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Assessing Impacts of Land Use/Land Cover Conversion on Changes in Ecosystem Services Value on the Loess Plateau, China

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Abstract: The Loess Plateau is not only a critical region that suffers from ecological threats but also a valuable region that provides various fundamental ecosystem services, including provisioning, regulating and cultural services to about 8% of the Chinese population. The specific natural environment and extensive human activities have led to substantial land use/land cover changes between 1990 and 2015, such as the decrease in cropland with the increase in forests and grasslands due to the implementation of the Grain for Green Program since 2000 and the expansion of built-up areas with economic development and population growth. However, the effects of these changes on ecosystem service values have not yet been considered. In this study, the approach based on a combination of land use/land cover proxies and benefit transfer is applied to assess ecosystem service value changes resulting from land use/land cover changes in the 1990–2000, 2000–2010 and 2010–2015 periods. The results reveal that the total value of ecosystem services has been reduced by \$6.787 million from 1990 to 2000 and increased by \$4.6 million from 2000 to 2015. The elasticity analysis shows that a 1% area conversion has induced average value changes of 1.03%, 0.38% and 0.05% in the three periods, respectively. Elasticity is developed as an indicator for locating unusual changes among different regions and identifying specific needs for ecosystem management.

Keywords: land use/land cover change; ecosystem service value; benefit transfer; elasticity analysis

1. Introduction

Ecosystem services, including provisioning, regulating and cultural services, are necessary for human subsistence, health and well-being [1,2]. The monetary valuation of these services intuitively illustrates the benefits people obtain from ecosystems [3,4], which can be further used to highlight the importance of ecosystems, support relevant policy-making and promote effective ecosystem conservation and management [5,6]. Therefore, the assessment of ecosystem service values (ESVs) has attracted much attention in recent years [7].

The approaches proposed for quantifying ESVs generally include two pathways, i.e., primary-data-based and land-use/land-cover (LULC)-proxy-based. The primary-data-based approach refers to ESVs being directly calculated by combined modeling and environmental valuation methods, while the LULC-proxy-based approach means that ESVs are calculated by benefit transfer methods combined with LULC types [8]. In comparison to the expensive and time-consuming primary-data-based approach, the LULC-proxy-based approach is widely used in practice because of its simple operability and effectiveness in areas such as the Ethiopian Highlands [9], China [10], Nigeria [11], and the Ebinur Lake Nature Reserve [12].

LULC changes have enormous impacts on ecosystem services. With the accelerated pace of economic development, industrialization and urbanization processes, anthropogenic disturbances of the natural environment are becoming more prevalent, resulting in the increasing vulnerability of ecosystems [13], which may affect ecosystem functions and ecosystem service delivery, such as carbon sequestration [14], air regulation [15], water supply [16], soil retention [17] and flow regulation [18]. LULC changes can be influenced by climate change [19,20] and policy implementation [21,22]. The increasing occupation of ecological lands such as forests, grasslands and wetlands through the agricultural transition and urban expansion [23] has led to a considerable loss of pollination [24], biodiversity [25] and wildlife habitats [26]. In contrast, the expansion of ecological lands through ecological restoration can enhance the supply of ecosystem services like carbon sequestration [27]. Different LULC types with specific characteristics play important roles in ecosystem service supply and record the extent of the influences of human activities on nature. Appropriate LULC management that aims to enhance ecosystem service supply can make necessary contributions to regional sustainable development.

The Chinese Loess Plateau (LP) suffers from drastic human activities (e.g., large-scale deforestation and long-term cultivation) and severe environmental conditions (e.g., highly erodible loess soil, unevenly distributed precipitation and fragmented landforms); thus, it has become one of the most vulnerable and eroded regions in the world. Soil erosion is the major ecological threat and has seriously reduced agricultural productivity, depleted water resources and degraded ecosystems. In order to alleviate soil erosion and improve ecosystem services, the Chinese government initiated the Grain for Green Program (GFGP) in 1999, which requires converting steep-slope cropland to forests or grasslands [28]. The effects of ecological restoration on ecosystem services after twenty years of the implementation of the GFGP have drawn widespread scientific and public attention. Many studies report the spatial patterns, temporal variations and trade-offs of different ecosystem services at the regional [29], subregional [30], watershed [31] and local scales [32]. However, few studies consider the impacts of LULC changes on ESVs in this critical region. Hence, this study attempts to make an effort by (1) identifying LULC changes from 1990 to 2015, (2) illustrating ESV changes resulting from LULC changes and (3) analyzing the elasticity of ESV changes in response to LULC changes.

