*land*

MDPI

*Article*

# Land Use and Land Cover Change in the Yellow River Basin from 1980 to 2015 and Its Impact on the Ecosystem Services

**Bo Liu, Libo Pan, Yue Qi, Xiao Guan * and Junsheng Li**

Institute of Ecology, Chinese Research Academy of Environmental Sciences, Beijing 100012, China; liubo@craes.org.cn (B.L.); panlb@craes.org.cn (L.P.); qiyue8351572@163.com (Y.Q.); lijsh@craes.org.cn (J.L.)
* Correspondence: cynthia815@126.com

**Abstract:** Land use and land cover change is an important driving force for changes in ecosystem services. We defined several important human-induced land cover change processes such as Ecological Restoration Project, Cropland Expansion, Land Degradation, and Urbanization by the land use/land cover transition matrix method. We studied human-induced land cover changes in the Yellow River Basin from 1980 to 2015 and evaluated its impact on ecosystem service values by the benefit transfer method and elasticity coefficient. The results show that the cumulative area of human-induced land cover change reaches 65.71 million ha from 1980 to 2015, which is close to the total area of the Yellow River Basin. Before 2000, Ecological Restoration Project was the most important human-induced land cover change process. However, due to the large amount of cropland expansion and land degradation, the area of natural vegetation was reduced and the ecosystem value declined. Since 2000, due to the implementation of the "Grain for Green" program, the natural vegetation of upstream area and midstream area of Yellow River Basin has been significantly improved. This implies that under an appropriate policy framework, a small amount of human-induced land cover change can also improve ecosystem services significantly.

**Keywords:** land use and land cover change; Yellow River Basin; human-induced land cover change; ecosystem services; benefit transfer method

check for updates

**Citation:** Liu, B.; Pan, L.; Qi, Y.; Guan, X.; Li, J. Land Use and Land Cover Change in the Yellow River Basin from 1980 to 2015 and Its Impact on the Ecosystem Services. *Land* **2021**, *10*, 1080. https://doi.org/10.3390/land10101080

Academic Editor: Nigussie Haregeweyn

Received: 26 August 2021
Accepted: 11 October 2021
Published: 13 October 2021



## 1. Introduction

Land use and land cover (LULC) change is an important indicator that characterizes the impact of human activities on the natural ecosystem [1]. It is the link between human social-economic activities and natural ecological processes [2], and it is also an important content of global climate change and environmental change research [2–4]. LULC change is of great significance for in-depth study of biosphere-atmosphere interaction, biodiversity, land surface radiative forcing, biogeochemical cycles, and sustainability of resources and environment [2,3,5].

LULC change is one of the important factors driving changes in ecosystem services provision [6,7]. Ecosystem services (ES) are the benefits that humans obtain from nature through direct or indirect approaches [8,9], and are the core contents of regional sustainable development and human well-beings [10–14]. By changing important ecological processes such as energy exchange, water cycle, soil erosion and deposition, and biogeochemical cycle of the ecosystem, LULC change can affect the provision of ES [15]. Furthermore, there are significant differences in the impact of different LULC change on the ES provision [16,17]. For example, ecosystem protection and ecological restoration projects will increase the key ES such as soil and water conservation, water yield, and nutrient cycling [18], whereas the fragmentation of landscapes caused by urbanization will reduce ES [19].

Ecosystem service value (ESV) assessment is one of the important tools to carry out ecosystem service evaluation [8,20,21]. The monetary value evaluation of ecosystem services has greatly promoted the development of research related to ecosystem services, including raising public awareness of the importance of ecosystem services to society [22,23], safeguard the benefits and interests of different stakeholders [24], guiding decision-making and policy-making [14], and developing knowledge about ecosystem management [25]. It can also provide incentives for ecosystem protection and restoration, such as payments for ecosystem services programs [26–28].

There have been many studies about the impact of LULC change on ES [29–31], and most of them focus on assessing the overall sensitivity of ES to LULC change [32,33], or analyzing the driving process of LULC changes affecting ES based on temperature, precipitation, population, and economy [34–36]. However, most studies only regard LULC changes as the result of land policy or human activities, and fail to distinguish between natural and human-induced processes in land cover changes. Land use (LU) is the use of land by humans for economic and social purposes [14], while land cover (LC) refers to the physical and biological cover over the surface of land including water, vegetation, bare soil, and artificial structures [37]. Although land use and land cover are intimately linked and are often studied as a whole [38], land cover change is influenced both by natural and human-induced processes. The natural processes that affect LC changes mainly include climate change and wildfires [39,40], while human-induced processes that affect land cover include agricultural expansion, water conservancy construction, urbanization, and ecological restoration projects. Therefore, in order to better understand the impact of land policy or human activities on ecosystem services, it is necessary to distinguish between natural and man-made processes in land cover change. Since few ES studies distinguish between human-induced LC changes and nature-process LC changes, and quantitatively evaluate the impact of human-induced LC changes on ES, our understanding of the impact of human-induced LC changes on ES still needs to be strengthened.

The Yellow River Basin (YRB) is an important ecological barrier in northern China, including the Qinghai-Tibet Plateau, the Loess Plateau, and the North China Plain [41]. The ecosystem of the YRB has undergone major changes due to frequent human activities [19,42,43], which in turn affected the ES provision and social economy and development in the YRB [36,44,45]. Investigating the impact of human-induced LC changes on ES in the YRB has important significance for ecological environmental protection and sustainable development policy making in the YRB. The objectives of this paper are to (1) investigate the land use/land cover (LULC) trend and human-induced LC changes in the YRB from 1980 to 2015, (2) assess the ES monetary values (ESV) of the YRB based on the benefit transfer method from 1980 to 2015, and (3) evaluate the impact of LULC changes on ESV.

## 2. Study Area and Methods

### *2.1. Study Area*

The Yellow River originates from the northern foot of the Bayan Har Mountain on the Qinghai-Tibet Plateau, with a total length of 5464 km. It is the second longest river in China with a basin area of 79,500,000 ha. The YRB is located in 96° E–119° E and 32° N–42° N, with a length of about 1900 km from east to west and a width of about 1100 km from north to south. (Figure 1a), the topography of the YRB is high in the west and low in the east (Figure 1b). The annual average temperature of the YRB is −13.1–15.3 °C (Figure 1c), and the annual average precipitation of the YRB is 116.2~1038.7 mm (Figure 1d), with a decreasing trend from southeast to northwest. The Yellow River basin (YRB) can generally be divided into four watersheds: the source area (SA), the upstream area (UA), the midstream area (MA), and the downstream areas (DA).

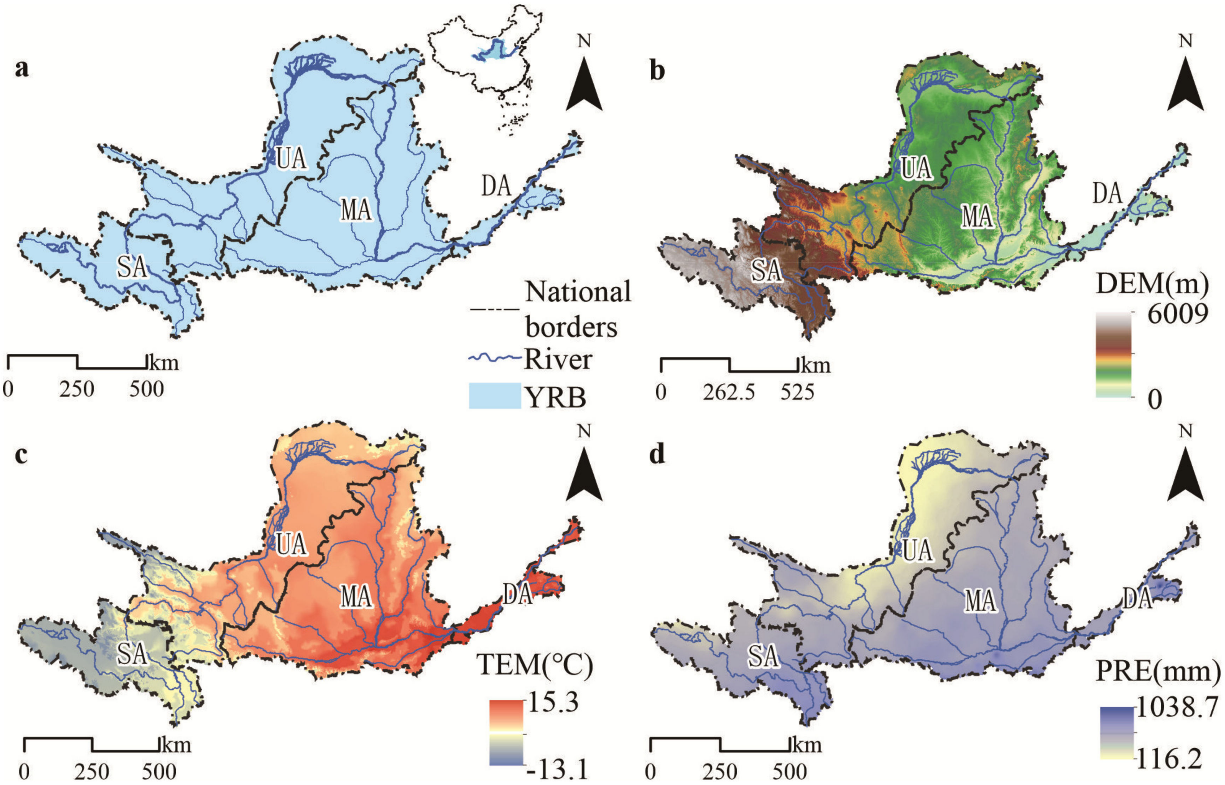


**Figure 1.** Location and overview of the YRB. (**a**) Basin area. (**b**) Digital elevation model (DEM). (**c**) The annual average temperature. (**d**) The annual average precipitation. SA, UA, MA, and DA represent the Source Area, Upstream Area, Midstream Area, and Downstream Areas of YRB, respectively.

### *2.2. Data Sources*

The land use and land cover (LULC) data come from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (RESDC) (http://www.resdc.cn accessed on 20 August 2021) [1,46–48]. These data are based on Landsat Thematic Mapper/Enhanced Thematic Mapper Plus remote sensing images from different periods and are generated through visual interpretation based on national field surveys. LULC data were used in this study from the year 1980, 1990, 1995, 2000, 2005, 2010, and 2015. The spatial resolution of LULC data used was 1 km × 1 km, which is resampled from the original dataset (30 m × 30 m) by nearest neighbor method. According to field surveys and records, the overall evaluation accuracy of the LULC primary types is over 94.3%, and the accuracy of the LULC secondary types is over 91.2% [1,46–48], which can meet the data requirements of this study. The LULC types of original data were classified into 6 primary categories (i.e., cropland, forestland, grassland, water area, construction land, unused land) and 24 secondary categories. By overlaying the LULC data and Vegetation Map of China (1:1,000,000), the LULC types are reclassified into seven primary categories including cropland, forest, grassland, wetland, bare land, urban land, and water area and 16 secondary categories (Table A1 in Appendix A). The boundary, Vegetation Map of China (1:1,000,000), temperature and precipitation data of the YRB also come from RESDC (http://www.resdc.cn accessed on 20 August 2021), where the temperature and precipitation data are obtained by the thin film spline interpolation method using ANUSPLIN software [49], with a spatial resolution of 1 km × 1 km. The DEM data come from the Geospatial Data Cloud Platform of the Computer Network Information Center of the Chinese Academy of Sciences (http://www.gscloud.cn accessed on 20 August 2021), with a spatial resolution of 90 m × 90 m, and the nearest neighbor method was used to resample the data into the resolution of 1 km × 1 km.

### 2.3. LULC Change Transition Analysis

The transition matrix method was used to detect the conversion information of LULC change during the study period. The general form of the LULC change transfer matrix is,

$$s_{ij} = \begin{bmatrix} s_{11} & s_{12} & \ldots & s_{1n} \\ s_{21} & s_{22} & \ldots & s_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ s_{n1} & s_{n2} & \ldots & s_{nn} \end{bmatrix} \quad (1)$$

where $s$ represents the area (ha); $n$ represents the number of LULC types before and after the transfer; $i$, $j$ ($i$, $j$ = 1,2, . . . , $n$) represent the LULC types before and after the transfer respectively; $s_{ij}$ represents the area (ha) of land type $i$ converted to land type $j$.

### 2.4. Estimation of Human-Induced LC Changes

In this study, LULC change was divided as human-induced LC changes and natural-process LC changes. Land cover or ecosystem transfer and change detection method [50] is used for LULC changes attribution analysis (Table 1). Different natural and human-induced land cover transition processes are defined through LULC change transition analysis described in Section 2.3. For example, cropland expansion (CE) is defined as the LC transition process from natural vegetation/desert/barren/ice to cropland; urbanization (UR) is defined as the LC transition process from natural vegetation/desert/barren/ice to urban; Ecological Restoration Project (ERP) is defined as the LC transition process from desert/desert/ice to natural vegetation; land degradation (LD) is defined as the LC transition process from natural vegetation/farmland/urban to desert/barren/ice. The details of LC changes definitions can be found in Figure A1. A summary of land policies implemented in the YRB can be found in Table A7.

