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# Evaluating Ecosystem Services and Trade-Offs Based on Land-Use Simulation: A Case Study in the Farming–Pastoral Ecotone of Northern China

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**Abstract:** Evaluating the impacts of land-use change (LUC) on ecosystem services (ESs) is necessary for regional sustainable development, especially for the farming–pastoral ecotone of northern China (FPENC), an ecologically sensitive and fragile region. This study aimed to assess the impacts of LUC on the ESs and provide valuable information for regional planning and management in the FPENC. To accomplish this, we assessed LUC in the FPENC from 2010 to 2020 and simulated land-use patterns in 2030 under three plausible scenarios: the business as usual scenario (BAUS), economic development scenario (EDS), and ecological protection scenario (EPS). Then, we quantified five ESs (including crop production, water yield, soil retention, water purification, and carbon storage) for 2020–2030 and analyzed the trade-offs and synergies among ESs in all scenarios. The results show that FPENC experienced expanding farming land and built-up land throughout 2010–2020. Under the BAUS and EDS from 2000 to 2030, especially EDS, the increase in farming land and built-up land will continue. As a result, crop production and water yield will increase, while soil retention, water purification, and carbon storage will decrease. In contrast, EPS will increase soil retention, water purification, and carbon storage at the cost of a decline in crop production and water yield. These results can provide effective reference information for future regional planning and management in the farming–pastoral ecotone.

**Keywords:** land-use change; scenario analysis; ecosystem services; trade-off and synergy

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## 1. Introduction

Ecosystem services (ESs) refer to the benefits people obtain directly or indirectly from nature, including provisioning services (e.g., food and water), regulating services (e.g., flood control), supporting services (e.g., nutrient cycling), and cultural services (e.g., spiritual benefits) [1,2]. Throughout human history, people's well-being has depended on the functioning of the ecosystem around them [3]. Meanwhile, human's impact on the ecosystem and the supply of their services is accelerating [3,4]. Humans have spent substantial effort modifying ecosystems to attain the ESs they need for production, such as food, raw material, and fuels [5,6]. However, relationships among ESs are complex and dynamic [7]. Increasing one ecosystem service may lead to an increase or decrease in other ESs [8,9]. The increasing of the Earth system to meet the demand for provisioning services will inevitably reduce the supply of other services [10]. The Millennium Ecosystem Assessment indicated that over 60% of the Earth's ESs had experienced degradation, and this trend may continue to accelerate [2]. In this context, decision makers need to think about how to balance human development demands with ESs changes to ensure the sustainable provision of desired ESs.

As major anthropogenic changes [11], land-use changes (LUCs) closely connect human activities with ecological processes [12]. LUCs affect the physicochemical properties of the land surface and thus affect the supply process of ESs [13,14] and are considered one of the most important drivers affecting ESs [15,16]. To meet social development, humans often alter regional land-use patterns to obtain desired ESs [17,18]. However, this often leads to the degradation or unsustainable use of other ESs [19,20]. Studies have shown that rapid LUC might affect the direction of ESs trade-offs [21]. For instance, rapid urban expansion could lead to a decline in regulating services through changes in carbon sequestration [22,23], nutrient flow [24,25], and biodiversity [26,27]. Therefore, exploring the impacts of land-use change on ESs is essential for further understanding the relationship between humans and nature and achieving sustainable development.

In recent years, scenario analysis has become an important tool for evaluating the impact of LUCs on ESs. By setting up possible development scenarios based on different land-use demands and calculating variations in and trade-offs among ESs under different scenarios, this approach can provide helpful information for decision makers to develop the best land management strategies [28–31]. Sharma et al. analyzed the trade-off among ESs of oil palm plantations under different scenarios in West Kalimantan, Indonesia, and provided information for future oil palm plantation expansion [32]. Srichaichana et al. evaluated water yield and sediment retention in Klong U-Tapao under different land-use scenarios and found that the forest conservation and prevention scenario could optimize ESs [33]. Sun et al. examined the impacts of different land scenarios on ESs globally, finding that forests, etc., are major land types providing ESs, and enhancing the utilization of barren land could increase ESs [34]. Peng et al. explored the impacts of different Grain-for-Green Programme scenarios on ESs in the Dali Autonomous Prefecture, finding that Grain-for-Green Programme might intensify ESs trade-offs [35].

Studies on the impacts of LUC on ESs have been conducted in various landscapes, such as cities [36,37], watersheds [38,39], and protected areas [40]. Few studies have explored the impacts of land use on ESs with the goal of providing valuable insights for regional planning and management, which remains a challenge [18], especially for the farming–pastoral ecotone. The farming–pastoral ecotone is a transition zone from traditional farming regions to pastoral regions over space and time [41,42]. The farming–pastoral ecotone of northern China (FPENC) covers nine provinces, and it is the largest ecotone in China in terms of area and spatial scale [43]. Given its unique geographic location and arid climatic conditions, the ecological environment of FPENC is sensitive and fragile and prone to being changed and disturbed by human activities [44,45]. In such areas, land-use patterns generally experience more frequent changes [46]. Under massive agricultural reclamation, the region has suffered severe vegetation degradation, land desertification, and salinization [47,48]. Therefore, it is more urgent for FPENC to understand the impact of LUC on ESs to develop effective regional planning and management policies to achieve sustainable development.

In order to assess the impact of LUC on the ESs variation, we developed three scenarios to analyze the ESs changes and their trade-offs. This study aimed to provide reference information for future regional planning and management. To achieve it, we (1) analyzed LUC from 2010 to 2020 and designed three LUC scenarios; (2) quantified and mapped variations in key ESs (crop production, water yield, soil retention, water purification, and carbon storage) under three scenarios; (3) analyzed trade-offs among ESs under three scenarios; and (4) proposed suggestions for future regional planning and management.

## 2. Materials and Methods

### 2.1. Study Area

In recent years, agro-meteorological factors have been widely used to define the range of the farming–pastoral ecotone. The 400 mm rainfall contour as the centerline and the 300–450 rainfall contour as the range is the most fundamental division basis and is generally accepted by researchers [49]. This study defined FPENC using 300 mm and 450 mm rainfall contours, supplemented by county administrative divisions (Figure 1b). The FPENC (34°50′25″–48°36′27″ N, 102°35′58″–125°55′4″ E) is located in the arid and semi-arid regions of northern China and covers nine provinces (i.e., Inner Mongolia, Heilongjiang, Jilin, Liaoning, Hebei, Shanxi, Ningxia, Shaanxi, and Gansu), with an area of 681,095.10 km$^2$ and an elevation ranging from −83 to 4286 m (Figure 1a). With a typical semi-arid continental climate, the annual average temperature in the study area ranges from 2 °C to 8 °C, and the annual average precipitation ranges from 300 to 450 mm, mostly concentrated within June to August [50]. Due to the limitation of water resources, drought-resistant crops such as spring corn are the main food crop in this region [51].