2. Materials and Methods

2.1. Study Area

The LP (33°43′–41°16′ N, 100°54′–114°33′ E) is located in north-central China, with an area of about 620,000 km². It is more than 1000 km long from east to west and 750 km wide from north to south; the elevation ranges from 88 to 5204 m (Figure 1). The LP belongs to the temperate continental climate zone; its annual temperature ranges from 4 to 14 °C, and its annual precipitation, from 200 to 750 mm. The unevenly distributed precipitation (60–70% of rainfall occurs between June and September) and the most concentrated and largest distribution of loess soil in the world have shaped a very complicated topography, including basins, sub plateaus, hills and gullies. Around 8.5% of the Chinese population lives in ca. 6.6% of China's territory; the population density reaches 168 people/km² [33]. The LP covers 44 administrative cities in seven provinces, including the Inner Mongolia Autonomous Region and Qinghai, Gansu, Ningxia, Shaanxi, Shanxi and Henan provinces.

The LP was covered by widespread forest steppes and grasslands in the Holocene [34]. Rapid population growth and increased human activities, especially over-reclamation and overgrazing, have led to significant vegetation degradation and accelerated soil erosion [35]. The average annual erosion amount reaches ca. 7500 tons/km², with the highest amount at ca. 25,000 tons/km², which forms the major source of sediment flowing into the Yellow River [36]. Water shortages are another critical concern on the LP. The water utilization ratio reaches 70%, significantly exceeding the international water utilization threshold of 40% [37]. The implementation of the GFGP has considerably improved

this situation [38], but the GFGP per se, together with economic development and urbanization progress, has greatly altered the LULC pattern on the LP.

Figure 1. The geography of the Loess Plateau.

2.2. Identifying LULC

The 30×30 m raster of LULC data from 1990, 2000, 2010 and 2015 were obtained from the ChinaCover dataset, which includes six primary classes (forestland, grassland, cropland, wetland, built-up land and other land) and 40 secondary classes. This dataset has been validated by over 100,000 ground test samples and 13 rounds of large-scale cross-checks; the average accuracy for 2010 reaches 94% in the primary classes and 86% in the secondary classes [39]. In order to be in accordance with the LULC classification used by [40], the ChinaCover data was redefined (Table 1).

Table 1. Reclassification of land use/land cover (LULC).

LULC [40]	China Cover [39]
Dry farmland	Dry farmland
Paddy field	Paddy field
Coniferous forest	Evergreen needleleaf forest
	Deciduous needleleaf forest
Mixed forest	Broadleaf and needleleaf mixed forest
Broad-leaved forest	Evergreen broadleaf forest
	Deciduous broadleaf forest
	Evergreen broadleaf shrubland
	Deciduous broadleaf shrubland
Bush	Evergreen needleleaf shrubland
	Sparse forest
	Sparse shrubland

Table 1. Cont.

LULC [40]	China Cover [39]
Bush	Tree orchard
	Shrub orchard
	Tree garden
	Shrub garden
Prairie	Temperate steppe
	Alpine steppe
Shrub grass	Tussock
	Sparse grassland
	Lawn
Meadow	Temperate meadow
	Alpine meadow
Wetland	Tree wetland
	Shrub wetland
	Herbaceous wetland
River and lake	Lake
	Reservoir/pond
	River
	Canal/channel
Glacier and snow	Permanent ice/snow
Desert	Moss/lichen
	Gobi
	Desert
Bare land	Bare rock
	Bare soil
	Salina
Built-up area	Settlement
	Transportation land
	Mining field

2.3. Calculating ESVs

The benefit transfer method was used to estimate the economic values of ecosystem services by transferring available information from one or more already-completed studies to other sites where primary information was lacking [41,42]. This method was applied to estimate the value of 17 ecosystem services of 16 LULC types at a global scale [3]. These results were adjusted for nine ecosystem services of the six main LULC types in China based on questionnaires from Chinese ecological specialists [43]. The equivalent coefficients method was developed for further improving the unit value of 11 ecosystem services of 14 LULC types [40]. Thus, these unit values were more reliable for calculating ESVs in China.

The equivalent coefficients method consists of a standard equivalent factor and an equivalent coefficients table. The standard equivalent factor is based on the price of natural grain output from 1 ha of farmland in China, which was estimated to be 503.2 US dollars per ha (\$/ha) at the price level in 2010. The equivalent coefficients table is the valuation weight for each ecosystem service provided by each LULC type. Thus, the unit value of a given ecosystem service provided by a given LULC type is equal to the product of the standard equivalent factor and the corresponding equivalent coefficients [40]. The unit value of a built-up area was assigned to be 0 because it was not considered (Table 2).

Table 2. Unit values of ecosystem services (US dollars per ha (\$/ha)).