**Table 1.** Land cover or ecosystem transfer and change detection method.

| LC Type before Change | → | LC Type after Change | Definitions |
|---|---|---|---|
| Desert/Barren/Ice | → | Natural Vegetation * | Ecological Restoration Project |
| Cropland | → | Natural Vegetation | |
| Desert/Barren/Ice | → | Reservoir | Water conservancy construction |
| Natural Vegetation | → | Reservoir | |
| Cropland | → | Reservoir | |
| Desert/Barren/Ice | → | Urban | Urbanization |
| Natural Vegetation | → | Urban | |
| Cropland | → | Urban | |
| Reservoir | → | Urban | |
| Natural Vegetation | → | Cropland | Cropland expansion |
| Desert/Barren/Ice | | Cropland | |
| Natural Vegetation | → | Desert/Barren/Ice | Land degradation |
| Reservoir | → | Desert/Barren/Ice | |
| Cropland | → | Desert/Barren/Ice | |
| Urban | → | Desert/Barren/Ice | |
| Desert/Barren/Ice | → | Desert/Barren/Ice | Natural process |
| Natural Vegetation | → | Natural Vegetation | |

* Natural Vegetation includes Forest, Grassland, Wetland, and Water land cover types.

Ecological restoration projects (ERP), water conservancy construction (WCC), urbanization (UR), and land degradation (LD) are considered as human-induced LC change processes. It should be noted that, drawing on the concept of "human influence on land" proposed by Zalles et al. [5], human-induced LC change only considers human production and life processes that directly affect the land, which is different from human occupation of net primary production [51] and human footprint [52], and did not consider factors such as population density and spatial distance [53] as an indicator of human activity.

*2.5. Estimation of ESV*

The Benefit Transfer Method refers to applying existing values or information from one or multiple previously established study sites to other unstudied sites with similar characteristics where the site-specific primary valuation is lacking [30,54]. The method proposed by Xie et al. [21] was used to evaluate the ecosystem service value (ESV) of the Yellow River Basin. The formula is as follows,

$$ESV = \sum_{k}^{n} A_k DVC_k \tag{2}$$

where $ESV$ is the value of ecosystem services, in US dollar (USD); $A_k$ is the area of the $k$-th LULC type, in ha; $VC_k$ is the equivalent coefficient of the $k$-th ESV, in USD ha$^{-1}$.

In the method proposed by Xie et al. [21], the $VC_k$ was estimated as the product of the standard equivalent factor and the equivalent coefficients. The standard equivalent factor, which serves as the benchmark for other ecosystem services, refers to the value provided by the natural ecological components of a certain ecosystem per unit land area. Based on the labor value theory [55], Xie et al. [21] take the average net benefit excluding the cost value of human input as the standard equivalent factor of the Chinese ecosystem and estimate the value of the standard equivalent coefficient of 503.2 USD ha$^{-1}$ in 2010. Equivalent coefficient is the weight coefficient of the service value of each ecosystem. Through a professional questionnaire survey of 500 Chinese ecologists and scholars in related disciplines, Xie et al. [21,56] proposed an $ESV$ equivalent coefficient table. In the $ESV$ equivalent coefficient table, the ecosystem includes six primary types (i.e., cropland, forest, grassland, wetland, wasteland, and waters) and 14 secondary types. Ecosystem services include four primary classifications (i.e., provisioning services, regulating services, habitat services, and culture and amenity services) [57] and 11 secondary classifications (Table 2). The method proposed by Xie et al. [21] has been used to calculate the monetary value of china's ecosystem services, and researchers have used this method to calculate the monetary value of ecosystem services in the YRB. Therefore, it is feasible to apply this method to study the monetary value of ecosystem services in the YRB.

*2.6. Elasticity-Sensitivity Analysis*

Elasticity coefficient ($E$), a concept from economics, was used to study response of ESV to LULC changes [30], and its formula is as follows,

$$E = \left| \frac{(ESV_j - ESV_i)/ESV_i}{\sum \Delta A_k / \sum A_k} \right| \tag{3}$$

where $ESV$ is the total estimated value of all $ES$, the unit is USD; $\Delta A_k$ is the land transfer area of $k$-th LULC type, the unit is ha; $A_k$ is the land area of the $k$-th LULC type, the unit is ha; $i$ and $j$ represent the beginning and end of the study period, respectively; $k$ represents LULC category. Elasticity (E) is a measure about percentage change in ESV as a result of percentage change in LULC. If a small area conversion resulted in a significant ESV change, then the elasticity is large. According to Jiang et al. [30], elasticity (E) can be divided into three categories, $0 < E < 0.5$, $0.5 < E < 1$, and $E > 1$, indicating that response of ESV to LULC change is inelastic, elastic, and very elastic.

**Table 2.** The equivalent coefficients table for ecosystem service value (ESV) per unit area for the 6 ecosystems and 4 ecosystem services. [21].

| Ecosystem Classification | | Provisioning Services | | | Regulating Services | | | | | | Habitat Services | Cultural & Amenity Services |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Primary | Secondary | Food | Materials | Water | Air Quality Regulation | Climate Regulation | Waste Treatment | Regulation of Water Flows | Erosion Prevention | Maintenance of Soil Fertility | Habitat Services | Cultural & Amenity Services |
| Cropland | Dry land | 0.85 | 0.40 | 0.02 | 0.67 | 0.36 | 0.10 | 0.27 | 1.03 | 0.12 | 0.13 | 0.06 |
| | Paddy field | 1.36 | 0.09 | −2.63 | 1.11 | 0.57 | 0.17 | 2.72 | 0.01 | 0.19 | 0.21 | 0.09 |
| Forest | Needle-leaf | 0.22 | 0.52 | 0.27 | 1.70 | 5.07 | 1.49 | 3.34 | 2.06 | 0.16 | 1.88 | 0.82 |
| | Mixed | 0.31 | 0.71 | 0.37 | 2.35 | 7.03 | 1.99 | 3.51 | 2.86 | 0.22 | 2.60 | 1.14 |
| | Broadleaf | 0.29 | 0.66 | 0.34 | 2.17 | 6.50 | 1.93 | 4.74 | 2.65 | 0.20 | 2.41 | 1.06 |
| | Bush | 0.19 | 0.43 | 0.22 | 1.41 | 4.23 | 1.28 | 3.35 | 1.72 | 0.13 | 1.57 | 0.69 |
| Grassland | Prairie | 0.10 | 0.14 | 0.08 | 0.51 | 1.34 | 0.44 | 0.98 | 0.62 | 0.05 | 0.56 | 0.25 |
| | Shrub grass | 0.38 | 0.56 | 0.31 | 1.97 | 5.21 | 1.72 | 3.82 | 2.40 | 0.18 | 2.18 | 0.96 |
| | Meadow | 0.22 | 0.33 | 0.18 | 1.14 | 3.02 | 1.00 | 2.21 | 1.39 | 0.11 | 1.27 | 0.56 |
| Wetland * | Wetland | 0.51 | 0.50 | 2.59 | 1.90 | 3.60 | 3.60 | 24.23 | 2.31 | 0.18 | 7.87 | 4.73 |
| Barren land | Desert | 0.01 | 0.03 | 0.02 | 0.11 | 0.10 | 0.31 | 0.21 | 0.13 | 0.01 | 0.12 | 0.05 |
| | Barren | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.10 | 0.03 | 0.02 | 0.00 | 0.02 | 0.01 |
| Water area ** | Water | 0.80 | 0.23 | 8.29 | 0.77 | 2.29 | 5.55 | 102.24 | 0.93 | 0.07 | 2.55 | 1.89 |
| | Glacier and snow | 0.00 | 0.00 | 2.16 | 0.18 | 0.54 | 0.16 | 7.13 | 0.00 | 0.00 | 0.01 | 0.09 |

* Wetland refers to marshland, swampland and beach. ** Water area refers to terrestrial aquatic ecosystems including natural river, lake, ditch and canal, etc.

## 3. Results

### *3.1. LULC Areas from 1980 to 2015*

#### 3.1.1. Basin Scale

In 1980, the area of grassland, cropland, and woodland in the YRB is about 61.36 million hectares (Mha), accounting for 86.76% of the total area of the basin; the area of barren land, wetland, and water areas is about 7.88 Mha, accounting for 11.14% of the total area of the basin; and the area of urban land is about 1.49 Mha, accounting for 2.10% of the total area of the basin (Figure 2). Croplands are mainly distributed in the UA (26.45%) and MA (63.06%); forests are mainly distributed in the UA (24.83%) and MA (63.95%); grasslands are widely distributed in the SA (24.27%), UA (44.07%), and MA (30.82%); wetlands are mainly distributed in the SA (26.79%) and UA (50.74%); urban land are mainly distributed in the UA (34.66%), MA (42.02%), and DA (22.42%); barren land are mainly distributed in the SA (20.69%), UA (63.87%), and MA (14.99%); and water bodies of the YRB are widely distributed. Details of LULC areas in YRB from 1980 to 2015 can be found in Table A2.

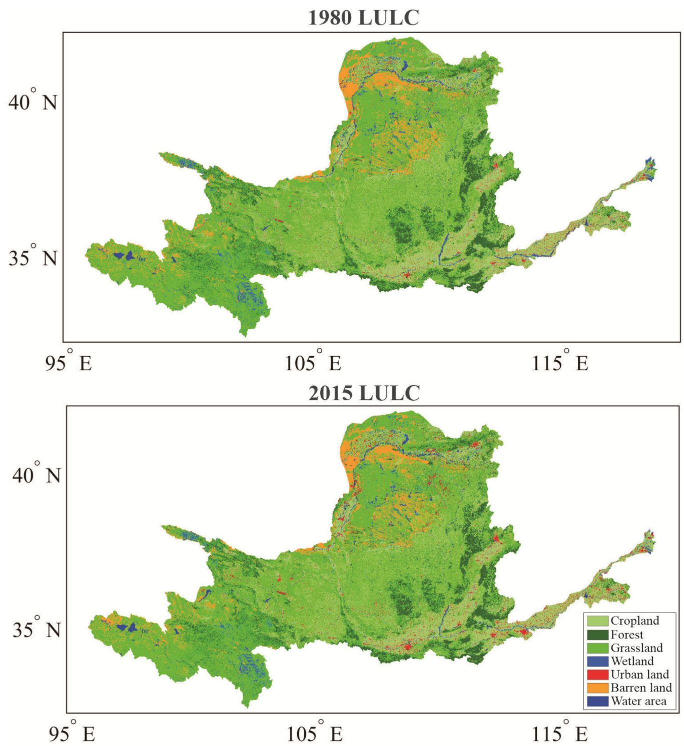


**Figure 2.** Areas of LULC in YRB, SA, UA, MA, and DA from 1980 to 2015.

Compared with 1980, the area of urban land, water bodies, and urban lands in the YRB increased by 45.10%, 3.44%, and 2.58% in 2015, while wetland, bare land, grassland, and farmland decreased by 7.18%, 2.27%, 1.31%, and 1.29%, respectively. However, only the average annual change rate (ACR) of urban land area continued to increase (Table A3), with the ACR reach its maximum value in 2010–2015 period (0.0673 Mha/a), while other LU/LC trends showed significant reversals or fluctuations, for example, the LU/LC with the largest variation in the ACR is grassland, and its maximum and minimum ACR values occurred in 1990–1995 period (0.1540 Mha/a) and 1995–2000 period (−0.1896 Mha/a), respectively. Details of average annual LULC change rate in YRB from 1980 to 2015 can be found in Table A3.

#### 3.1.2. Watershed Scale

In 1980, the LULC in SA and UA of the YRB was dominated by grasslands, with an area of 8.14 Mha (75.60% of SA) and 14.78 Mha (54.51% of UA), respectively (Figure 2). The

LULC in MA and DA of the YRB was dominated by cropland, with an area of 11.88 Mha (39.84% of MA) and 1.87 Mha (67.81% of DA), respectively. Compared with 1980, the grassland area in the SA and UA decreased by 0.72% and 2.09% respectively in 2015, the area of cropland in the MA decreased by 2.70%, and the area of cropland in the DA increased by 0.61%. Details of LULC areas in SA, UA, MA, and DA from 1980 to 2015 can be found in Table A2.