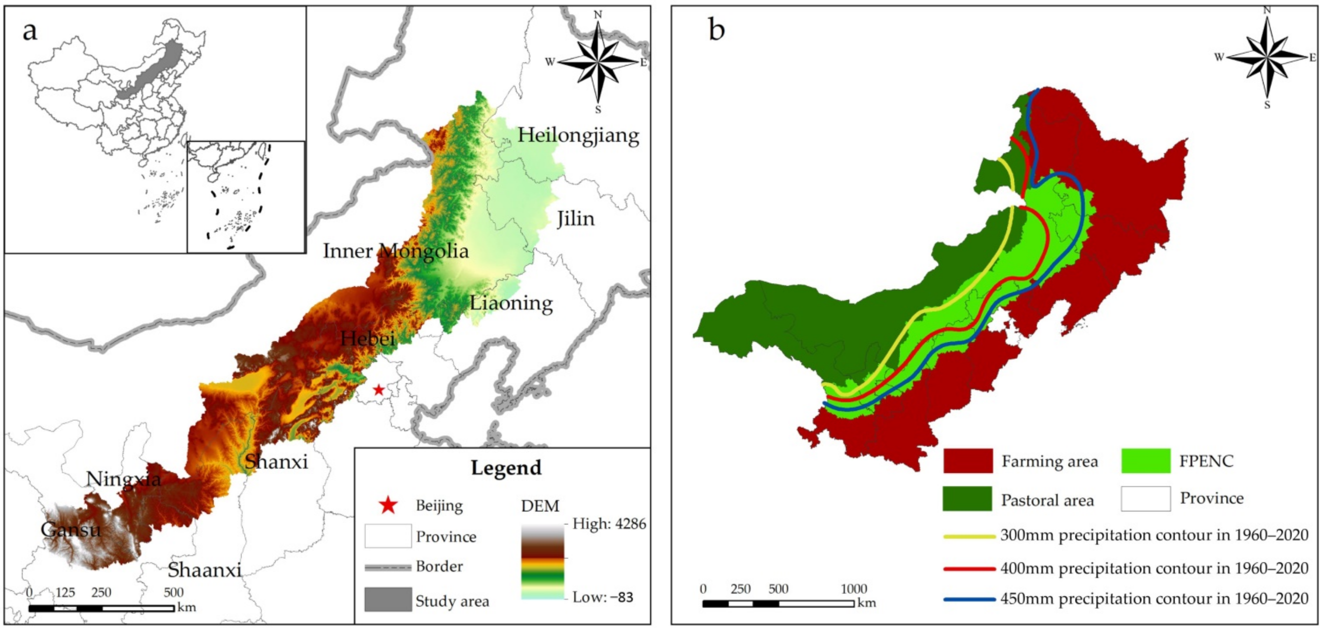


**Figure 1.** Geographical location and elevation (**a**) and the definition (**b**) of the farming–pastoral ecotone of northern China.

### 2.2. Data Sources

In this study, the data used and their sources are as follows: (1) land-use data in 2010 and 2020 were obtained from the Globeland30 platform (http://globeland30.org/ (accessed on 4 October 2021)). They were divided into ten categories (i.e., farming land, forest, grassland, shrub, wetland, waterbody, built-up land, tundra, barren land and glaciers, and permanent snow). Based on the actual land use in the FPENC, land-use types were classified into seven categories: farming land, forest, grassland, wetland, waterbody, built-up land, and barren land in this study. (2) Climate data (i.e., precipitation, temperature, and potential evapotranspiration) were taken from the National Earth System Science Data Center (http://www.geodata.cn/data/ (accessed on 2 March 2022)). (3) Digital elevation model data (DEM), gross domestic product (GDP) [52], and population [53] data were provided by Resource and Environment Science and Data Center (https://www.resdc.cn/ (accessed on 19 March 2022)). (4) Road data were from Open Street Map (https://www.openstreetmap.org/ (accessed on 14 March 2022)). (5) Other socio-economic data were collected from the statistical yearbooks and national economic and social development bulletins of the counties and cities in the study area.

### 2.3. Framework

A process framework with three core steps was developed to evaluate the impact of LUC on ESs in the FPENC (Figure 2). First, the Future Land-Use Simulation (FLUS) model was used to simulate land use in 2030 under three alternative scenarios. Second, we quantified and mapped five ecosystem services under the three scenarios. Finally, we analyzed trade-offs among the ESs.

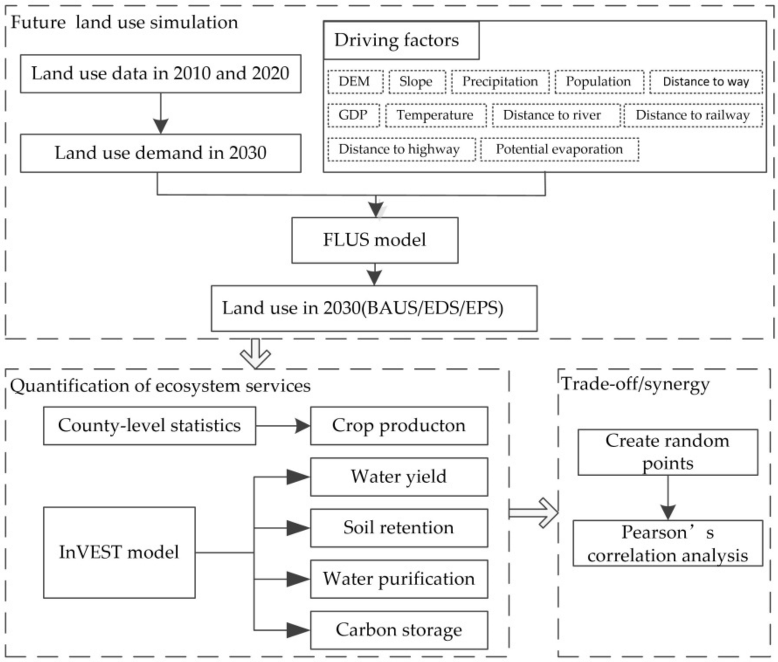


**Figure 2.** Framework.

### 2.3.1. FLUS Model

The FLUS model is a model for LUC simulation that couples human and natural effects. The model integrates the top-down system dynamics model and bottom-up meta-cellular automata (CA) model [54]. Based on the traditional CA model, the FLUS model introduces the self-adaptive inertia mechanism and roulette mechanism, which makes it more advantageous for spatial simulation. [55]. It has been successfully applied in regional and global LUC simulations [55–57]. The operation of the model is divided into two main parts: the first part generates a probability layer for each land-use type through an artificial network algorithm (ANN) based on the land use and its drivers; the second part mainly adopts self-adaptive inertia and a competition mechanism to predict the probability of all LUCs (Equation (1)) by considering probability surface, neighborhood effect, inertia coefficient, and conversion cost, and finally obtains land-use simulation results via roulette mechanism [58].