[illegible]

The total ESV is calculated by

$$V_i = \sum_{k=1}^{11} UV_{ik} \quad (1)$$

$$ESV = \sum_{i=1}^{15} V_i \times A_i \quad (2)$$

where V_i is the total value of LULC type i , which equals the sum of the unit value (UV_{ik}) of ecosystem services for 11 categories that can be obtained from Table 2. A_i is the area of LULC type i , which is automatically calculated by ArcMap 10.6. The total ESV is the sum of the products of V_i and A_i for the 15 LULC types.

2.4. Analyzing Elasticity of ESV Changes in Response to LULC Changes

By analogy to the concept of elasticity in economics, Jiang et al. [44] proposed an indicator of elasticity for reflecting the response of ESV changes to LULC changes. It measures the percentage change in ESVs as a result of the percentage change in LULC.

For a given LULC type i , its elasticity is calculated by

$$E_i = \left| \frac{\Delta ESV_i / ESV_{start}}{\Delta A_i / A_{total}} \right| \quad (3)$$

where E_i is the elasticity of LULC type i , ΔA_i is the converted area of LULC type i in a given period, ΔESV_i is the ESV change resulting from LULC conversion, A_{total} is the total area of a given region and ESV_{start} is the total ESV at the beginning of the given period.

For a given region, like a municipality or the whole study area, the elasticity is calculated by

$$E = \left| \frac{\Delta ESV / ESV_{start}}{\Delta A / A_{total}} \right| \quad (4)$$

where E is the elasticity of the given region, ΔA is the total area of the converted LULC types in a given period, ΔESV is the total ESV change in the given region during the given period, A_{total} is the total area of the region and ESV_{start} is the total ESV in the region at the beginning of the period. The larger the elasticity of a LULC type is, the greater the impact this LULC type has on the total ESV change.

The elasticity was explained as follows: a 1% area conversion results in the $E\%$ of ESV changes in the given region in the given period. It is reasonable that the elasticity would be large when a small area conversion resulted in a great ESV change. The elasticity could be divided into three levels, $0 < E < 0.5$, $0.5 \leq E < 1$ and $E \geq 1$, indicating that the responses of ESV changes to LULC changes were inelastic, elastic and very elastic, respectively.

3. Results

3.1. LULC Conversion between 1990 and 2015

In 1990, the LP was predominantly covered by grasslands, including prairies, shrub grass and meadows (ca. 23 million ha, taking up 37% of the region); dry farmland (ca. 19 million ha, taking up 31%); and forestlands, including coniferous forests, broad-leaved forests, mixed forests and bush (ca. 13 million ha, taking up 21%). Grasslands were mainly located in the center and southwest of the LP; dry farmland was distributed in the north, east and south; and most of the forestlands were found in the east (Figure 2). Bare land accounted for 4% of the LP; built-up areas and deserts respectively occupied ca. 3 %; wetlands, rivers and lakes as well as glaciers and snow together accounted for less than 1% (Table 3).

Table 3. The area of land use/land cover types in 1990, 2000, 2010 and 2015.

Year	1990		2000		2010		2015	
LULC	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent
Dry farmland	19,472,293	31.25%	19,506,873	31.30%	18,151,785	29.13%	17,947,533	28.80%
Paddy field	174,004	0.28%	182,162	0.29%	184,742	0.30%	179,297	0.29%
Coniferous forest	1,047,766	1.68%	1,047,277	1.68%	1,048,730	1.68%	1,048,223	1.68%
Mixed forest	375,272	0.60%	373,266	0.60%	374,515	0.60%	374,076	0.60%
Broad-leaved forest	3,461,729	5.56%	3,470,623	5.57%	3,498,933	5.62%	3,499,165	5.62%
Bush	8,460,955	13.58%	8,505,503	13.65%	8,741,112	14.03%	8,742,781	14.03%
Prairie	12,116,088	19.44%	12,117,713	19.45%	12,589,808	20.20%	12,590,323	20.20%
Shrub grass	10,312,821	16.55%	10,267,643	16.48%	10,473,953	16.81%	10,446,975	16.77%
Meadow	777,767	1.25%	779,398	1.25%	795,663	1.28%	796,513	1.28%
Wetland	98,295	0.16%	93,982	0.15%	99,295	0.16%	85,520	0.14%
River and lake	439,548	0.71%	333,719	0.54%	357,665	0.57%	377,282	0.61%
Glacier and snow	10,679	0.02%	5358	0.01%	8248	0.01%	7793	0.01%
Desert	1,601,789	2.57%	1,572,011	2.52%	1,546,439	2.48%	1,507,441	2.42%
Bare land	2,363,022	3.79%	2,268,582	3.64%	2,233,455	3.58%	2,252,058	3.61%
Built-up area	1,602,038	2.57%	1,789,957	2.87%	2,209,725	3.55%	2,459,089	3.95%
Total	62,314,068	100.00%	62,314,068	100.00%	62,314,068	100.00%	62,314,068	100.00%

Figure 2. The land use/land cover in 1990.