In the SA of the YRB, all the LULC trends showed fluctuations (Table A2), where the LULC with the largest variation in ACR is barren land, followed by grassland; in the UA of the YRB, all the LULC trends also showed fluctuations, where the LULC with the largest variation in ACR is cropland, followed by grassland; in the MA of YRB, the urban land area continued to increase from 1980 to 2015, with the ACR reached its maximum value in 2010–2015 period (0.0313 Mha/a), while other LULC trends showed significant reversals or fluctuations, and LULC with the largest variation in ACR is grassland, followed by forest; in the DA of the YRB, the urban land area also continued to increase from 1980 to 2015, with the ACR reached its maximum value in 2000–2005 period, while other LULC trends showed significant reversals or fluctuations, and LULC with the largest variation in the ACR is grassland, followed by cropland. Details of average annual LULC change rate in SA, UA, MA, and DA from 1980 to 2015 can be found in Table A3.

### *3.2. LULC Change Area from 1980 to 2015*

#### 3.2.1. Basin Scale

The LULC change area in the YRB showed an increasing trend before the year 2000 (Figure 3) and reached its maximum value (26.02 Mha) in 1995–2000 period; the LULC change area in the YRB showed a decreasing trend after the year 2000, with its minimum value (0.81 Mha) appeared in 2010–2015 period. From 1990 to 2015, the human-induced LC change dominates, with the minimum and maximum percentages appearing in 2005–2010 period (74.19%) and 2010–2015 period (92.39%), respectively; the natural-process LC in the YRB accounted for less than 25% of the total LULC change areas. For all LULC change types, the proportion of ecological restoration projects (ERP) was the highest before the year 2010, with the maximum value appearing in the 1990–1995 period (accounting for 38.08% of the total LULC change areas); the proportion of urbanization (UR) was the highest in 2010–2015, accounting for 43.39% of the total LULC change areas. Details of LULC change areas in YRB from 1980 to 2015 can be found in Table A4.

#### 3.2.2. Watershed Scale

In the SA, UA, MA, and DA of the YRB, the LULC change areas decreased significantly after the year 2000 (Figure 3). Except for the maximum value of DA which appeared in the 1980–1990 period, the maximum values of the other watersheds all appeared in the 1995–2000 period. The highest proportion of LULC change areas in SA was human-induced LC change areas; except that the proportion of human-induced LC change areas in 2005–2010 period was only 40.34%, the proportion of human-induced LC change areas was higher than 65.04% in the rest of time periods; before the year 2000, ecological restoration projects (ERP) areas accounted for the highest proportion of the total LULC change areas (≥32.15%), after the year 2000, land degradation (LD) areas accounted for 69.67% of the total LULC change areas in 2000–2005 period, and urbanization (UR) areas accounted for 28.46% of the total land use area in the 2010–2015 period. The human-induced LC change areas in UA dominated the LULC change areas before the year 2000; ecological restoration projects (ERP) areas accounted for the highest proportion of the total LULC change areas (≥29.36%), and after the year 2000, urbanization (UR) accounted for 34.62% of the total LULC change in the 2010–2015 period. The human-induced LC change areas in MA dominated the total LULC change areas before the year 2010; cropland expansion (CE) areas and ecological restoration projects (ERP) areas accounted for the most proportion of the total LULC change, and after the year 2010, urbanization (UR) areas accounted for 54.47% of the total LULC change in 2010–2015 period. The human-induced LC areas in

DA dominated the LULC change areas; before the year 2005, cropland expansion (CE) areas accounted for the highest proportion of the total LULC change areas (≥44.15%), and after the year 2005, urbanization (UR) areas accounted for the largest proportion of human-induced LC change areas, reaching its maximum value (71.28%) in the 2010–2015 period. Details of LULC change areas in SA, UA, MA, and DA from 1980 to 2015 can be found in Table A5.

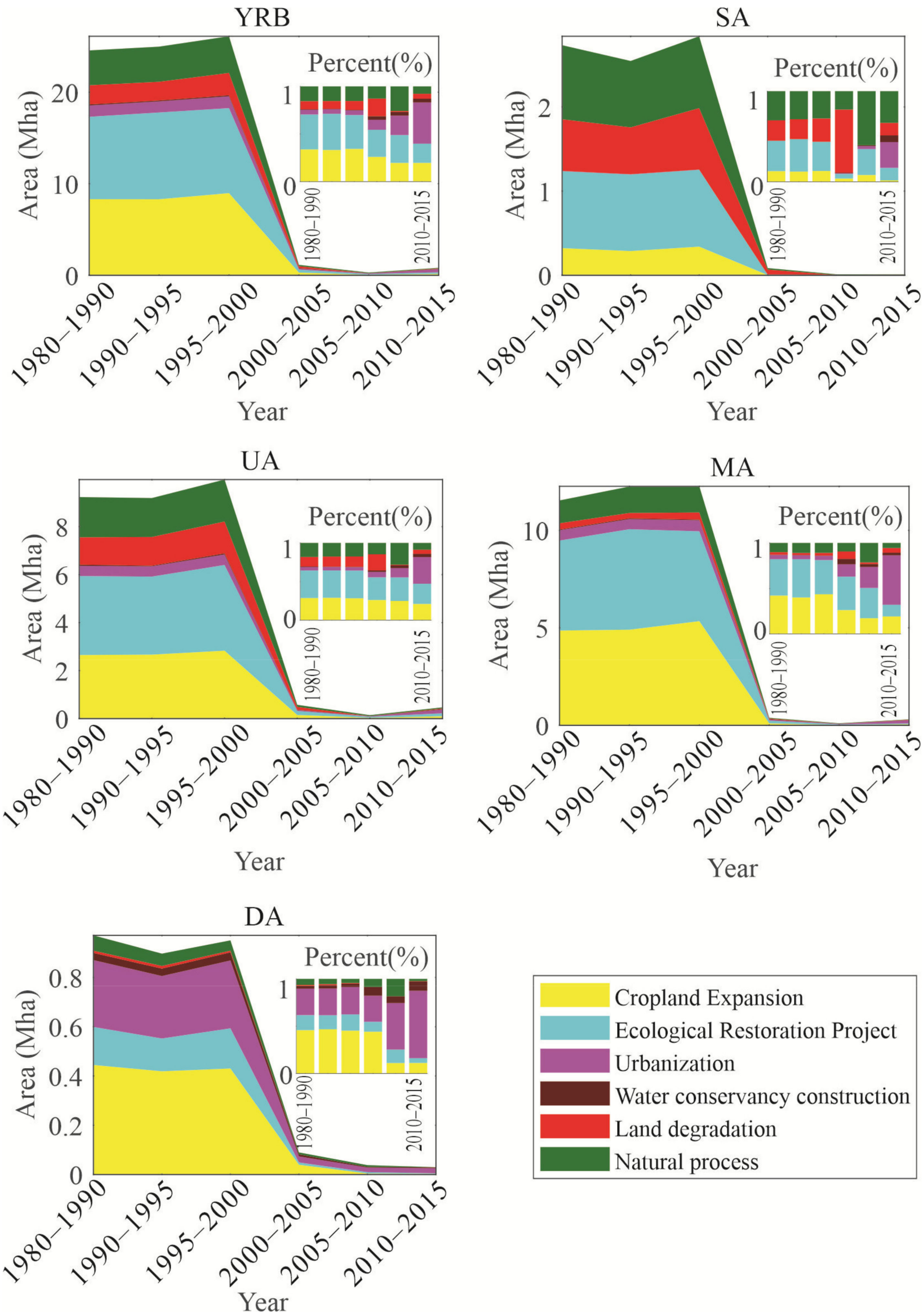


**Figure 3.** LULC change areas of YRB, SA, UA, MA, and DA from 1980 to 2015. The sub-figure describes the proportion of each LULC types. Cropland expansion (CE), ecological restoration projects (ERP), water conservancy construction (WCC), urbanization (UR), and land degradation (LD) are considered as human-induced LC change processes.

### 3.3. ESV from 1980 to 2015

#### 3.3.1. Basin Scale

In 1980, the ESV of the Yellow River Basin (YRB) was 394.25 billion USD (Figure 4). From the perspective of ES types, the main ES in the YRB were regulating services (329.07 billion USD) and habitat services (38.17 billion USD), which accounted for 83.47% and 9.68% of ESV, respectively; from the perspective of watersheds, ESV in the YRB mainly come from the UA and MA, which accounted for 31.46% and 34.46% of the ESV in YRB, respectively. Compared with 1980, the ESV of the YRB in 2015 decreased by 0.94%, valued at 390.55 billion USD, with the main ES was still Regulating Services (83.65%) and habitat services (9.58%), and the ESV still mainly come from the UA (31.49%) and MA (34.76%) of the YRB.

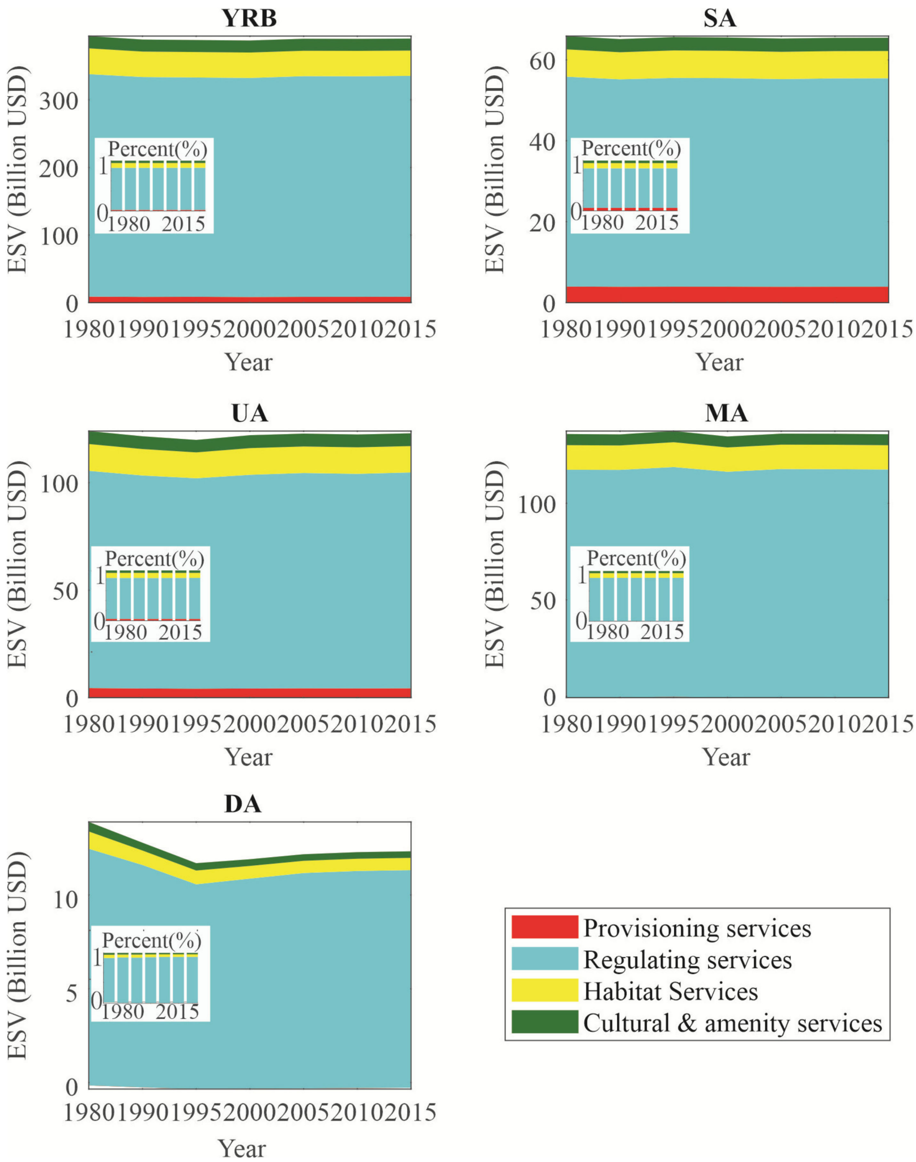


**Figure 4.** ESV of YRB, SA, UA, MA, and DA from 1980 to 2015. The sub-figure describes the proportion of each ES types.

The ACR of ESV in the YRB showed fluctuations or variations (Table A5). The maximum ACR of provisioning services value, regulating services value, and total ESV of all appeared in 2000–2005 period, while the maximum ACR of habitat services value and cultural and amenity services value appeared in 2005–2010 period and 1995–2000 period, respectively; the minimum ACR of ESV appeared in 1980–1990 period. Details of annual ESV change rate in YRB from 1980–2015 can be found in Table A5.