$$TP^t_{p,k} = P_{p,k} \times \Omega^t_{p,k} \times Inertia^t_k \times (1 - sc_{c\to k}) \quad (1)$$

where $TP^t_{p,k}$ refers to the combined probability of pixel p to transform from the original land use type to the target type k at the iteration time t; $P_{p,k}$ represents the probability of occurrence of land use type k in pixel p; $\Omega^t_{p,k}$ is the neighborhood effect of land use type k on pixel p at time t, and $sc_{c\to k}$ is the conversion possibility from original land use type c to target type k (1 represents possible conversion and 0 represents impossible conversion).

In addition, to validate the simulation results, we introduced the Kappa coefficient, a commonly used coefficient reflecting the confidence of the prediction results. If it is greater than 0.75, it indicates that the simulation results are credible. We tried to adjust the neighborhood effect and conversion cost to obtain a higher kappa coefficient.

### 2.3.2. Scenarios Setting

Considering the geographical location, ecological characteristics, and strategic position of FPENC, we set three land-use scenarios for 2030.

Scenario 1: business as usual scenarios (BUS). In this scenario, the LUC follows the historical pattern and transition rules (2010–2020), and no constraints are set in land use allocation.

Scenario 2: economic development scenario (EDS). In this scenario, it is inevitable to expand the farming land and accelerate the urbanization process to meet the needs of economic development. Therefore, in line with previous studies [59,60] and with reference to land use conversion in 2010–2020, we set the probability of transferring forest, grassland, water, wetland, and barren land to farming land by an increase of 50% and the probability of transferring farming land, forest, and grassland to built-up land by an increase of 100% under the EDS.

Scenario 3: ecological protection scenario (EPS). In this scenario, the primary goal is to strengthen the protection of semi-natural land and maintain the stability of ecosystem functions. Therefore, in line with previous studies [59,60] and with reference to land use conversion in 2010–2020, we set the probability of conversion of forest, waterbody, and wetland to farming land to decrease by 100%; the probability of conversion of forest to built-up land to decrease by 100%; the probability of conversion of grassland and barren land to farming land to decrease by 50%; the probability of conversion of farming to forest, grassland, waterbody, and wetland to increase by 100%; and the probability of conversion of farming land to built-up land to decrease by 50%.

#### 2.3.3. Quantification of Ecosystem Services (ESs)

Considering stakeholder concerns, social and service connections, and good data availability, we selected crop production, water yield, soil retention, water purification, and carbon storage to characterize the ecosystem status of the FPENC. First, based on the significant correlation between Net Primary Productivity (NPP) and crop yield [61], crop production was downscaled from county to grid levels. In addition, the Integrate Valuation of Ecosystem Services and Trade-offs (InVEST) model is a computer tool developed by the Natural Capital Project. The InVEST model aims to inform decisions about natural resource management [62], works on a grid map, and reports the results in biophysical and monetary terms [63], which is an effective tool to quantify and map the values of ESs. This study used water yield, sediment delivery ratio, and carbon modules in InVEST to assess the spatial distribution of water yield, soil retention, and carbon storage. The nutrient delivery radio module in InVEST was used to calculate nitrogen export, an indicator of water purification service. High nitrogen export level indicates a low water purification service supply [64]. Table 1 shows the method employed to quantify each ES.

**Table 1.** Methods for quantifying ecosystem services. (CP, crop production; WY, water yield; SR, soil retention; NE, nitrogen export; CS, carbon storage).

| | Formulas | Description | References |
|---|---|---|---|
| CP | $C_i = C_{sum} \times \frac{NPP_i}{NPP_{sum}}$ | $C_{ij}$ refers to the crop production in pixel x(t), $C_{sum}$ refers to the total crop yield (t), $NPP_i$ refers to the $NPP$ of grid $i$, and $NPP_{sum}$ refers to the sum of the regional $NPP$. | [61] |
| WY | $Y_{(x)} = \left(1 - \frac{AET_{(x)}}{P_{(x)}}\right) \cdot P_{(x)}$ | $Y_{(x)}$ refers to water yield for the landscape x, $AET_{(x)}$ refers to the actual evapotranspiration for pixel x, and $P_{(x)}$ refers to the actual precipitation on pixel x. | [65] |
| SR | USLE = R × K × LS × C × P<br>SR = RKLS − USLE | USLE is the amount of soil loss; R is rainfall erosivity; K is soil erodibility; LS is a slope length–gradient factor; C is vegetation cover management factor; P is support practice factor; SR is the amount of soil retention. | [65] |
| NE | $N\_export_i = load_i \times NDR_i$ | $N\_export_i$ refers to the nitrogen export on pixel $i$, $load_i$ refers to the modified nitrogen load on pixel $i$, and $NDR_i$ refers to nitrogen delivery ratio on pixel $i$. | [65] |
| CS | $C_{total} = C_{above} + C_{below} + C_{soil} + C_{dead}$ | $C_{total}$, $C_{above}$, $C_{below}$, $C_{soil}$, and $C_{dead}$ refer to total carbon, aboveground biomass, belowground biomass, soil organic carbon, and dead matter, respectively. | [65] |

2.3.4. Statistical Analysis

This paper used Pearson's correlation test to examine the relationship among ESs. It can quickly identify and quantitatively compare relationships among ESs [66]. First, we randomly generated 300 points in the study area and extracted the corresponding values of all ESs to those points in all scenarios. Then, Origin software was used to examine the linear correlation of paired ESs. When the correlation coefficient of the paired ESs was negative and passed the significance test at the 0.01 level, it was considered that there was a trade-off. Conversely, if the correlation coefficient was positive and passed the significance test, there was a synergy [67]. Moreover, the value of the correlation coefficient can be used to determine the strength of trade-off/synergistic relationships between pairs of ecosystems [68]. The larger the absolute value of the correlation coefficient, the stronger the trade-off/synergistic relationship between ESs. Conversely, the smaller the absolute value, the weaker the trade-off/synergistic relationship. However, it is essential to emphasize that the significance tests in this research are just indicative because the dependence between the spatial variables tends to invalidate the independent hypothesis.