The trend in LULC changes on the LP over 25 years was marked by a substantial reduction in dry farmland (from 31.25% in 1990 to 28.80% in 2015); the enlargement of the bush (from 13.58% in 1990 to 14.03% in 2015); the increase in prairies (from 19.44% in 1990 to 20.20% in 2015) and shrub grass (from 16.55% in 1990 to 16.77% in 2015); the decrease in wetlands (from 0.16% in 1990 to 0.14% in 2015), rivers and lakes (from 0.71% in 1990 to 0.61% in 2015); the shrinkage of deserts (from 2.57% in 1990 to 2.42% in 2015) and bare land (from 3.79% in 1990 to 3.61% in 2015); and the considerable expansion of built-up areas (from 2.57% in 1990 to 3.95% in 2015) (Table 3). The spatial distribution and transition matrices of LULC conversion in the 1990–2000, 2000–2010 and 2010–2015 periods are illustrated in Appendix A, Figures A1–A3 and Tables A1–A3, respectively.

3.2. ESV Changes between 1990 and 2015

From 1990 to 2000, the total ESV on the LP experienced a decrease of \$6.787 million. Since the implementation of the GFGP in 2000, it began to rise steadily, reaching \$324.745 million in 2010 and \$324.924 million in 2015, but did not exceed the total ESV in 1990. The value of regulating services accounted for the largest percentage (ca. \$250 million). Its changing trend was the same as that of the total ESV, decreasing in the first period and increasing in the last two periods. The value of provisioning services was reduced gradually from \$29.982 million in 1990 to \$28.994 million in 2015. The values of habitat and cultural services declined from 1990 to 2000; peaked in 2010 at \$30.352 million and \$13.6 million, respectively; and were slightly diminished in 2015 but still exceeded the values in 1990 (Figure 3).

At the municipal scale, in 1990, Erdos provided the greatest value of provisioning services (more than \$2 million), while Wuhai and Hainan provided the smallest ones (less than \$100 million; Figure 4a). Erdos also had the largest value of regulating services (more than \$30 million), while Wuhai and Zhengzhou had the smallest ones (less than \$1 million; Figure 4b). The greatest values of habitat services were found in Erdos and Yan'an (more than \$2 million), while the smallest ones were found in Zhengzhou and Wuhai (less than \$100 million; Figure 4c). The largest values of cultural services were also provided by Erdos and Yan'an (more than \$1 million), but the smallest ones were found in six cities (less than \$100 million; Figure 4d). In total, the ESVs of Erdos and Yan'an were greater than \$20 million, while the ESVs of Wuhai and Zhengzhou were smaller than \$1 million (Figure 4e). On average, the highest unit ESVs (more than \$7000/ha) were found in Jiaozuo, Lüliang, Yuncheng, Baoji and Yangquan, while the lowest ones (less than \$4000/ha) were provided by Dingxi, Guyuan, Baiyin, Hainan, Hohhot, Shuozhou and Qingyang (Figure 4f).

Figure 3. The change in ecosystem service values (ESVs) from 1990 to 2015.

Figure 4. The distribution of ecosystem service values at a municipal scale in 1990.

During the first decade, although the total ESV experienced a decline, eight cities still had an increase in ESVs, among which Luoyang had the largest gain (ca. \$175 million). The greatest ESV loss occurred in Erdos (\$1.365 million; Figure 5a). Huangnan had the largest gain in its unit ESV (\$11,290/ha), and Yuncheng had the largest loss (\$23,031/ha; Figure 5b). Between 2000 and 2010, in the context of the obvious recovery of the total ESV, nine cities still experienced a decrease, among which Yuncheng had the greatest loss (\$191 million). The greatest increase appeared in Yan'an (\$976 million; Figure 5c). However, the largest decrease in the unit ESV was found in Linxia (\$8.619 million/ha), and the largest increase was found in Huangnan (\$13,000/ha; Figure 5d). From 2010 to 2015, almost half of the cities on the LP experienced an increase in ESVs, while the other half experienced a decrease. The greatest increases (more than \$100 million) were found in Wuhai, Yan'an, Jiaozuo, Luoyang and Sanmenxia, while the greatest decreases (more than \$100 million) were found in Weinan and Shizuishan (Figure 5e). The largest gains in the unit ESV (more than \$10,000/ha) occurred in Wuhai, Hainan, Jiaozuo and Linxia, among which Linxia had the greatest one (\$42,296/ha), while the largest losses in the unit ESV (more than \$5000/ha) occurred in Shizuishan, Weinan, Taiyuan, Yangquan and Huangnan, among which Shizuishan had the greatest one (\$13,076/ha; Figure 5f). The changes in provisioning service values, regulating service values, habitat service values and cultural service values at a municipal scale during the three periods are illustrated in Appendix A, Figures A4–A6, respectively.