#### 3.3.2. Watershed Scale

In 1980, the ESV in the SA was ranked as (Figure 4) regulating services > habitat services > provisioning services > cultural and amenity service; the ESV in the UA was ranked as regulating services > habitat services > cultural and amenity service > provisioning services; the ESV in the MA was ranked as regulating services > habitat services > cultural and amenity service > provisioning services; the ESV in the DA was ranked as regulating services > habitat services > cultural and amenity service > provisioning services. Compared with 1980, the total amount of ESV in the SA, UA, MA, and DA of YRB decreased by 0.62%, 0.85%, 0.09%, and 11.29% respectively, reaching 873.5, 164.44, 1801.4, and 18.42 billion USD, respectively. The ACR of ESV in the SA, UA, MA, and DA of YRB all showed fluctuations and variations (Table A5). The maximum ACR of ESV occurred in 1990–1995 period, 1995–2000 period, 1990–1995 period, and 2000–2005 period respectively, and the minimum ACR of ESV all appeared in 1980–1990 period. Details of annual ESV change rate in SA, UA, MA, and DA from 1980–2015 can be found in Table A5.

### *3.4. Elasticity of ESV Changes in Relation to LUCC*

During 1980–2015 (Figure 5), the elasticity (E) of the YRB was always less than 0.5, and its minimum and maximum values appeared in 1995–2000 period and 2000–2005 period, respectively. This shows that the elasticity of ESV changes in response to LUCC in the YRB is always an inelastic process. In different watershed regions (Table A6), elasticity (E) of ESV changes in response to LUCC showed great differences. The elasticity of SA has changed significantly, with its minimum and maximum values appearing in the 1995–2000 period and 2005–2010 period, respectively; the minimum and maximum values of elasticity in UA appeared in 1990–1995 period and 2005–2010 period, respectively; the minimum and maximum values of elasticity in MA appeared in 1980–1990 period and 2000–2005 period; and the minimum and maximum values of elasticity in DA appeared in 1995–2000 period and 2000–2005 period, respectively. This shows that the SA, UA, MA, and DA of the YRB have all experienced the transformation process from inelasticity to elasticity to inelasticity, which mainly occurred in 2000–2005 period and 2005–2010 period. Details of elasticity (E) in YRB, SA, UA, MA, and DA from 1980 to 2015 can be found in Table A6.

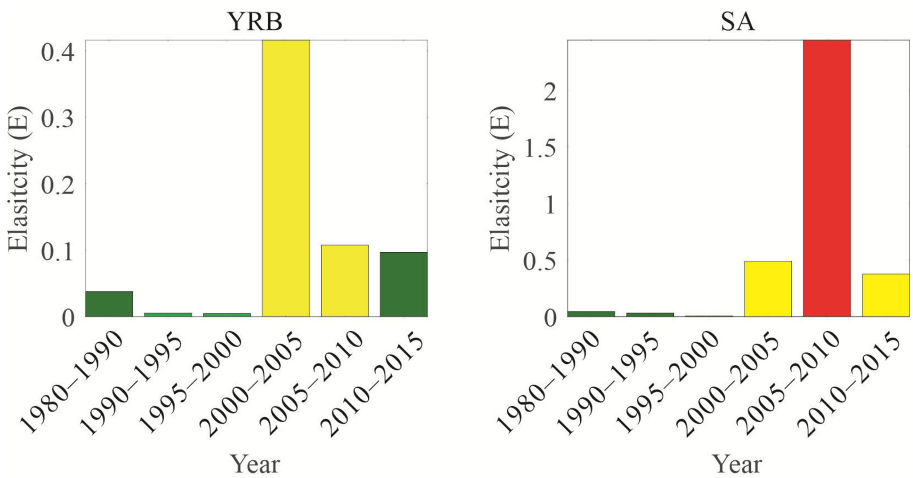


**Figure 5.** *Cont.*

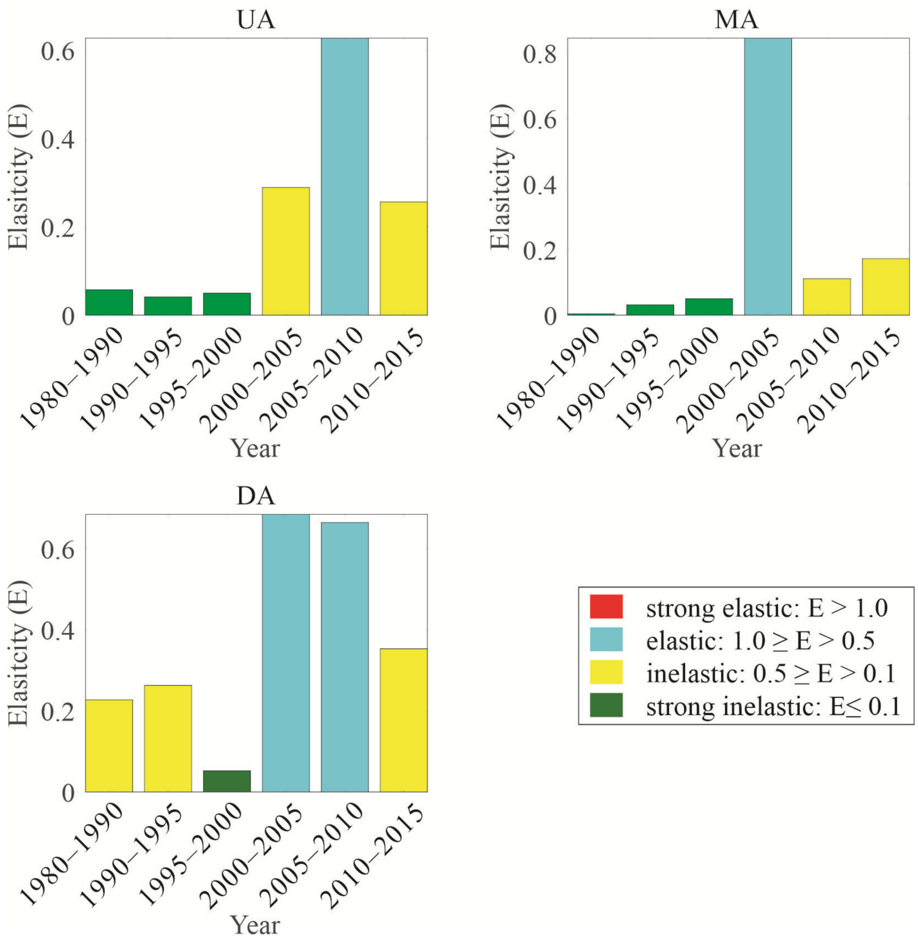


**Figure 5.** Elasticity of ESV changes in response to LULC change of YRB, SA, UA, MA, and DA from 1980 to 2015.

## 4. Discussions

### *4.1. Implications for Sustainable Development*

Humans can significantly alter environments through the conversion of natural vegetation, cropland, reservoir, urban, and other land uses [5]. This process can change the regional climate by adjusting the surface energy, water balance [58,59], and greenhouse gas emissions [60], and it can also lead to a decline in biodiversity through the loss, modification, and fragmentation of habitats [61], and ultimately affect ES and human well-being [6,7].

In the past 35 years, the cumulative area of human-induced LUCC in the YRB has reached 65.71 Mha (i.e., cumulative areas in Figure 3), which is close to the total area of YRB; the ESV of the YRB is between 387.71–394.25 billion USD (Figure 4), which is close to the ESV of the Tibet Autonomous Region in China [21]. Since the 1970s, vegetation restoration and reconstruction has been the important measure for ecological protection and soil erosion control in the YRB [62]. The area of ERP in the YRB in 1980–2000 period was 27.77 Mha (Figure 3), but the area of natural vegetation such as woodland, grassland, and wetland in the YRB declined from 1980 to 2000 (Figure 1), resulting in a decline in ESV (Figure 4). This contradiction shows that ERP has not reversed the decline of natural vegetation and ES in the YRB. The reason is that FR reduces the area of natural vegetation [63]. For a long time, agricultural activities have been an important human activity in the YRB in response to population growth [45,63]. From 1980 to 2000, the area of FR in the YRB reached 25.58 Mha. A large amount of natural vegetation has been replaced with cropland, coupled with the land degradation (about 6.58 Mha) caused by unreasonable human activities such as overexploitation of [64] and overuse of water resources [65]. Eventually, the area of natural vegetation in the YRB decreased from 1980 to 2000.

Since the year 2000, benefit from the implementation of the "grain for green program" (Table A7), the natural vegetation of the YRB, especially the natural vegetation in the UA and MA (i.e., the Loess Plateau) has been significantly improved [66,67]. The area of cropland in the YRB decreased by 0.51 Mha from 2000 to 2015, the area of forest land increased by 0.27 Mha (Figure 1), and ESV increased by 2.84 billion USD (Figure 4). It is worth noting that the area of ERP in 2000–2015 period was only 0.57 Mha, and the elasticity coefficient of ESV to LULC change in 2000–2015 period increased significantly compared with that in the 1980–2000 period (Figure 5). This shows that under the guidance of inappropriate policies, a large amount of LUCC may be harmful to the ecosystem, while under the guidance of appropriate policies, a small amount of LULC change may be beneficial to the ecosystem.

In addition, UR is also an important human-induced LULC change process in YRB, and the area of UR gradually increased from 1980 to 2015 (Figure 1). It is foreseeable that the UR process will become the most important LULC change process in the YRB in the future, and the ecological security issues that may arise from this process need more attention [65,68].

### 4.2. Uncertainties in ESV Assessment

ESV assessment is usually regarded as an important tool for sustainable land development decision-making and trade-offs [20,69,70]. In this study, the benefit transfer method proposed by Xie et al. [21] was used to calculate the ESV of the YRB. However, recent studies have calculated that the ESV in the YRB is 264.42–266.4 billion USD [71] or 78.17–96.39 billion USD [72]. There is a big difference between these results. It is worth noting that, in these studies, different versions of the value equivalent method [56,73] were used to calculate ESV, and different methods were used to revise the key coefficients [71,72]. We also tried to add revisions to the CPI index in the calculation of ESV to obtain comparable ESV values in different periods (Figure A2). Based on this calculation, the ESV of the YRB increased from US$80.53 billion to US$452.43 billion from 1980 to 2015. However, this result to a large extent only reflects the influence of economic factors and conceals the impact of LULC changes on ESV. Therefore, the result was not used in the study of ESV on LULC changes in the YRB. This shows that the benefit transfer method has huge uncertainties in calculating ESV [74]. Some studies have conducted sensitivity-analysis based on elasticity-sensitivity coefficient to study the impact of changes in ES coefficients on ESV assessment [75,76]. However, Aschonitis et al. [77] pointed out the elasticity-sensitivity coefficient should be used for ranking the importance of land use and land cover (LULC) changes rather than assessing the robustness and sensitivity of the ES coefficients.

ES trade-off refers to the situation where one type of ES increases while the other type of ES decreases [78]. In the current ES research community, ES trade-offs are often regarded as key indicators that guide land policy and management to support the provision of ES [79]. It is generally accepted that all decisions that involve trade-offs involve valuation, whether implicitly or explicitly [8,22]. Due to the ability to examine multiple ESs at the same time, ESV assessment has been used in many studies to study trade-offs between different ESs [80,81]. Since the ES trade-offs can be studied from the perspective of relative value, this can reduce the uncertainty of ESV to a certain extent [79]. However, affected by the temporal and spatial scales [79] and landscape history [82], the uncertainty of ES trade-offs are not well understood.

It is generally accepted that when ESV assessment is used to raise public awareness rather than specific policy guidance, lower confidence is acceptable [55,62]. However, it has been reported that about 82% of ecosystem services mapping studies have cited decision-making purposes [63]. Therefore, it is necessary to construct an uncertainty evaluation framework to increase confidence in ESV assessments and trade-offs to support decision-making in the future.

### 4.3. Limitations

Human-induced land cover (LC) changes are only defined by land cover (LC) transition, but the impact of different categories and intensities of land use on land cover was not considered. For example, the grazing area and grazing intensity will significantly affect the grassland, but it does not necessarily cause the grassland transfer to other land cover type. This will be one of the important research directions for future LULC changes.

Time-series land use and land cover (LULC) datasets are used to analyze the response of ecosystem services to LULC changes in this study. However, due to the coarse temporal resolution ($\geq$5 years), the time lags of LULC changes to ecosystem services (ES) are unable to be detected. The time lags of ES's responses to LULC changes is the key direction of future land change sciences.

## 5. Conclusions

Land use and land cover (LULC) transition matrix and benefit transfer methods were used to study LULC changes in the Yellow River Basin (YRB) and their impact on ecosystem services values (ESV). From 1980 to 2015, the area of urban land, water bodies, and urban lands in the YRB increased by 45.10%, 3.44%, and 2.58%, while wetland, bare land, grassland, and farmland decreased by 7.18%, 2.27%, 1.31%, and 1.29%, respectively. The LULC change area in the YRB showed an increasing trend before the year 2000 and a decreasing trend after the year 2000. From 1990 to 2015, the human-induced LC change dominates in YRB, and the natural-process LC in the YRB accounted for less than 25% of the total LULC change areas. The proportion of ecological restoration projects (ERP) areas was the highest before the year 2010, the proportion of urbanization (UR) was the highest in 2010–2015. From 1980 to 2015, the ESV of the YRB decreased by 0.94%, valued at 390.55 billion USD, and the elasticity of ESV changes in response to LUCC in the YRB is always an inelastic process. We found that under the guidance of inappropriate policies, a large amount of LUCC may be harmful to the ecosystem, while under the guidance of appropriate policies, a small amount of LULC change may be beneficial to the ecosystem.