## 3. Results

### *3.1. Land-Use Change (LUC)*

3.1.1. Land-Use Change (LUC) in the Past

Figures 3 and 4 show the spatial and temporal LUCs in the FPENC throughout 2010–2020. Grassland and farming land were the main land use types in the study area, occupying 48.58% and 37.75%, respectively, in 2010. Forests occupied 8.14% of the total area, and other land use types (i.e., built-up land, barren land, waterbody, and wetland) occupied less. From 2010 to 2020, FPENC experienced an increase in farming land and built-up land and a decrease in grassland. We used Chord Diagram to visualize the conversion direction between land use types (Figure 4). In 2020, the grassland area decreased to 45.18% of the total area, mainly converted to farming land, forest, and barren land. The forest and wetland area also decreased to 7.82% and 0.36% of the total area in 2020, respectively. Forest was mainly converted to grassland and farming land. Wetland was largely converted to farming land and grassland. The farming land, waterbody, built-up land, and barren land increased to 39.47%, 1.38%, 3.14%, and 2.65% of the total area, respectively. The increase in farming land and barren land largely came from grassland. The increase in built-up land mainly came from the conversion of farming land.

3.1.2. Land-Use Change (LUC) under the Scenarios

In 2010, the kappa coefficient and accuracy between simulated and actual land use were 0.8516 and 91.12%, respectively, indicating that FLUS has a good simulation effect in the study area. Figures 5 and 6 show the land-use patterns in 2030 under the three scenarios. The land-use pattern is still dominated by grassland and farming land for all scenarios. However, LUCs differ in the three scenarios. Under the BAUS, grassland, forest, and wetland further declined to 42.48%, 7.48%, and 0.35% of the total area, respectively. On the contrary, the farming land, built-up land, barren land, and waterbody showed an increasing trend. The farming land increased the most at 1.42% (9648.56 km$^2$), followed by built-up land with an increase of 1.07% (7311.56 km$^2$). The EDS shows a more significant increase in farming land and built-up land, with an increase of 3.26% (22,173.88 km$^2$) and 1.88% (12,779.06 km$^2$). Similarly, under the EDS from 2020 to 2030, grassland, forest land, and wetland declined more dramatically, by 5.14% (35,019.13 km$^2$), 0.45% (3078.25 km$^2$), and 0.02% (119.25 km$^2$). Unlike the BAUS, the barren land showed a decreasing trend (−0.05%) under the EDS. Compared to the other scenarios, the EPS had the smallest increase in built-up land, with an increase of 0.25% (1733.69 km$^2$). Under the EPS, the grassland, forest land, and wetland increased by 2.25% (15,323.63 km$^2$), 0.09% (624.50 km$^2$), and 0.03% (177.44 km$^2$), respectively. The farming land and barren land area decreased by 3.27% (22,268.25 km$^2$) and 0.09% (612.63 km$^2$), respectively. Overall, the farming land and built-up land area under the EDS were larger than those under the other scenarios. The grassland area, forestland area, and wetland area under the EPS were larger than those under the other scenarios. The barren land area under the BAUS was the largest due to the low economic cost and ecological benefits.