Figure 5. The changes in the total and unit ecosystem service values from 1990 to 2015.

3.3. Elasticity Analysis

The elasticity of each LULC type except for built-up areas was calculated for the three periods (Table 4). Since built-up areas were not assigned any value, they were not considered. The elasticities of all LULC types were very close but not identical in the three periods because the total ESVs at the beginning of these periods were not the same. Taking the elasticities in the 2000–2010 period as an example, the elasticity values of coniferous forests, mixed forests, broad-leaved forests, bush, shrub grass, meadows, wetlands, rivers/lakes and glaciers/snow were larger than 1, indicating that the ESV changes resulting from area conversion of these LULC types was very elastic. Since rivers and lakes provided larger ESVs than other LULC types, especially the considerably larger values of water provisioning and water flow regulation, their elasticity was the largest, equal to 12.3, meaning that a 1% area conversion of rivers/lakes led to a 12.3% ESV change.

Table 4. Elasticity of LULC types in the three periods.

LULC	Period		
	1990–2000	2000–2010	2010–2015
Dry farmland	0.38	0.39	0.39
Paddy field	0.37	0.38	0.38
Coniferous forest	1.68	1.72	1.69
Mixed forest	2.21	2.26	2.23
Broad-leaved forest	2.2	2.25	2.22
Bush	1.46	1.49	1.47
Prairie	0.49	0.5	0.49
Shrub grass	1.89	1.93	1.9
Meadow	1.1	1.12	1.1
Wetland	4.99	5.09	5.02
River and lake	12.04	12.3	12.13
Glacier and snow	0.98	1.01	0.99
Desert	0.11	0.11	0.11
Bare land	0.02	0.02	0.02

In summary, the converted area during the three periods accounted for 2.01%, 3.61% and 1.32% of the total area on the LP, respectively. The ESVs decreased by \$6.787 million in the first period and then increased by \$4.421 million and \$179 million in the last two periods, respectively, accounting for 2.07%, 13.8% and 0.06% of the ESVs at the beginning of the corresponding periods (Table 5). At a regional level, the elasticity in the three periods was 1.03, 0.38 and 0.05, respectively, meaning that a 1% LULC conversion resulted in 1.03%, 0.38% and 0.05% ESV changes. The elasticity indicated that the response of the ESV changes to LULC conversion was very elastic from 1990 to 2000 but inelastic in the other two periods.

Table 5. Land use/land cover conversion and ecosystem service changes during the three periods.

Period	Total Area (ha)	Converted Area (ha)	Percent	ESV Start (millions of \$)	ESV Change (millions of \$)	Percent
1990–2000	62,314,068	1,250,860	2.01%	327,111	-6787	2.07%
2000–2010	62,314,068	2,250,331	3.61%	320,324	4421	1.38%
2010–2015	62,314,068	823,434	1.32%	324,745	179	0.06%

At a municipal level, cities had different elasticities in the three periods. Between 1990 and 2000, 19 cities were very elastic, among which Baotou had the largest elasticity at 3.78 (Figure 6a). From 2000 to 2010, only seven cities had an elasticity over 1, among which Huangnan had the largest one at 2.44 (Figure 6b). During the last period, the elasticities in 11 cities were larger than 1, among which the elasticity in Linxia was the greatest one, even reaching 9.18 (Figure 6c). The elasticity of a city varied obviously in different periods. This was determined by the conversion of LULC types, their areas and the ESV changes resulting from the conversion. In the three periods, the elasticity of three cities on the LP were always larger than 1, i.e., Wuhai, Shizuishan and Linxia (Figure 6).

Figure 6. Municipal elasticity in the three periods.

4. Discussion

4.1. The Implications for Policy-Making

Since elasticity is an indicator that reflects the response of ESV changes to LULC conversions, it is helpful for detecting unusual changes among different regions and identifying policy needs for ecosystem management. Taking Linxia as an example, its elasticity was 9.18 from 2010 to 2015 (Table 4). In 2010, the central part of Linxia was mainly covered by dry farmland (ca. 46%); prairies, shrub grass and bare land were widely distributed in the northern region, while bush and meadows were located in the southern region. Note that a large lake was found in the north-central region (Figure 7). Between 2010 and 2015, Linxia experienced substantial ESV growth by around \$4.536 million, which could be attributed to the expansion of the lake. On the one hand, the conversion of 1468 ha of bare land, shrub grass and dry farmland to rivers and lakes resulted in an ESV increase of around \$4.537 million; on the other hand, it should be noted that the expansion of 597 ha of built-up areas from dry farmland led to around \$1 million in ESV reductions (Table 6). Considering the ecological importance and economic value of rivers and lakes, the effective protection and management of the lake in Linxia is urgently needed for policy-making, such as establishing a protected area [45,46] in order to avoid its shrinkage and occupation by other LULC types during the progress of urbanization.