**Author Contributions:** Conceptualization, B.L., X.G. and J.L.; methodology, B.L.; software, B.L.; validation, B.L., L.P. and Y.Q.; writing—original draft preparation, B.L.; writing—review and editing, B.L., L.P., Y.Q., X.G. and J.L.; project administration, X.G. and J.L. All authors have read and agreed to the published version of the manuscript.

**Funding:** This study was funded by the National Key R&D Program of China (No. 2016YFD0800905) and the Special Fund for Basic Scientific Research Business of Central Public Research Institutes (Grant No.2019YSKY-017).

**Acknowledgments:** Acknowledgement for the data support from "Geographic Data Sharing Infrastructure, Geographic Data Sharing Infrastructure, Resource and Environment Science and Data Center" (http://www.resdc.cn accessed on 20 August 2021).

**Conflicts of Interest:** The authors declare no conflict of interest.

## Abbreviations

LU, land use; LC, land cover; LULC, land use and land cover; ES, ecosystem services; BTM, benefit transfer method; YRB, yellow river basin; ESV, ecosystem service value; ERP, ecological restoration project; CE, Cropland Expansion; LD, land degradation; SA, source area; UA, upstream area; MA, midstream area; DA, downstream area.

## Appendix A

**Table A1.** Land use and land cover types.

| Primary Categories | Secondary Categories |
|---|---|
| Cropland | Dry land |
| | Paddy field |
| Forest | Needle-leaf |
| | Mixed |
| | Broadleaf |
| | Bush |
| Grassland | Prairie |
| | Shrub grass |
| | Meadow |
| Wetland | Wetland |
| Urban land | Urban |
| Barren land | Desert |
| | Barren |
| Water area | Water |
| | Reservoir |
| | Ice |

**Table A2.** LULC in the Yellow River Basin from 1980 to 2015.

| Region | LULC | 1980 | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|---|---|---|---|
| YRB | Cropland | 18.84 | 18.97 | 18.94 | 19.11 | 18.79 | 18.73 | 18.60 |
| | Forest | 9.00 | 8.96 | 8.53 | 8.99 | 9.20 | 9.22 | 9.23 |
| | Grassland | 33.52 | 33.53 | 34.30 | 33.35 | 33.16 | 33.19 | 33.08 |
| | Wetland | 1.71 | 1.57 | 1.50 | 1.62 | 1.61 | 1.60 | 1.58 |
| | Urban land | 1.49 | 1.51 | 1.58 | 1.65 | 1.76 | 1.82 | 2.16 |
| | Barren land | 5.43 | 5.47 | 5.20 | 5.33 | 5.48 | 5.43 | 5.31 |
| | Water area | 0.74 | 0.70 | 0.68 | 0.67 | 0.74 | 0.73 | 0.76 |
| SA | Cropland | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| | Forest | 0.80 | 0.79 | 0.79 | 0.80 | 0.80 | 0.80 | 0.80 |
| | Grassland | 8.14 | 8.18 | 8.27 | 8.15 | 8.08 | 8.08 | 8.08 |
| | Wetland | 0.46 | 0.44 | 0.45 | 0.46 | 0.46 | 0.46 | 0.46 |
| | Urban land | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| | Barren land | 1.12 | 1.14 | 1.02 | 1.13 | 1.19 | 1.19 | 1.19 |
| | Water area | 0.20 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 |
| UA | Cropland | 4.98 | 5.02 | 5.12 | 5.16 | 5.07 | 5.07 | 5.04 |
| | Forest | 2.23 | 2.26 | 2.26 | 2.24 | 2.30 | 2.30 | 2.32 |
| | Grassland | 14.78 | 14.74 | 14.65 | 14.56 | 14.48 | 14.50 | 14.47 |
| | Wetland | 0.87 | 0.83 | 0.78 | 0.89 | 0.88 | 0.87 | 0.85 |
| | Urban land | 0.52 | 0.52 | 0.56 | 0.56 | 0.59 | 0.61 | 0.77 |
| | Barren land | 3.47 | 3.50 | 3.50 | 3.47 | 3.53 | 3.50 | 3.38 |
| | Water area | 0.26 | 0.23 | 0.24 | 0.23 | 0.25 | 0.25 | 0.27 |
| MA | Cropland | 11.88 | 11.94 | 11.79 | 11.91 | 11.69 | 11.64 | 11.56 |
| | Forest | 5.75 | 5.70 | 5.25 | 5.74 | 5.89 | 5.91 | 5.90 |
| | Grassland | 10.33 | 10.32 | 11.11 | 10.36 | 10.35 | 10.36 | 10.29 |
| | Wetland | 0.25 | 0.22 | 0.19 | 0.22 | 0.21 | 0.21 | 0.21 |
| | Urban land | 0.63 | 0.64 | 0.66 | 0.71 | 0.76 | 0.79 | 0.94 |
| | Barren land | 0.81 | 0.81 | 0.65 | 0.71 | 0.74 | 0.73 | 0.72 |
| | Water area | 0.17 | 0.18 | 0.17 | 0.16 | 0.19 | 0.19 | 0.19 |

**Table A2.** *Cont.*

| Region | LULC | 1980 | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|---|---|---|---|
| DA | Cropland | 1.87 | 1.90 | 1.91 | 1.92 | 1.92 | 1.90 | 1.88 |
| | Forest | 0.13 | 0.13 | 0.15 | 0.13 | 0.13 | 0.13 | 0.13 |
| | Grassland | 0.18 | 0.18 | 0.17 | 0.18 | 0.15 | 0.15 | 0.15 |
| | Wetland | 0.12 | 0.08 | 0.08 | 0.05 | 0.05 | 0.05 | 0.05 |
| | Urban land | 0.33 | 0.34 | 0.35 | 0.37 | 0.39 | 0.41 | 0.43 |
| | Barren land | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 |
| | Water area | 0.11 | 0.10 | 0.09 | 0.10 | 0.11 | 0.11 | 0.11 |

**Table A3.** LULC change rate (Mha/a) in different periods.

| Region | LULC | 1980–1990 | 1990–1995 | 1995–2000 | 2000–2005 | 2005–2010 | 2010–2015 |
|---|---|---|---|---|---|---|---|
| YRB | Cropland | 0.0133 | −0.0075 | 0.0336 | −0.0629 | −0.0125 | −0.0257 |
| | Forest | −0.0042 | −0.0862 | 0.0932 | 0.0409 | 0.0051 | 0.0016 |
| | Grassland | 0.0006 | 0.1540 | −0.1896 | −0.0390 | 0.0061 | −0.0208 |
| | Wetland | −0.0132 | −0.0140 | 0.0233 | −0.0028 | −0.0006 | −0.0040 |
| | Urban land | 0.0023 | 0.0132 | 0.0146 | 0.0229 | 0.0117 | 0.0673 |
| | Barren land | 0.0038 | −0.0531 | 0.0263 | 0.0284 | −0.0088 | −0.0249 |
| | Water area | −0.0044 | −0.0035 | −0.0008 | 0.0125 | −0.0010 | 0.0067 |
| SA | Cropland | −0.0001 | 0.0013 | −0.0010 | 0.0005 | 0.0002 | −0.0000 |
| | Forest | −0.0016 | 0.0013 | 0.0019 | −0.0002 | 0.0000 | 0.0000 |
| | Grassland | 0.0043 | 0.0186 | −0.0254 | −0.0123 | 0.0000 | −0.0011 |
| | Wetland | −0.0022 | 0.0031 | 0.0015 | 0.0011 | −0.0004 | 0.0003 |
| | Urban land | 0.0000 | 0.0002 | −0.0002 | 0.0001 | 0.0001 | 0.0007 |
| | Barren land | 0.0012 | −0.0225 | 0.0219 | 0.0112 | −0.0007 | 0.0000 |
| | Water area | −0.0020 | −0.0012 | 0.0013 | −0.0005 | 0.0008 | 0.0001 |
| UA | Cropland | 0.0034 | 0.0193 | 0.0098 | −0.0192 | 0.0012 | −0.0061 |
| | Forest | 0.0024 | 0.0002 | −0.0039 | 0.0126 | 0.0002 | 0.0037 |
| | Grassland | −0.0031 | −0.0194 | −0.0170 | −0.0172 | 0.0045 | −0.0065 |
| | Wetland | −0.0035 | −0.0104 | 0.0219 | −0.0023 | −0.0008 | −0.0039 |
| | Urban land | 0.0003 | 0.0077 | −0.0005 | 0.0074 | 0.0033 | 0.0312 |
| | Barren land | 0.0027 | 0.0013 | −0.0073 | 0.0132 | −0.0067 | −0.0235 |
| | Water area | −0.0030 | 0.0020 | −0.0025 | 0.0055 | −0.0018 | 0.0051 |
| MA | Cropland | 0.0061 | −0.0308 | 0.0246 | −0.0454 | −0.0095 | −0.0152 |
| | Forest | −0.0052 | −0.0905 | 0.0989 | 0.0287 | 0.0045 | −0.0020 |
| | Grassland | −0.0006 | 0.1569 | −0.1491 | −0.0025 | 0.0018 | −0.0133 |
| | Wetland | −0.0029 | −0.0062 | 0.0048 | −0.0009 | 0.0006 | −0.0004 |
| | Urban land | 0.0012 | 0.0040 | 0.0109 | 0.0102 | 0.0047 | 0.0313 |
| | Barren land | −0.0001 | −0.0320 | 0.0120 | 0.0045 | −0.0015 | −0.0015 |
| | Water area | 0.0008 | −0.0004 | −0.0021 | 0.0054 | −0.0006 | 0.0012 |
| DA | Cropland | 0.0033 | 0.0027 | 0.0004 | 0.0010 | −0.0042 | −0.0042 |
| | Forest | 0.0003 | 0.0026 | −0.0033 | −0.0002 | 0.0002 | −0.0000 |
| | Grassland | 0.0000 | −0.0021 | 0.0015 | −0.0063 | −0.0001 | 0.0000 |
| | Wetland | −0.0045 | −0.0008 | −0.0043 | −0.0007 | 0.0000 | −0.0000 |
| | Urban land | 0.0008 | 0.0012 | 0.0040 | 0.0049 | 0.0036 | 0.0039 |
| | Barren land | 0.0002 | 0.0002 | −0.0009 | −0.0006 | 0.0000 | 0.0000 |
| | Water area | −0.0003 | −0.0036 | 0.0026 | 0.0020 | 0.0005 | 0.0003 |