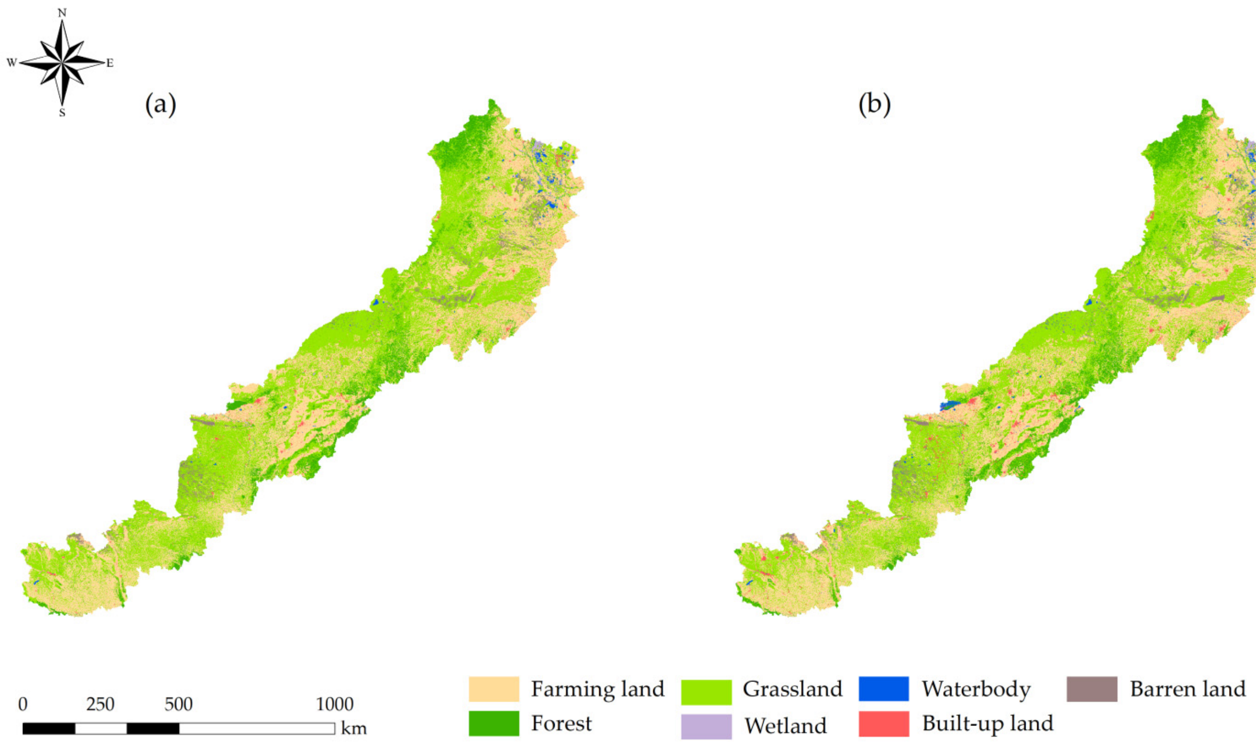


**Figure 3.** Land-use change in the past: (**a**) 2010; (**b**) 2020.

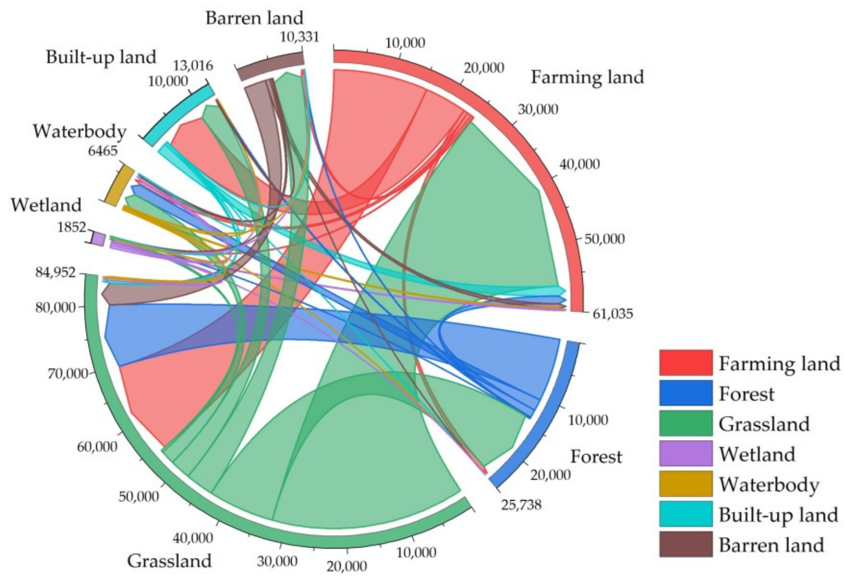


**Figure 4.** Land use conversion direction from 2010 to 2020.

### *3.2. Comparison of the Ecosystem Services (ESs) under the Future Scenarios*

Figure 7 shows the spatial characteristics of crop production, water yield, soil retention, nitrogen export, and carbon storage in 2020 and the future scenarios. High-value areas for crop production are mainly distributed in the southwest, south-central, and southeastern areas of the study area, where the rainfall is abundant and suitable for agricultural production. In contrast, low-value areas are distributed in the northern arid zone. Likewise, influenced by precipitation, the water yield is also characterized by a spatial distribution of high value in the southwest and northeast and low value in the north. High-value soil retention and carbon storage areas are located in the southern and northeastern regions with high terrain and dense vegetation. Low-value areas are concentrated in regions with flat terrain and sparse vegetation. The high nitrogen export values are found in the farming land and built-up land, which are the primary nitrogen sources. In comparison, the no-farmed areas with high terrain present low nitrogen export values.

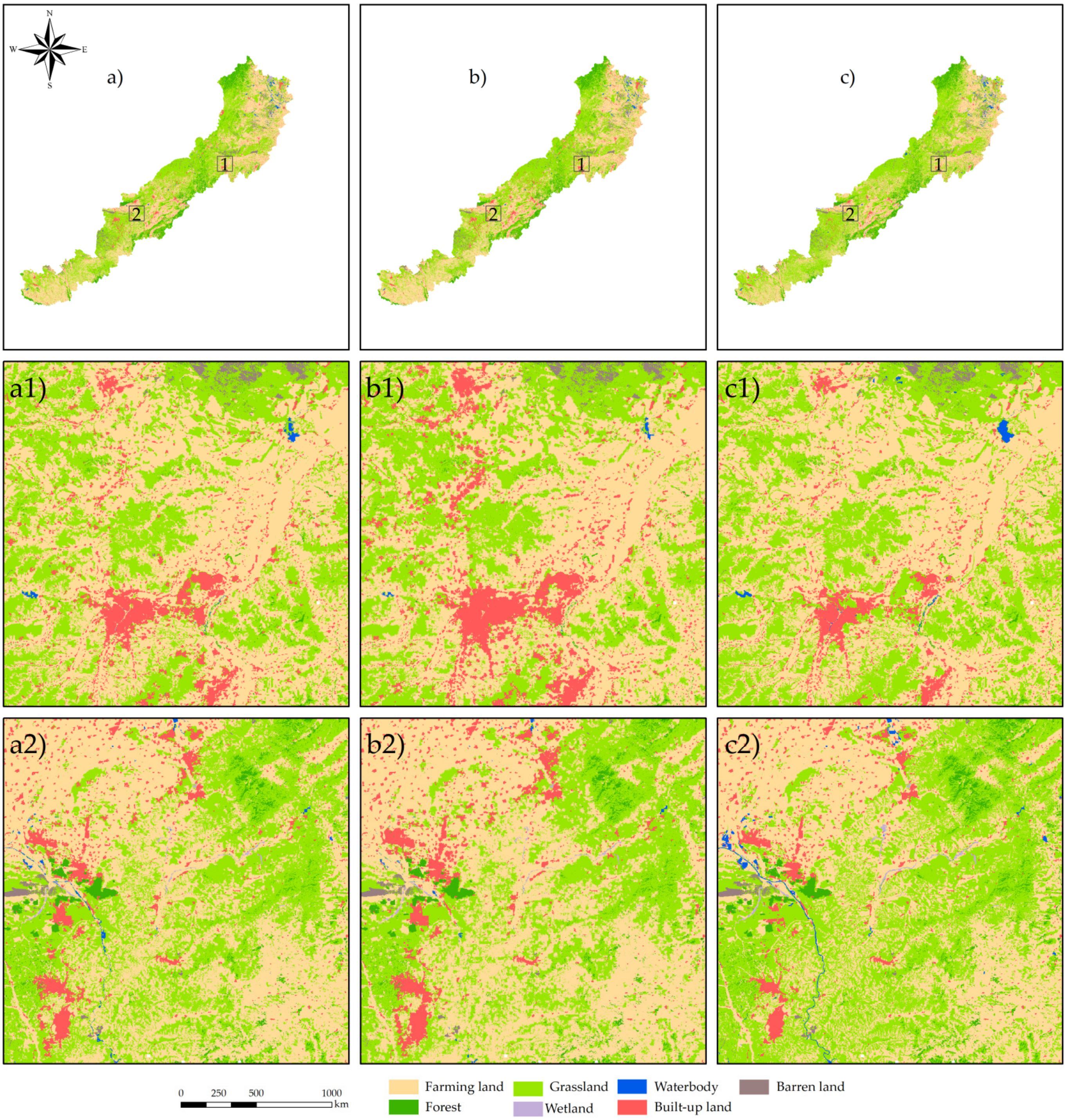


**Figure 5.** Land-use patterns in 2030 under three scenarios: (**a**) BAUS; (**b**) EDS; (**c**) EPS; with (**a1**–**c2**) detailed simulation results.