Figure 7. The distribution of LULC in Linxia in 2010.

Table 6. LULC and ESV changes in Linxia from 2010 to 2015.

LULC Change	Area (ha)	ESV Change (millions of \$)
Bare land–River/lake	1040.15	4513.26
Shrub grass–River/lake	419.94	22.38
Dry farmland–River/lake	25.69	1.57
Dry farmland–Shrub grass	0.09	0.001
Dry farmland–Built-up area	597.24	−1.21
Total	2083.12	4536.01

Another example is Shizuishan: its elasticity was 2.46 from 2010 to 2015 (Table 4). In 2010, the central region was covered by dry farmland, paddy fields, built-up areas and rivers/lakes; bare land and grasslands (e.g., prairies and shrub grass) were widely distributed in the western region, and deserts could be found at the northwestern and eastern edges (Figure 8). Between 2010 and 2015, Shizuishan witnessed a considerable reduction in ESVs by ca. \$130 million; the unit value loss even reached \$13,076/ha. The ESV loss mainly resulted from the large occupation of rivers and lakes (ca. 2200 ha) and the rapid expansion of built-up areas (ca. 3100 ha), which led to ESV decreases of ca. \$135 and \$20 million, respectively (Table 7). Hence, the effective management of rivers and lakes and appropriate urban planning for Shizuishan are urgently needed. Decision-makers should keep in mind that the occupation of highly valuable lands such as rivers and lakes must be avoided during the urbanization process.

Figure 8. The distribution of LULC in Shizuishan in 2010.

Table 7. LULC and ESV changes in Shizuishan from 2010 to 2015.

LULC Change	Area (ha)	ESV Change (millions of \$)
River/lake–Bare land	989.76	−62.46
River/lake–Paddy field	519.45	−31.82
River/lake–Prairie	340.01	−20.62
River/lake–Shrub grass	288.15	−15.36
Shrub grass–Built-up area	987.35	−9.78
River/lake–Built-up area	70.28	−4.44
Wetland–Prairie	67.54	−1.60
Bush–Built-up area	169.24	−1.30
Prairie–Built-up area	497.03	−1.27
Dry farmland–Built-up area	570.24	−1.15
Wetland–Built-up area	41.67	−1.09
Wetland–Paddy field	27.30	−0.66
River/lake–Bush	9.03	−0.50
Wetland–Bare land	17.25	−0.45

Table 7. Cont.

LULC Change	Area (ha)	ESV Change (millions of \$)
Paddy field–Bare land	183.97	−0.34
Coniferous forest–Built-up area	37.03	−0.33
Wetland–Shrub grass	15.69	−0.26
Paddy field–Built-up area	111.84	−0.22
Shrub grass–Desert	15.74	−0.15
Dry farmland–Bare land	43.29	−0.08
Bush–Prairie	16.15	−0.08
Bare land–Built-up area	569.28	−0.06
Desert–Built-up area	99.97	−0.06
Wetland–Dry farmland	1.76	−0.04
Bush–Bare land	3.01	−0.02
Dry farmland–Desert	3.06	−0.0045
Desert–Bare land	1.45	−0.0007
Prairie–Desert	0.22	−0.0004
Dry farmland–Bush	0.18	0.0010
Paddy field–Bush	1.28	0.01
Dry farmland–Prairie	14.06	0.01
Paddy field–Dry farmland	159.00	0.01
Prairie–Shrub grass	1.68	0.01
Bush–Shrub grass	6.44	0.01
Bare land–Prairie	8.01	0.02
Paddy field–Shrub grass	8.05	0.06
Bare land–Shrub grass	31.73	0.31
Paddy field–Prairie	528.14	0.31
Dry farmland–Shrub grass	71.40	0.56
Dry farmland–River/lake	162.90	9.97
Wetland–River/lake	338.12	12.52
Total	7027.74	−130.32

4.2. The Driving Factors for LULC Conversion on the LP

LULC conversion on the LP is influenced by internal natural and external socioeconomic driving factors. Natural factors include altitude, slope, annual temperatures and annual precipitation. Altitude is the common dominant factor associated with changes in forestlands (including coniferous forests, mixed forests, broad-leaved forests and the bush), grasslands (including prairies, shrub grass and meadows), cropland (including dry farmland and paddy fields) and built-up areas. Altitude and slope are positively related to forestland conversion but negatively related to cropland conversion in the central region. Annual temperatures and annual precipitation positively affect forestland and grassland conversion in the northwestern region [47].