**Table A4.** LULC change area (M ha) in different periods.

| Region | LULC Change | 1980–1990 | 1990–1995 | 1995–2000 | 2000–2005 | 2005–2010 | 2010–2015 |
|---|---|---|---|---|---|---|---|
| YRB | CE * | 8.3068 | 8.3043 | 8.9735 | 0.2954 | 0.0586 | 0.1604 |
| | ERP * | 9.0055 | 9.4788 | 9.2847 | 0.3234 | 0.0871 | 0.1644 |
| | UR * | 1.2429 | 1.2175 | 1.3013 | 0.1198 | 0.0609 | 0.3529 |
| | WCC * | 0.1072 | 0.0915 | 0.1052 | 0.0423 | 0.0114 | 0.0314 |
| | LD * | 2.0922 | 2.0444 | 2.4389 | 0.2104 | 0.0030 | 0.0424 |
| | Natural-process | 3.8058 | 3.8361 | 4.0041 | 0.1457 | 0.0769 | 0.0631 |
| | Total | 24.4848 | 24.8913 | 26.0247 | 1.1325 | 0.2979 | 0.8134 |
| SA | CE | 0.3225 | 0.2878 | 0.3403 | 0.0031 | 0.0009 | 0.0002 |
| | ERP | 0.9139 | 0.9092 | 0.9128 | 0.0044 | 0.0034 | 0.0017 |
| | UR | 0.0029 | 0.0034 | 0.0027 | 0.0006 | 0.0004 | 0.0035 |
| | WCC | 0.0003 | 0.0003 | 0.0001 | 0.0005 | 0.0001 | 0.0009 |
| | LD | 0.6140 | 0.5564 | 0.7298 | 0.0595 | 0.0000 | 0.0017 |
| | Natural-process | 0.8794 | 0.7886 | 0.8535 | 0.0173 | 0.0071 | 0.0043 |
| | Total | 2.7330 | 2.5457 | 2.8392 | 0.0854 | 0.0119 | 0.0123 |
| UA | CE | 2.6498 | 2.6662 | 2.8302 | 0.1499 | 0.0354 | 0.0986 |
| | ERP | 3.2929 | 3.2520 | 3.5728 | 0.1682 | 0.0433 | 0.1220 |
| | UR | 0.4262 | 0.4314 | 0.4415 | 0.0403 | 0.0172 | 0.1619 |
| | WCC | 0.0476 | 0.0224 | 0.0427 | 0.0105 | 0.0049 | 0.0192 |
| | LD | 1.1414 | 1.1977 | 1.3263 | 0.1197 | 0.0012 | 0.0249 |
| | Natural-process | 1.6766 | 1.6229 | 1.7496 | 0.0842 | 0.0401 | 0.0411 |
| | Total | 9.2345 | 9.1926 | 9.9631 | 0.5728 | 0.1421 | 0.4677 |
| MA | CE | 4.8586 | 4.9029 | 5.3409 | 0.1006 | 0.0179 | 0.0583 |
| | ERP | 4.6156 | 5.1541 | 4.6081 | 0.1410 | 0.0346 | 0.0391 |
| | UR | 0.5344 | 0.5217 | 0.5720 | 0.0526 | 0.0241 | 0.1657 |
| | WCC | 0.0293 | 0.0383 | 0.0283 | 0.0224 | 0.0033 | 0.0084 |
| | LD | 0.3232 | 0.2728 | 0.3668 | 0.0312 | 0.0018 | 0.0157 |
| | Natural-process | 1.1709 | 1.3562 | 1.3409 | 0.0361 | 0.0223 | 0.0170 |
| | Total | 11.5320 | 12.2460 | 12.2570 | 0.3839 | 0.1040 | 0.3042 |
| DA | CE | 0.4447 | 0.4191 | 0.4304 | 0.0396 | 0.0042 | 0.0033 |
| | ERP | 0.1545 | 0.1331 | 0.1631 | 0.0094 | 0.0054 | 0.0015 |
| | UR | 0.2717 | 0.2538 | 0.2758 | 0.0248 | 0.0187 | 0.0211 |
| | WCC | 0.0288 | 0.0300 | 0.0329 | 0.0082 | 0.0027 | 0.0029 |
| | LD | 0.0092 | 0.0107 | 0.0067 | 0.0000 | 0.0000 | 0.0001 |
| | Natural-process | 0.0622 | 0.0502 | 0.0419 | 0.0077 | 0.0070 | 0.0007 |
| | Total | 0.9711 | 0.8969 | 0.9508 | 0.0897 | 0.0380 | 0.0296 |

* CE, Cropland Expansion; ERP, Ecological Restoration Project; UR, Urbanization; WCC, Water Conservation Construction; LD, Land Degradation.

**Table A5.** ESV change rate (billion USD/a) in different periods.

| Region | ES | 1980–1990 | 1990–1995 | 1995–2000 | 2000–2005 | 2005–2010 | 2010–2015 |
|---|---|---|---|---|---|---|---|
| YRB | Provisioning services | −0.0414 | 0.0350 | −0.0699 | 0.0547 | 0.0013 | 0.0247 |
| | Regulating services | −0.3864 | −0.1710 | −0.0751 | 0.4801 | −0.0382 | 0.1044 |
| | Habitat Services | −0.0534 | 0.0015 | −0.0035 | −0.0146 | 0.0015 | −0.0294 |
| | Cultural & amenity services | −0.0332 | −0.0103 | 0.0138 | −0.0034 | −0.0000 | −0.0128 |
| | Total | −0.5143 | −0.1448 | −0.1347 | 0.5168 | −0.0355 | 0.0869 |

**Table A5.** *Cont.*

| Region | ES | 1980–1990 | 1990–1995 | 1995–2000 | 2000–2005 | 2005–2010 | 2010–2015 |
|---|---|---|---|---|---|---|---|
| SA | Provisioning services | −0.0051 | 0.0042 | −0.0010 | −0.0035 | 0.0026 | 0.0005 |
| | Regulating services | −0.0602 | 0.0652 | −0.0090 | −0.0450 | 0.0333 | 0.0044 |
| | Habitat Services | −0.0059 | 0.0206 | −0.0085 | −0.0019 | −0.0005 | 0.0004 |
| | Cultural & amenity services | −0.0041 | 0.0103 | −0.0024 | −0.0004 | −0.0002 | 0.0004 |
| | Total | −0.0752 | 0.1003 | −0.0210 | −0.0508 | 0.0353 | 0.0056 |
| UA | Provisioning services | −0.0185 | −0.0234 | 0.0237 | 0.0158 | −0.0078 | 0.0104 |
| | Regulating services | −0.1987 | −0.2354 | 0.2984 | 0.1501 | −0.0695 | 0.1213 |
| | Habitat Services | −0.0159 | −0.0535 | 0.0738 | −0.0120 | −0.0017 | −0.0161 |
| | Cultural & amenity services | −0.0099 | −0.0289 | 0.0441 | −0.0047 | −0.0018 | −0.0075 |
| | Total | −0.2430 | −0.3411 | 0.4399 | 0.1493 | −0.0808 | 0.1082 |
| MA | Provisioning services | −0.0022 | 0.0679 | −0.0861 | 0.0317 | 0.0023 | 0.0075 |
| | Regulating services | −0.0041 | 0.2243 | −0.4020 | 0.2508 | −0.0171 | −0.0417 |
| | Habitat Services | −0.0091 | 0.0409 | −0.0539 | 0.0062 | 0.0029 | −0.0096 |
| | Cultural & amenity services | −0.0053 | 0.0144 | −0.0216 | 0.0040 | 0.0014 | −0.0040 |
| | Total | −0.0207 | 0.3475 | −0.5636 | 0.2927 | −0.0105 | −0.0478 |
| DA | Provisioning services | −0.0102 | −0.0178 | 0.0041 | 0.0033 | 0.0038 | 0.0029 |
| | Regulating services | −0.0767 | −0.1883 | 0.0568 | 0.0561 | 0.0180 | 0.0066 |
| | Habitat Services | −0.0150 | −0.0075 | −0.0119 | −0.0045 | 0.0002 | −0.0002 |
| | Cultural & amenity services | −0.0092 | −0.0049 | −0.0067 | −0.0017 | 0.0003 | 0.0000 |
| | Total | −0.1111 | −0.2185 | 0.0422 | 0.0531 | 0.0223 | 0.0093 |

**Table A6.** Elasticity (E) from 1980 to 2015.

| Region | 1980–1990 | 1990–1995 | 1995–2000 | 2000–2005 | 2005–2010 | 2010–2015 |
|---|---|---|---|---|---|---|
| **YRB** | 0.0377 | 0.0053 | 0.0047 | 0.4162 | 0.1079 | 0.0968 |
| **SA** | 0.0450 | 0.0325 | 0.0061 | 0.4886 | 2.4434 | 0.3763 |
| **UA** | 0.0575 | 0.0413 | 0.0499 | 0.2892 | 0.6271 | 0.2561 |
| **MA** | 0.0039 | 0.0312 | 0.0499 | 0.8448 | 0.1112 | 0.1724 |
| **DA** | 0.2265 | 0.2622 | 0.0523 | 0.6849 | 0.6648 | 0.3526 |

**Table A7.** Summary of the land policy implemented in the Yellow River Basin.

| No. | Programs | Planned Timeframe | Aims and Objectives |
|---|---|---|---|
| 1 | Three-North Shelterbelt Development Program | 1978–2050 | Control the expansion of sandy/desertified land, and mitigate wind erosion of sand/soil and dust storms in northern China via forest plantation, mountain closure, and sandy area regeneration. |
| 2 | Natural Forest Conservation Program | 1998–2020 | Increase the area of cultivated land and revenues via consolidation (reorganizing and merging fragmented and underused land), reclamation, constructing high-quality cropland, and improving land use and management. |
| 3 | Grain for Green Program | 1999–2020 | Prevent soil erosion, mitigate flooding, store carbon, and improve livelihoods by increasing forest and grassland cover on cropped hillslopes and converting cropland, barren hills and wasteland to forest. |
| 4 | Beijing-Tianjin Sand Source Control Engineering | 2001–2022 | Reduce desertification and dust storms, and improve the environment in the Beijing/Tianjin area via reforestation, grassland management, and water conservation, relocating affected people and establishing basic governance of desertified lands. |

**Table A7.** *Cont.*

| No. | Programs | Planned Timeframe | Aims and Objectives |
|---|---|---|---|
| 5 | Comprehensive Agricultural Development Program | 1988–2020 | Raise rural quality of life, incomes and food security through land reform, land management, ecological construction, agricultural infrastructure and industry development, and production/efficiency gains using science and technology. |
| 6 | National Land Consolidation Program. | 1997–2020 | Increase the area of cultivated land and revenues via consolidation (reorganizing and merging fragmented and underused land), reclamation, constructing high-quality cropland, and improving land use and management. |