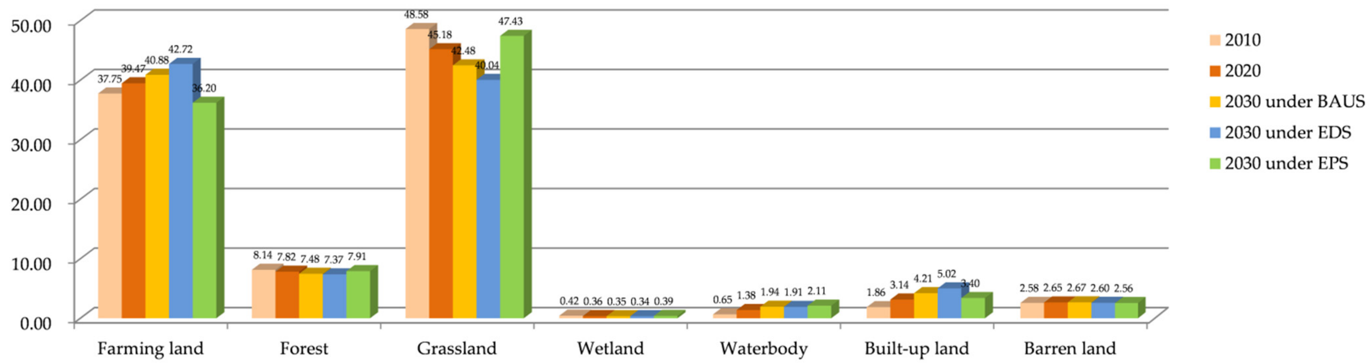


**Figure 6.** Area percentage of land use in the farming–pastoral ecotone of northern China.

The total amount of each ecosystem service in 2020 and three scenarios is shown in Table 2. The BAUS shows an increasing trend in crop production and water yield while performing poorly in soil retention, water purification, and carbon storage. In Figure 8, we can see that, compared with 2020, crop production increases by 3.68% (244.57 × $10^4$ t), and water yield increases by 1.05% (3.37 × $10^8$ $m^3$) under the BAUS. These increases in provision services are the results of the expansion of farming land and built-up land. These expansions, in turn, directly lead to a decrease in water purification services. Compared with 2020, the amount of nitrogen export increased to 4.57% (325.13 × $10^4$ kg) under the BAUS. Additionally, due to the reduction in forest and grassland in the BAUS, soil retention and carbon storage decreased by 0.16% (0.03 × $10^8$ t) and 2.40% (0.52 × $10^8$ t), respectively.

**Table 2.** Total amount of each ecosystem service in 2020 and under three scenarios in 2030.

| | Crop Production ($10^4$ ton) | Water Yield ($10^8$ $m^3$) | Soil Retention ($10^8$ ton) | Nitrogen Export ($10^4$ kg) | Carbon Storage ($10^8$ ton) |
|---|---|---|---|---|---|
| 2020 | 6628.24 | 322.02 | 16.71 | 7112.37 | 21.65 |
| BAUS | 6872.81 | 325.39 | 16.68 | 7437.50 | 21.13 |
| EDS | 7148.08 | 330.49 | 16.60 | 7704.70 | 20.87 |
| EPS | 6095.66 | 315.15 | 16.74 | 6665.30 | 21.70 |

Under the EDS, further increases could be observed in crop production and water yield. Likewise, decreases in soil retention, water purification, and carbon storage are more significant. Compared with 2020, crop production increases by 7.84% (519.84 × $10^4$ t), water yield increases by 2.60% (8.47 × $10^8$ $m^3$), and nitrogen export increases by 7.96% (592.33 × $10^4$ kg) under the EDS. On the contrary, compared with 2020, soil retention and carbon storage under the EDS decreased by 0.63% (0.11 × $10^8$ t) and 3.60% (0.78 × $10^8$ t), respectively.

Unlike the other scenarios, the EPS performs well in soil retention, water purification, and carbon storage while performing more weakly in crop production and carbon storage. Compared with 2020 under the EPS, crop production decreases by 8.03% (532.58 × $10^4$ t), water yield decreases by 2.08% (6.87 × $10^8$ $m^3$), and nitrogen export decreases by 5.80% (447.07 × $10^4$ kg). Instead, soil retention increases by 0.19% (0.03 × $10^8$ t) and carbon storage increases by 0.23% (0.05 × $10^8$ t).