Socioeconomic factors include population growth (including population density, urban populations and rural populations), industry structure (including primary industries and secondary industries), economic indicators (including GDP and farmer income) and GFGP policies (including afforestation areas, fiscal revenue and fiscal expenditure). From 1990 to 2000, the change in forestlands was mainly affected by population density and primary industries; the conversion of grasslands was determined by urban populations and population density; the expansion of cropland and built-up areas depended on urban and rural populations, population density, farmer income and GDP growth. Between 2000 and 2015, urban populations and population density were responsible for forestland conversion; afforestation areas, fiscal expenditure, GDP growth and urban populations were the main

driving forces for grassland conversion; farmer income, primary industries and population density affected the conversion of cropland; and population density, GDP growth, fiscal expenditure and fiscal revenue determined the expansion of built-up areas [47]. In total, ecological restoration policies contributed about 72%, and the natural environment contributed about 28% to LULC changes on the LP, indicating that the GFGP had a profound impact on LULC conversion [48].

4.3. The Improvement of Accuracy

It is obvious that the quality of LULC data and the precision of unit values of ecosystem services provided by different LULC types determine the accuracy of the assessment. An improvement should consider both aspects. Misclassification errors based on LULC data may lead to bias in area estimates, further resulting in significantly faulty calculations of LULC conversion. Besides, data validation is often rare or inadequately undertaken because its importance is overlooked [49,50]. Furthermore, the consistency and comparability among different LULC datasets are limited by the lack of classification standards [51]. Hence, enhancing the resolution and precision of LULC datasets with validation and standardization of LULC classification systems towards harmonization are important directions in future studies.

To improve the unit ESVs of LULC types, the first step is to ensure completeness by taking more LULC types into account, such as urban types because an urban ecosystem also provides multiple valuable ecosystem services [52,53]. The development of dynamic unit ESVs is an effort made for improving precision, which can be used for assessing monthly or seasonal variations in ESVs within a given year when the LULC does not obviously change [40]. For the comparison of ESVs among different years, especially over quite a long period when the LULC has significantly changed, dynamic unit values are not appropriate. Thus, the other way is the expansion of the database to consist of more and more empirical studies based on physical modeling and environmental valuation techniques [8]. The amount of high-quality primary studies is the key basis for the benefit transfer method.

5. Conclusions

The LP is not only a vulnerable region that suffers from ecological threats, like soil erosion and water shortages, but also a valuable region that provides a variety of fundamental ecosystem services to a large population in China. Various natural and socioeconomic factors have significantly changed the pattern of LULC on the LP from 1990 to 2015. Based on the combined approach of LULC proxies and the benefit transfer method, we assessed the ESV changes in response to LULC conversion, revealing that the total ESV has been reduced by \$6.787 million from 1990 to 2000 and increased by \$4.6 million after the implementation of the GFGP from 2000 to 2015. We also showed that a 1% area conversion has resulted in 1.03%, 0.38% and 0.05% ESV changes in the 1990–2000, 2000–2010 and 2010–2015 periods, respectively. We suggested that elasticity as a simplified indicator is helpful for detecting unusual changes among different regions and identifying specific policy needs for ecosystem management, such as in the cases of Linxia and Shizuishan. Appropriate ecosystem management not only enhances ecosystem service supply but also contributes to regional sustainable development. An increase in the accuracy of results should be considered from the perspectives of LULC data quality and unit ESV precision in the future.

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Appendix A

Figure A1. Distribution of changed areas from 1990 to 2000.

Figure A2. Distribution of changed areas from 2000 to 2010.

Figure A3. Distribution of changed areas from 2010 to 2015.

Table A1. Transition matrix from 1990 to 2000 (unit: ha).

From \ To	Dry Farmland	Paddy Field	Coniferous Forest	Mixed Forest	Broad-Leaved Forest	Bush	Prairie	Shrub Grass	Meadow	Wetland	River and Lake	Glacier and Snow	Desert	Bare Land	Built-Up Area
Dry farmland	-	1987	148	516	9546	54,646	55,740	80,831	2073	1732	20,191	0	103	13,628	149,663
Paddy field	8208	-	0	2	1	235	208	73	0	112	811	0	0	21	1772
Coniferous forest	121	0	-	153	788	1732	227	661	149	0	16	0	0	30	13
Mixed forest	315	0	259	-	2410	1208	36	274	9	1	36	0	0	25	38
Broad-leaved forest	2721	0	762	909	-	7666	998	2233	74	0	79	0	10	101	356
Bush	23,520	30	1321	707	7781	-	13,140	11,528	1682	90	619	0	2979	839	3201
Prairie	74,943	848	192	32	822	10,057	-	13,438	843	1044	2576	1	6141	5272	10,663
Shrub grass	107,384	5365	646	223	2562	20,085	22,741	-	118	514	4003	23	6697	18,583	19,445
Meadow	1179	0	62	2	12	1175	708	112	-	7	3	0	0	182	103
Wetland	7630	199	1	0	14	308	952	594	29	-	8020	0	3	1760	199
River and lake	75,876	5346	6	66	423	3280	8405	10,936	7	10,818	-	0	729	37,079	2820
Glacier and snow	0	0	0	0	0	1	2	0	0	0	0	-	0	6776	0
Desert	5387	0	0	0	10	4900	14,641	20,722	1	42	22	0	-	416	398
Bare land	111,765	5748	22	21	166	5552	9969	20,863	171	1007	13,916	1438	111	-	8263
Built-up area	7456	67	15	5	224	504	788	806	10	6	97	0	12	147	-