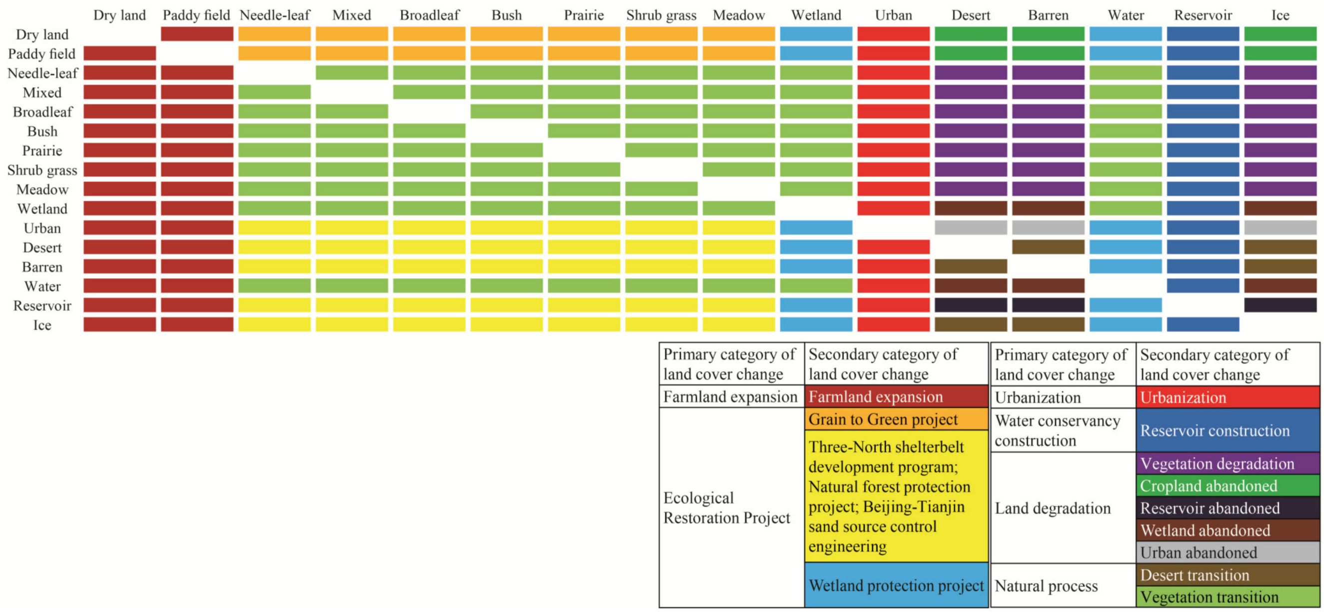


**Figure A1.** Definition of LULC change.

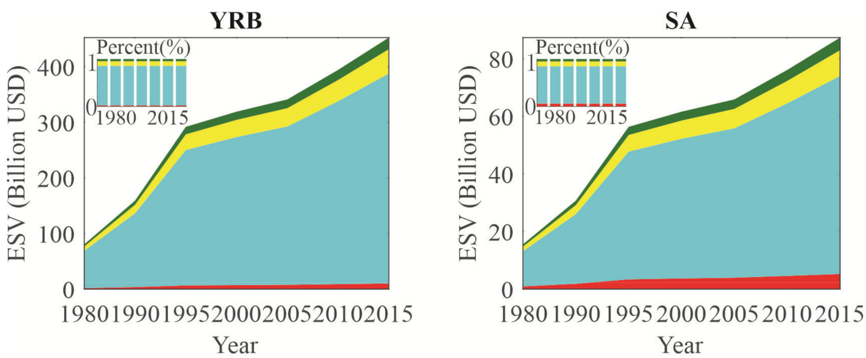


**Figure A2.** *Cont.*

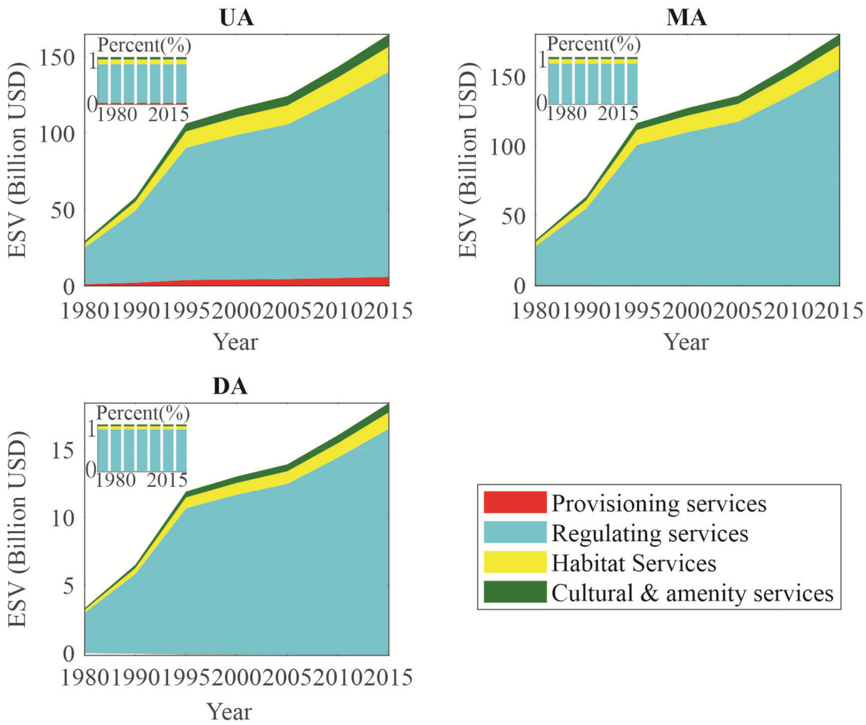


**Figure A2.** ESV of YRB, SA, UA, MA, and DA from 1980 to 2015 considering changing standard equivalence coefficients. The annual Consumer Price Index (CPI) was used to revise the standard equivalence coefficients for different periods, the revised standard equivalent coefficient values for the years 1980, 1990, 1995, 2000, 2005, 2010, and 2015 are 102.78, 203.12, 372.54, 407.37, 435.52, 503.2, and 577.45 USD ha$^{-1}$, respectively. The sub-figure describes the proportion of each ES types.

## References


1. Liu, J.Y.; Kuang, W.H.; Zhang, Z.X.; Xu, X.L.; Qin, Y.W.; Ning, J.; Zhou, W.C.; Zhang, S.W.; Li, R.D.; Yan, C.Z.; et al. Spatiotemporal characteristics, patterns, and causes of land-use changes in China since the late 1980s. *J. Geogr. Sci.* **2014**, *24*, 195–210. [CrossRef]
2. Mooney, H.A.; Duraiappah, A.; Larigauderie, A. Evolution of natural and social science interactions in global change research programs. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 3665–3672. [CrossRef]
3. Sterling, S.M.; Ducharne, A.; Polcher, J. The impact of global land-cover change on the terrestrial water cycle. *Nat. Clim. Chang.* **2013**, *3*, 385–390. [CrossRef]
4. Meyfroidt, P.; Lambin, E.F.; Erb, K.H.; Hertel, T.W. Globalization of land use: Distant drivers of land change and geographic displacement of land use. *Curr. Opin. Environ. Sustain.* **2013**, *5*, 438–444. [CrossRef]
5. Zalles, V.; Hansen, M.C.; Potapov, P.V.; Parker, D.; Stehman, S.V.; Pickens, A.H.; Parente, L.L.; Ferreira, L.G.; Song, X.P.; Hernandez-Serna, A.; et al. Rapid expansion of human impact on natural land in South America since 1985. *Sci. Adv.* **2021**, *7*, 11. [CrossRef]
6. MEA. *Ecosystems and Human Well-Being: Synthesis*; Island Press: Washington, DC, USA, 2005.
7. IPBES. *Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*; IPBES Secretariat: Bonn, Germany, 2019; p. 1148.
8. Costanza, R.; d'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; ONeill, R.V.; Paruelo, J.; et al. The value of the world's ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [CrossRef]
9. Costanza, R.; de Groot, R.; Braat, L.; Kubiszewski, I.; Fioramonti, L.; Sutton, P.; Farber, S.; Grasso, M. Twenty years of ecosystem services: How far have we come and how far do we still need to go? *Ecosyst. Serv.* **2017**, *28*, 1–16. [CrossRef]
10. Palmer, M.A.; Filoso, S.; Fanelli, R.M. From ecosystems to ecosystem services: Stream restoration as ecological engineering. *Ecol. Eng.* **2014**, *65*, 62–70. [CrossRef]
11. Sutherland, W.J.; Armstrong-Brown, S.; Armsworth, P.R.; Brereton, T.; Brickland, J.; Campbell, C.D.; Chamberlain, D.E.; Cooke, A.I.; Dulvy, N.K.; Dusic, N.R.; et al. The identification of 100 ecological questions of high policy relevance in the UK. *J. Appl. Ecol.* **2006**, *43*, 617–627. [CrossRef]
12. Crossman, N.D.; Burkhard, B.; Nedkov, S.; Willemen, L.; Petz, K.; Palomo, I.; Drakou, E.G.; Martin-Lopez, B.; McPhearson, T.; Boyanova, K.; et al. A blueprint for mapping and modelling ecosystem services. *Ecosyst. Serv.* **2013**, *4*, 4–14. [CrossRef]

13. Maes, J.; Hauck, J.; Paracchini, M.L.; Ratamaki, O.; Hutchins, M.; Termansen, M.; Furman, E.; Perez-Soba, M.; Braat, L.; Bidoglio, G. Mainstreaming ecosystem services into EU policy. *Curr. Opin. Environ. Sustain.* **2013**, *5*, 128–134. [CrossRef]
14. Fu, B.; Zhang, L. Land-use change and ecosystem services: Concepts, methods and progress. *Prog. Geogr.* **2014**, *33*, 441–446.
15. Fu, B.J.; Wang, S.; Su, C.H.; Forsius, M. Linking ecosystem processes and ecosystem services. *Curr. Opin. Environ. Sustain.* **2013**, *5*, 4–10. [CrossRef]
16. Inkoom, J.N.; Frank, S.; Greve, K.; Furst, C. A framework to assess landscape structural capacity to provide regulating ecosystem services in West Africa. *J. Environ. Manag.* **2018**, *209*, 393–408. [CrossRef]
17. Cao, S.X.; Chen, L.; Yu, X.X. Impact of China's Grain for Green Project on the landscape of vulnerable arid and semi-arid agricultural regions: A case study in northern Shaanxi Province. *J. Appl. Ecol.* **2009**, *46*, 536–543. [CrossRef]
18. Li, T.; Lu, Y.H.; Fu, B.J.; Hu, W.Y.; Comber, A.J. Bundling ecosystem services for detecting their interactions driven by large-scale vegetation restoration: Enhanced services while depressed synergies. *Ecol. Indic.* **2019**, *99*, 332–342. [CrossRef]
19. Su, C.H.; Fu, B.J.; Wei, Y.P.; Lu, Y.H.; Liu, G.H.; Wang, D.L.; Mao, K.B.; Feng, X.M. Ecosystem management based on ecosystem services and human activities: A case study in the Yanhe watershed. *Sustain. Sci.* **2012**, *7*, 17–32. [CrossRef]
20. Costanza, R.; de Groot, R.; Sutton, P.; van der Ploeg, S.; Anderson, S.J.; Kubiszewski, I.; Farber, S.; Turner, R.K. Changes in the global value of ecosystem services. *Glob. Environ. Chang.* **2014**, *26*, 152–158. [CrossRef]
21. Xie, G.; Zhang, C.; Zhen, L.; Zhang, L. Dynamic changes in the value of China's ecosystem services. *Ecosyst. Serv.* **2017**, *26*, 146–154. [CrossRef]
22. Costanza, R.; Chichakly, K.; Dale, V.; Farber, S.; Finnigan, D.; Grigg, K.; Heckbert, S.; Kubiszewski, I.; Lee, H.; Liu, S.; et al. Simulation games that integrate research, entertainment, and learning around ecosystem services. *Ecosyst. Serv.* **2014**, *10*, 195–201. [CrossRef]
23. de Groot, R.; Brander, L.; van der Ploeg, S.; Costanza, R.; Bernard, F.; Braat, L.; Christie, M.; Crossman, N.; Ghermandi, A.; Hein, L.; et al. Global estimates of the value of ecosystems and their services in monetary units. *Ecosyst. Serv.* **2012**, *1*, 50–61. [CrossRef]
24. Viglizzo, E.F.; Paruelo, J.M.; Laterra, P.; Jobbágy, E.G. Ecosystem service evaluation to support land-use policy. *Agric. Ecosyst. Environ.* **2012**, *154*, 78–84. [CrossRef]
25. Hasan, S.S.; Zhen, L.; Miah, M.G.; Ahamed, T.; Samie, A. Impact of land use change on ecosystem services: A review. *Environ. Dev.* **2020**, *34*, 14. [CrossRef]
26. Bateman, I.J.; Mace, G.M. The natural capital framework for sustainably efficient and equitable decision making. *Nat. Sustain.* **2020**, *3*, 776–783. [CrossRef]
27. Bateman, I.J.; Harwood, A.R.; Mace, G.M.; Watson, R.T.; Abson, D.J.; Andrews, B.; Binner, A.; Crowe, A.; Day, B.H.; Dugdale, S.; et al. Bringing ecosystem services into economic decision-making: Land use in the United Kingdom. *Science* **2013**, *341*, 45–50. [CrossRef] [PubMed]
28. Lü, Y.; Lü, D.; Feng, X.; Fu, B. Multi-scale analyses on the ecosystem services in the Chinese Loess Plateau and implications for dryland sustainability. *Curr. Opin. Environ. Sustain.* **2021**, *48*, 1–9. [CrossRef]
29. Wang, Y.; Li, X.; Zhang, Q.; Li, J.; Zhou, X. Projections of future land use changes: Multiple scenarios-based impacts analysis on ecosystem services for Wuhan city, China. *Ecol. Indic.* **2018**, *94*, 430–445. [CrossRef]
30. Jiang, W.; Lü, Y.; Liu, Y.; Gao, W. Ecosystem service value of the Qinghai-Tibet Plateau significantly increased during 25 years. *Ecosyst. Serv.* **2020**, *44*, 101146. [CrossRef]
31. Peng, K.; Jiang, W.; Ling, Z.; Hou, P.; Deng, Y. Evaluating the potential impacts of land use changes on ecosystem service value under multiple scenarios in support of SDG reporting: A case study of the Wuhan urban agglomeration. *J. Clean. Prod.* **2021**, *307*, 127321. [CrossRef]
32. Grimaldi, M.; Oszwald, J.; Doledec, S.; Hurtado, M.D.; Miranda, I.D.; de Sartre, X.A.; de Assis, W.S.; Castaneda, E.; Desjardins, T.; Dubs, F.; et al. Ecosystem services of regulation and support in Amazonian pioneer fronts: Searching for landscape drivers. *Landsc. Ecol.* **2014**, *29*, 311–328. [CrossRef]
33. Spake, R.; Lasseur, R.; Crouzat, E.; Bullock, J.M.; Lavorel, S.; Parks, K.E.; Schaafsma, M.; Bennett, E.M.; Maes, J.; Mulligan, M.; et al. Unpacking ecosystem service bundles: Towards predictive mapping of synergies and trade-offs between ecosystem services. *Glob. Environ. Chang.—Hum. Policy Dimens.* **2017**, *47*, 37–50. [CrossRef]
34. Peng, J.; Tian, L.; Zhang, Z.; Zhao, Y.; Green, S.M.; Quine, T.A.; Liu, H.; Meersmans, J. Distinguishing the impacts of land use and climate change on ecosystem services in a karst landscape in China. *Ecosyst. Serv.* **2020**, *46*, 101199. [CrossRef]
35. Cui, F.; Wang, B.; Zhang, Q.; Tang, H.; De Maeyer, P.; Hamdi, R.; Dai, L. Climate change versus land-use change-What affects the ecosystem services more in the forest-steppe ecotone? *Sci. Total Environ.* **2021**, *759*, 143525. [CrossRef] [PubMed]
36. Zhang, X.; Wang, G.; Xue, B.; Zhang, M.; Tan, Z. Dynamic landscapes and the driving forces in the Yellow River Delta wetland region in the past four decades. *Sci. Total Environ.* **2021**, *787*, 147644. [CrossRef] [PubMed]
37. Giri, C.; Zhu, Z.L.; Reed, B. A comparative analysis of the Global Land Cover 2000 and MODIS land cover data sets. *Remote Sens. Environ.* **2005**, *94*, 123–132. [CrossRef]
38. Chang, Y.; Hou, K.; Li, X.X.; Zhang, Y.W.; Chen, P. Review of Land Use and Land Cover Change research progress. *IOP Conf. Ser. Earth Environ. Sci.* **2018**, *113*, 012087. [CrossRef]
39. Roy, D.P.; Boschetti, L.; Justice, C.O.; Ju, J. The collection 5 MODIS burned area product-Global evaluation by comparison with the MODIS active fire product. *Remote Sens. Environ.* **2008**, *112*, 3690–3707. [CrossRef]