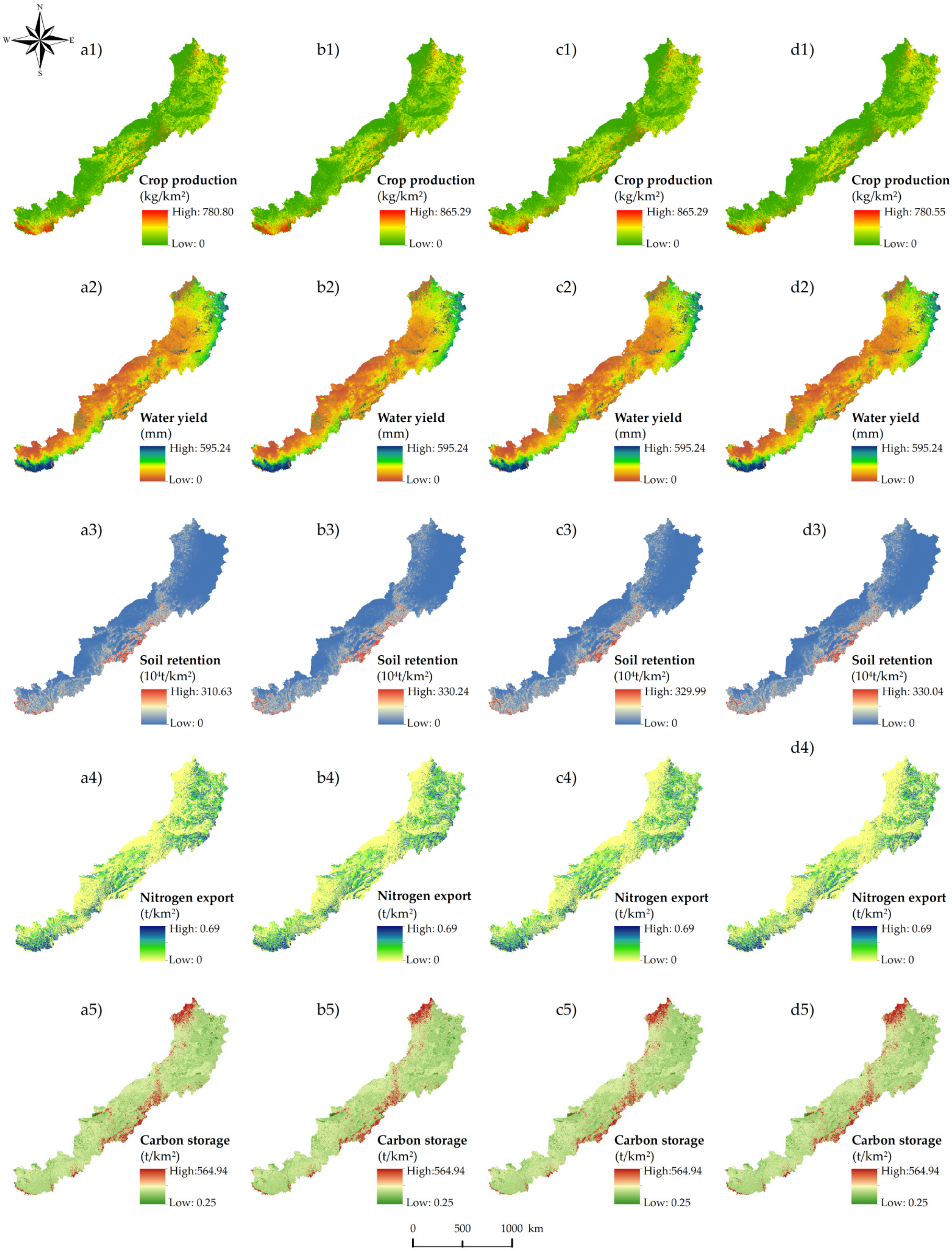


**Figure 7.** Ecosystem services in 2020 and the alternative future scenarios: (**a**) 2020; (**b**) BAUS; (**c**) EDS; (**d**) EPS.

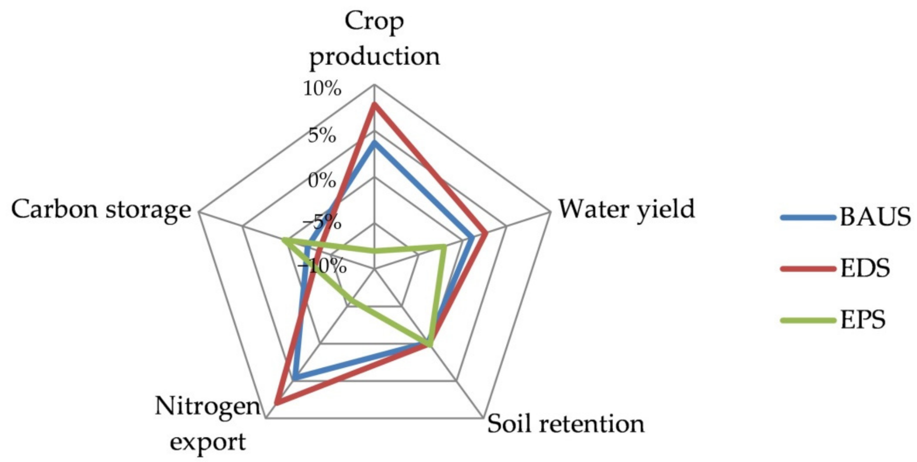


**Figure 8.** Percentage difference of the ecosystem services under the alternative scenarios.

## 3.3. Ecosystem Services (ESs) Trade-Offs

ESs are not independent; instead, they are interdependent [13]. Figure 9 reveals the correlation among five ESs in 2030 under three scenarios. It can be seen that, of the ten possible pairs of ESs, seven pairs are significantly correlated ($p < 0.01$) in all scenarios. Overall, the relationships among ecosystem service pairs are consistent under three scenarios. Crop production is positively correlated with water yield. Under the agricultural drought conditions in the FPENC, agricultural practices are influenced mainly by precipitation, which is the main primary of water yield. Crop production and water yield positively correlate with nitrogen export, indicating the trade-offs between them and water purification. Soil retention is not significantly correlated with crop production, water yield, and nitrogen export, while it is significantly and positively correlated with carbon storage. Soil retention is largely, in fact, dependent on vegetation regulation, and vegetation-rich areas accumulate abundant organic matter, which leads to higher carbon storage [64]. In addition, areas with high vegetation cover have lower agricultural production activities and higher evapotranspiration. Therefore, carbon storage is negatively correlated with crop production and water yield. Moreover, carbon storage is negatively correlated with nitrogen export, indicating a synergistic relationship between carbon storage and water purification.