Table A2. Transition matrix from 2000 to 2010 (unit: ha).

From \ To	Dry Farmland	Paddy Field	Coniferous Forest	Mixed Forest	Broad-Leaved Forest	Bush	Prairie	Shrub Grass	Meadow	Wetland	River and Lake	Glacier and Snow	Desert	Bare Land	Built-Up Area
Dry farmland	-	8706	577	1252	27,139	232,021	595,344	320,514	16,900	6967	40,955	0	306	36,357	254,592
Paddy field	9912	-	0	0	17	214	102	43		29	1709	0	0	76	1192
Coniferous forest	84	0	-	157	2099	707	35	307	4	0	13	0	0	16	80
Mixed forest	141	0	147	-	925	544	18	237	0	0	5	0	0	5	37
Broad-leaved forest	2089	3	2773	874	-	10,033	496	1791	0	0	222	0	0	243	677
Bush	11,926	4	928	664	13,485	-	6004	8944	124	27	725	0	668	1280	8654
Prairie	58,295	692	181	20	728	13,773	-	8518	235	1731	6308	1	4097	13,008	75,909
Shrub grass	45,516	1790	225	292	2124	19,979	17,254	-	12	1081	10,787	6	6484	12,744	54,031
Meadow	60	0	13	1	0	566	165	2	-	0	23	2	0	6	319
Wetland	3758	78	0	0	96	627	2257	764	0	-	8015	0	6	1669	1030
River and lake	21,206	3324	27	19	155	2411	5804	5545	5	10,028	-	0	110	18,747	4779
Glacier and snow	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0
Desert	2300	30	192	2193	12,381	15,616	0	0	0	127	167	0	-	521	4260
Bare land	30,622	584	13	18	361	3921	12,391	14,113	130	3567	26,562	2878	580	-	24,159
Built-up area	10,118	636	1	3	68	347	114	470	1	11	233	0	1	86	-

Table A3. Transition matrix from 2010 to 2015 (unit: ha).

From \ To	Dry Farmland	Paddy Field	Coniferous Forest	Mixed Forest	Broad-Leaved Forest	Bush	Prairie	Shrub Grass	Meadow	Wetland	River and Lake	Glacier and Snow	Desert	Bare Land	Built-Up Area
Dry farmland	-	1466	0	1	833	24,214	117,626	50,456	2576	1358	21,071	0	58	15,245	106,479
Paddy field	577	-	0	0	0	401	598	35	0	0	2403	0	0	243	4878
Coniferous forest	0	0	-	0	3	16	10	5	0	0	5	0	0	12	476
Mixed forest	32	0	0	-	0	1	0	44	0	0	0	0	0	17	347
Broad-leaved forest	795	0	2	0	-	94	107	198	0	0	111	0	0	443	2006
Bush	9877	0	9	0	2835	-	1375	745	0	88	949	0	96	3043	15,688
Prairie	64,399	5	0	0	72	2868	-	2765	0	157	5665	0	715	12,980	61,211
Shrub grass	33,188	0	0	0	100	1552	3538	-	5	323	5751	0	1622	20,920	40,445
Meadow	199	0	0	0	0	0	0	0	-	0	265	0	0	1170	213
Wetland	3183	66	0	0	24	277	1819	554	0	-	13,052	0	6	2248	654
River and lake	8542	2103	1	0	28	1120	6936	5251	26	4903	-	0	117	17,418	624
Glacier and snow	0	0	0	0	0	0	0	0	0	0	0	-	0	454	0
Desert	5372	0	0	0	55	3780	12,277	13,866	0	67	98	0	-	3146	5759
Bare land	11,939	58	0	0	21	1879	7017	6481	96	1216	16,630	0	2921	-	10,478
Built-up area	38	0	0	0	2	39	7	31	0	3	660	0	1	14	-

Figure A4. ESV changes from 1990 to 2000.

Figure A5. ESV changes from 2000 to 2010.

Figure A6. ESV changes from 2010 to 2015.

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