40. Vicente-Serrano, S.M.; Gouveia, C.; Camarero, J.J.; Begueria, S.; Trigo, R.; Lopez-Moreno, J.I.; Azorin-Molina, C.; Pasho, E.; Lorenzo-Lacruz, J.; Revuelto, J.; et al. Response of vegetation to drought time-scales across global land biomes. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 52–57. [CrossRef]
41. Zhang, Y.; Lu, X.; Liu, B.; Wu, D.; Fu, G.; Zhao, Y.; Sun, P. Spatial relationships between ecosystem services and socioecological drivers across a large-scale region: A case study in the Yellow River Basin. *Sci. Total Environ.* **2021**, *766*, 142480. [CrossRef]
42. Wang, S.A.; Fu, B.J.; Piao, S.L.; Lu, Y.H.; Ciais, P.; Feng, X.M.; Wang, Y.F. Reduced sediment transport in the Yellow River due to anthropogenic changes. *Nat. Geosci.* **2016**, *9*, 38–41. [CrossRef]
43. Jiang, C.; Li, D.Q.; Wang, D.W.; Zhang, L.B. Quantification and assessment of changes in ecosystem service in the Three-River Headwaters Region, China as a result of climate variability and land cover change. *Ecol. Indic.* **2016**, *66*, 199–211. [CrossRef]
44. Wu, Y.; Tao, Y.; Yang, G.S.; Ou, W.X.; Pueppke, S.; Sun, X.; Chen, G.T.; Tao, Q. Impact of land use change on multiple ecosystem services in the rapidly urbanizing Kunshan City of China: Past trajectories and future projections. *Land Use Policy* **2019**, *85*, 419–427. [CrossRef]
45. Wu, X.; Wei, Y.; Fu, B.; Wang, S.; Zhao, Y.; Moran, E.F. Evolution and effects of the social-ecological system over a millennium in China's Loess Plateau. *Sci. Adv.* **2020**, *6*, eabc0276. [CrossRef] [PubMed]
46. Liu, J.; Zhang, Z.; Zhuang, D.; Wang, Y.; Zhou, W.; Zhang, S.; Li, R.; Jiang, N.; Wu, S. A study on the spatial temporal dynamic changes of land use and driving forces analyses of China in the 1990s. *Geogr. Res.* **2003**, *22*, 1–12.
47. Liu, J.Y.; Zhang, Z.X.; Xu, X.L.; Kuang, W.H.; Zhou, W.C.; Zhang, S.W.; Li, R.D.; Yan, C.Z.; Yu, D.S.; Wu, S.X.; et al. Spatial patterns and driving forces of land use change in China during the early 21st century. *J. Geogr. Sci.* **2010**, *20*, 483–494. [CrossRef]
48. Ning, J.; Liu, J.Y.; Kuang, W.H.; Xu, X.L.; Zhang, S.W.; Yan, C.Z.; Li, R.D.; Wu, S.X.; Hu, Y.F.; Du, G.M.; et al. Spatiotemporal patterns and characteristics of land-use change in China during 2010-2015. *J. Geogr. Sci.* **2018**, *28*, 547–562. [CrossRef]
49. Hutchinson, M.F. Interpolation of Rainfall Data with Thin Plate Smoothing Splines-Part I: Two Dimensional Smoothing of Data with Short Range Correlation. *J. Geogr. Inf. Decis. Anal.* **1998**, *2*, 168–185.
50. Ouyang, Z.; Jin, L.; Zhen, L.; Xu, L.; Ge, C.; Zhang, Y.; Xiao, Y. *Developing Gross Ecosystem Product and Ecological Asset Accounting for Eco-Compensation*; Science Press: Beijing, China, 2018.
51. Krausmann, F.; Erb, K.H.; Gingrich, S.; Haberl, H.; Bondeau, A.; Gaube, V.; Lauk, C.; Plutzar, C.; Searchinger, T.D. Global human appropriation of net primary production doubled in the 20th century. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 10324–10329. [CrossRef]
52. Sanderson, E.W.; Jaiteh, M.; Levy, M.A.; Redford, K.H.; Wannebo, A.V.; Woolmer, G. The human footprint and the last of the wild. *Bioscience* **2002**, *52*, 891–904. [CrossRef]
53. Venter, O.; Sanderson, E.W.; Magrach, A.; Allan, J.R.; Beher, J.; Jones, K.R.; Possingham, H.P.; Laurance, W.F.; Wood, P.; Fekete, B.M.; et al. Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. *Nat. Commun.* **2016**, *7*, 11. [CrossRef]
54. Richardson, L.; Loomis, J.; Kroeger, T.; Casey, F. The role of benefit transfer in ecosystem service valuation. *Ecol. Econ.* **2015**, *115*, 51–58. [CrossRef]
55. Meng, J. Labor Theory of Value and the Uncertainty in Capitalist Economy. *Front. Econ.* **2010**, *5*, 657–676. [CrossRef]
56. Xie, G.; Zhang, C.; Zhang, L.; Chen, W.; Li, S. Improvement of the Evaluation Method for Ecosystem Service Value Based on Per Unit Area. *J. Nat. Resour.* **2015**, *30*, 1243–1254.
57. TEEB. *The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations*; Earthscan: London, UK; Washington, DC, USA, 2010.
58. Pielke, R.A.; Marland, G.; Betts, R.A.; Chase, T.N.; Eastman, J.L.; Niles, J.O.; Niyogi, D.D.S.; Running, S.W. The influence of land-use change and landscape dynamics on the climate system: Relevance to climate-change policy beyond the radiative effect of greenhouse gases. *Philos. Trans. R. Soc. Lond. Ser. A-Math. Phys. Eng. Sci.* **2002**, *360*, 1705–1719. [CrossRef]
59. Kalnay, E.; Cai, M. Impact of urbanization and land-use change on climate. *Nature* **2003**, *423*, 528–531. [CrossRef]
60. Dale, V.H. The relationship between land-use change and climate change. *Ecol. Appl.* **1997**, *7*, 753–769. [CrossRef]
61. Foley, J.A.; Defries, R.; Asner, G.P.; Barford, C.; Bonan, G.; Carpenter, S.R.; Chapin, F.S.; Coe, M.T.; Daily, G.C.; Gibbs, H.K.; et al. Global consequences of land use. *Science* **2005**, *309*, 570–574. [CrossRef]
62. Lu, Y.H.; Fu, B.J.; Feng, X.M.; Zeng, Y.; Liu, Y.; Chang, R.Y.; Sun, G.; Wu, B.F. A Policy-Driven Large Scale Ecological Restoration: Quantifying Ecosystem Services Changes in the Loess Plateau of China. *PLoS ONE* **2012**, *7*, e31782. [CrossRef]
63. Fu, B.J.; Wang, S.; Liu, Y.; Liu, J.B.; Liang, W.; Miao, C.Y. Hydrogeomorphic Ecosystem Responses to Natural and Anthropogenic Changes in the Loess Plateau of China. *Annu. Rev. Earth Planet. Sci.* **2017**, *45*, 223–243. [CrossRef]
64. Bian, Z.; Yu, H.; Lei, S.; Yin, D.; Zhu, G.; Mu, S.; Yang, D. Strategic consideration of exploitation on coal resources and its ecological restoration in the Yellow River Basin, China. *J. China Coal Soc.* **2021**, *46*, 1378–1391.
65. Jing, W.L.; Yao, L.; Zhao, X.D.; Zhang, P.Y.; Liu, Y.X.Y.; Xia, X.L.; Song, J.; Yang, J.; Li, Y.; Zhou, C.H. Understanding Terrestrial Water Storage Declining Trends in the Yellow River Basin. *J. Geophys. Res.-Atmos.* **2019**, *124*, 12963–12984. [CrossRef]
66. Lü, Y.; Zhang, L.; Feng, X.; Zeng, Y.; Fu, B.; Yao, X.; Li, J.; Wu, B. Recent ecological transitions in China: Greening, browning, and influential factors. *Sci. Rep.* **2015**, *5*, 8732. [CrossRef] [PubMed]
67. Xin, Z.B.; Xu, J.X.; Zheng, W. Spatiotemporal variations of vegetation cover on the Chinese Loess Plateau (1981–2006): Impacts of climate changes and human activities. *Sci. China Ser. D—Earth Sci.* **2008**, *51*, 67–78. [CrossRef]

68. Wang, X.H.; Shen, J.X.; Zhang, W. Emergy evaluation of agricultural sustainability of Northwest China before and after the grain-for-green policy. *Energy Policy* **2014**, *67*, 508–516. [CrossRef]
69. Turner, K.G.; Anderson, S.; Gonzales-Chang, M.; Costanza, R.; Courville, S.; Dalgaard, T.; Dominati, E.; Kubiszewski, I.; Ogilvy, S.; Porfirio, L.; et al. A review of methods, data, and models to assess changes in the value of ecosystem services from land degradation and restoration. *Ecol. Model.* **2016**, *319*, 190–207. [CrossRef]
70. Farber, S.C.; Costanza, R.; Wilson, M.A. Economic and ecological concepts for valuing ecosystem services. *Ecol. Econ.* **2002**, *41*, 375–392. [CrossRef]
71. Yin, D.Y.; Li, X.S.; Li, G.I.; Zhang, J.; Yu, H.C. Spatio-Temporal Evolution of Land Use Transition and Its Eco-Environmental Effects: A Case Study of the Yellow River Basin, China. *Land* **2020**, *9*, 514. [CrossRef]
72. Guo, A.; Zhang, Y.; Zhong, F.; Jiang, D. Spatiotemporal Patterns of Ecosystem Service Value Changes and Their Coordination with Economic Development: A Case Study of the Yellow River Basin, China. *Int. J. Environ. Res. Public Health* **2020**, *17*, 8474. [CrossRef]
73. Xie, G.; Lin, Z.; Lu, C.; Yu, X.; Cao, C. Expert Knowledge Based Valuation Method of Ecosystem Services in China. *J. Nat. Resour.* **2008**, *23*, 911–919.
74. Eigenbrod, F.; Armsworth, P.R.; Anderson, B.J.; Heinemeyer, A.; Gillings, S.; Roy, D.B.; Thomas, C.D.; Gaston, K.J. The impact of proxy-based methods on mapping the distribution of ecosystem services. *J. Appl. Ecol.* **2010**, *47*, 377–385. [CrossRef]
75. Hasan, S.; Shi, W.Z.; Zhu, X.L. Impact of land use land cover changes on ecosystem service value-A case study of Guangdong, Hong Kong, and Macao in South China. *PLoS ONE* **2020**, *15*, e0231259. [CrossRef] [PubMed]
76. Wang, Y.R.; Zhang, X.J.; Peng, P.H. Spatio-Temporal Changes of Land-Use/Land Cover Change and the Effects on Ecosystem Service Values in Derong County, China, from 1992–2018. *Sustainability* **2021**, *13*, 827. [CrossRef]
77. Aschonitis, V.G.; Gaglio, M.; Castaldelli, G.; Fano, E.A. Criticism onelasticity-sensitivity coefficient for assessing the robustness and sensitivity of ecosystem services values. *Ecosyst. Serv.* **2016**, *20*, 66–68. [CrossRef]
78. Rodriguez-Echeverry, J.; Echeverria, C.; Oyarzun, C.; Morales, L. Impact of land-use change on biodiversity and ecosystem services in the Chilean temperate forests. *Landsc. Ecol.* **2018**, *33*, 439–453. [CrossRef]
79. Zheng, H.; Li, Y.F.; Robinson, B.E.; Liu, G.; Ma, D.C.; Wang, F.C.; Lu, F.; Ouyang, Z.Y.; Daily, G.C. Using ecosystem service trade-offs to inform water conservation policies and management practices. *Front. Ecol. Environ.* **2016**, *14*, 527–532. [CrossRef]
80. Ellis, E.C.; Pascual, U.; Mertz, O. Ecosystem services and nature's contribution to people: Negotiating diverse values and trade-offs in land systems. *Curr. Opin. Environ. Sustain.* **2019**, *38*, 86–94. [CrossRef]
81. Martín-López, B.; Gómez-Baggethun, E.; García-Llorente, M.; Montes, C. Trade-offs across value-domains in ecosystem services assessment. *Ecol. Indic.* **2014**, *37*, 220–228. [CrossRef]
82. Tomscha, S.A.; Gergel, S.E. Ecosystem service trade-offs and synergies misunderstood without landscape history. *Ecol. Soc.* **2016**, *21*, 43. [CrossRef]