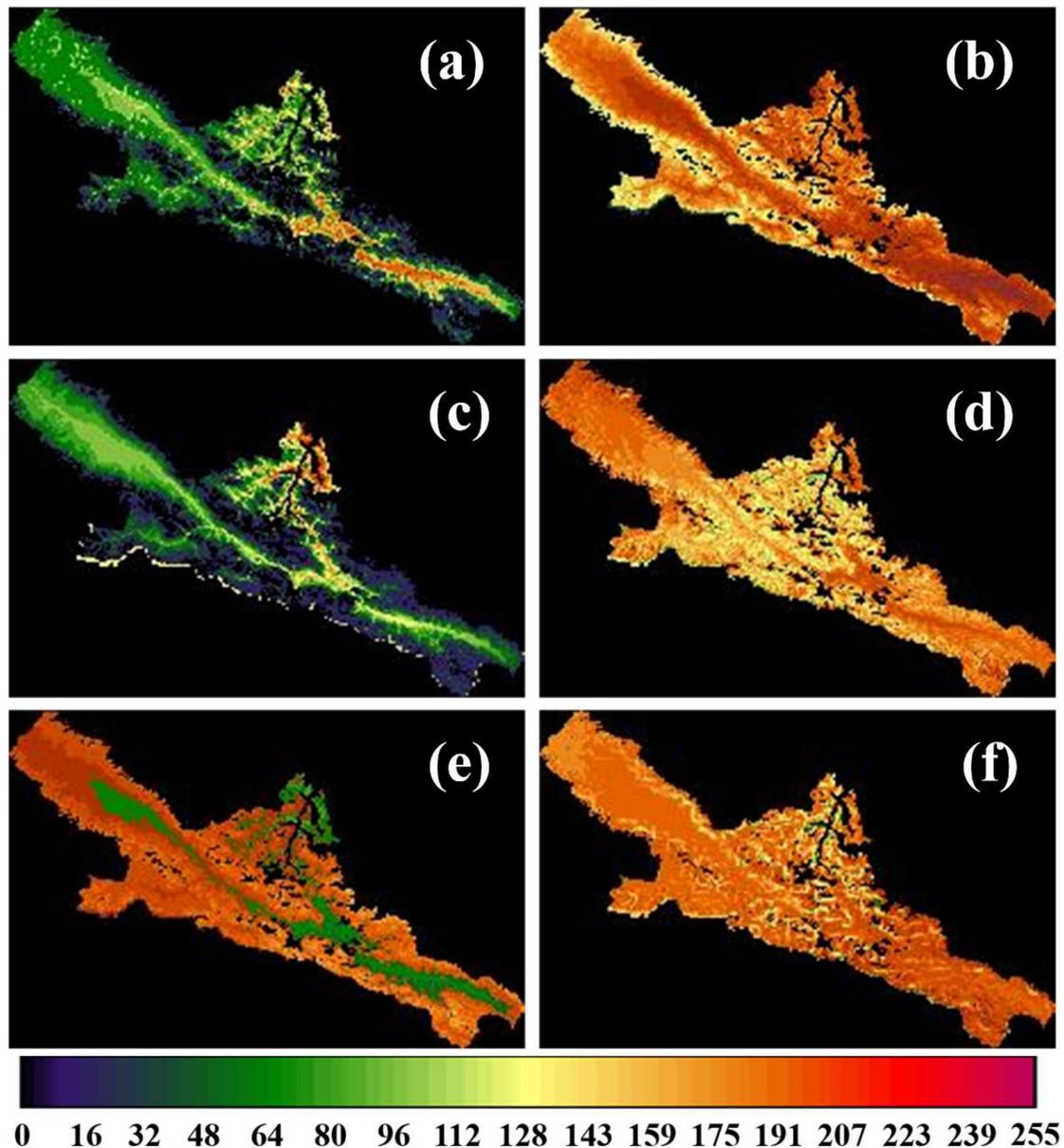
## Appendix A

**Table A1.** Parameters and weights used in simulations of suitability maps.

Land Cover Types	Consistency Ratio	Variables	Description	Factor Weight	Function Type <sup>b</sup>
Woodland	0.0139	Temperature	8.0–14.0 °C, 11 °C <sup>a</sup>	0.4175	SS
		Precipitation	320–600 mm, 460 mm <sup>a</sup>	0.2241	SS
		Elevation	2200–3800 m, 3000 m <sup>a</sup>	0.1132	SS
		Slope	0°–37°	0.0575	DS
		Aspect	0°–180°; 180°–360°	0.1876	DJ;IJ
High-cover grassland	0.0116	Temperature	–5–16 °C	0.4849	IS
		Precipitation	240–960 mm	0.2800	IS
		Elevation	2000–4800 m, 3500 m <sup>a</sup>	0.1669	SS
		Slope	0°–37°	0.0681	DS
Medium-cover grassland	0.0152	Temperature	–5–16 °C	0.1605	IS
		Precipitation	Less than 600 mm	0.4881	DS
		Elevation	Less than 3500 m	0.2515	DS
		Slope	0°–37°	0.0999	IS
Closed shrub land	0.0250	Temperature	–5–16 °C	0.4750	IS
		Precipitation	240–960 mm	0.1654	IS
		Elevation	More than 3300 m	0.3113	IS
		Slope	0°–37°	0.0483	DS
Wetland	0.0000	Precipitation	240–960 mm	0.2857	IS
		Elevation	2000–4800m	0.1429	DS
		Slope	0°–37°	0.5714	DS
Bare land	0.0000	Temperature	–5–16 °C	0.6000	DS
		Precipitation	240–960 mm	0.3000	DS
		Slope	0°–37°	0.1000	IS

Note: <sup>a</sup>—The value at the symmetry point. <sup>b</sup> SS—Symmetric sigmoidal function, DS—Decreasing sigmoidal function, IS—Increasing sigmoidal function, IJ—Increasing J-shaped function, DJ—Decreasing J-shaped function.

## Appendix B



**Figure A1.** Suitability maps of each land cover type: (a)—Woodland, (b)—High-cover grassland, (c)—Medium-cover grassland, (d)—Closed shrub land, (e)—Bare land, (f)—Wetland.

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