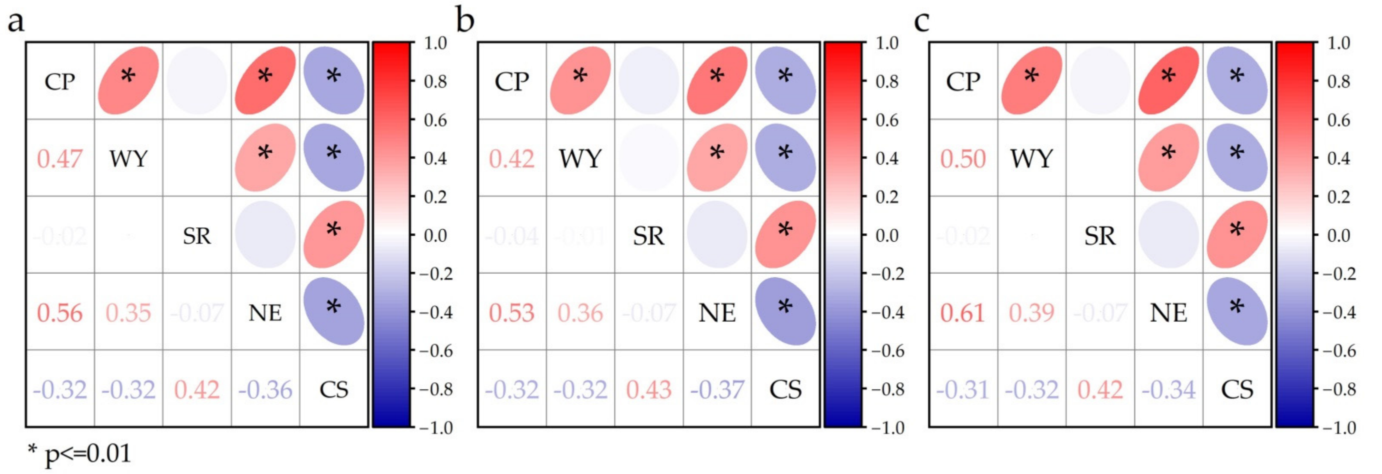


**Figure 9.** Trade-offs among ecosystem services under three scenarios in 2030: (**a**) BAUS; (**b**) EDS; (**c**) EPS. (CP, crop production; WY, water yield; SR, soil retention; NE, nitrogen export; CS, carbon storage).

## 4. Discussion

### 4.1. Land-Use Change (LUC) and Its Impacts on Ecosystem Services (ESs) in the FPENC

In the land use conversion from 2010 to 2020, it can be seen that the mutual conversion of farming land and grassland is the main feature of the FPENC. After balancing, the conversion of grassland to farming land still dominated in this region (Figure 4). On the one hand, due to the growth of population, the drive for economic interests, and the policy orientation of "stressing agriculture and restraining animal husbandry," FPENC experienced large-scale agricultural reclamation [48]. On the other hand, the agricultural drought conditions cannot support intensive farming practices. Farmers here tend to adopt extensive cultivation to increase the farming land area and crop yield, resulting in soil fertility loss. Due to the low population density and the vast land resources, farmers are forced to abandon the fertility-depleted land and find new grassland to reclaim [69]. The extensive cultivation practices have accelerated soil desertification [70]. A total of 5409.75 $km^2$ of land was converted to barren land throughout 2010–2020. How would dramatic LUCs affect the ecosystem?

Our study found that the BAUS and the EDS raise water yield compared to the EPS. The increase in the farming land area will increase the regional crop production. The increase in farming land and built-up land can increase the water yield, consistent with previous studies' results [71,72]. When grassland is replaced by farming land, water yield will increase due to lower evapotranspiration. Simultaneously, the increased built-up land area increases the area of impervious surfaces, which vastly increases the water yield. Studies have shown that moderate urbanization can help alleviate water scarcity in semi-arid regions [73]. However, the increase in farming land and built-up land led to increased nitrogen discharge, resulting in a decline in water purification. For instance, under the BAUS, farming land and built-up land are projected to be 9648.56 $km^2$ and 7311.56 $km^2$, respectively, resulting in an increase in nitrogen export by $3.25 \times 10^6$ t. Studies indicated that agricultural and urban expansion leads to water quality degradation [30,64]. On the other hand, both the BAUS and EDS decrease carbon storage and soil retention. Previous studies have shown that the loss of natural ecosystems (forest, grassland, and marsh) results in a decline in carbon storage [74]. Meanwhile, the reclamation of grassland and forest increases soil erosion [73]. In addition, due to agricultural drought conditions, dryland maize is the major crop in the FPENC, while the large distance between the maize rows also increases the risk of soil erosion [75,76].

### 4.2. Trade-Offs/Synergies under Different Scenarios

Previous studies have shown that trade-offs are generally found between provisioning services and regulating services, and synergies are generally found among regulating services [77]. According to the Millennium Ecosystem Assessment (MEA) framework, crop production and water yield were classified as provisioning services, and soil retention, water purification, and carbon storage were regulating services. Our findings supported previous conclusions that crop production and water yield were negatively correlated with carbon storage and water purification, while carbon storage was positively correlated with soil retention and water purification (Figure 9). Further, a synergistic relationship between provisioning services was found in this study. Our results showed that the synergistic relationship between provisioning services was highest in EPS, followed by BAUS, and the lowest in EDS. This indicated that the over-cultivation of farming land was not entirely beneficial to water yield in the arid region. Meanwhile, the trade-offs between provisioning services and carbon storage in the BAUS and EDS were higher than the EPS. The BAUS and EDS tend to obtain provisioning services at the expense of regulation services. In contrast, the EPS is a better scenario to maintain regulation services in the FPENC.

### 4.3. Suggestions for Future Regional Planning and Management

Integrating ESs trade-offs in regional and management remains a complex challenge due to the complexity of management [18,40]. Although the FPENC is regarded as a specific ecologically fragile area, it is an essential ecological barrier that prevents the invasion of the northwestern desert to the southeast, maintaining ecological security in northern China [48,78]. In recent decades, the FPENC has become a region facing vegetation degradation and land desertification due to the disturbance of human activities and frequent occurrence of severe climate, urgently requiring our attention. We developed three land-use scenarios to provide options for future planning in the FPENC. The BAUS continues the 2010–2020 land-use pattern; the EDS has the most significant economic benefits at the cost of loss of multiple regulating services, while the EPS has the most considerable ecological benefits at the cost of slower urban expansion and a significant loss of farming land. Notably, these trade-offs are issues facing FPENC planning. In this regard, we propose some recommendations for regional management and planning. The first and most important is strengthening ecological construction to improve the regional ecological environment. The Grain for Green Program has been implemented in this region. However, due to intense transpiration, large-scale tree planting can cause water shortages in arid and semi-arid zones [79]. In contrast, grasses and scrubs are better adapted to arid climatic conditions [79,80]. Therefore, in the future, local policy makers should adjust the implementation plan and intensity of ecological restoration projects concerning the geographical location and climatic conditions. Second, optimizing the structure of agricultural production is an inevitable choice for the sustainable development of FPENC. That is, to change the current crude agricultural production and management methods, advocate for conservation farming, reduce low-yielding farmland, and promote the development of grass-fed animal husbandry based on Grain-for-Green to achieve increased productivity and efficiency of animal husbandry. Meanwhile, the government can enhance the means of animal husbandry operation and create grassland ecological tourism to realize the unification of ecological and economic benefits. In addition, raising farmers' and herders' awareness of protecting grassland ecosystems is also necessary for the future sustainable development of FPENC.

### *4.4. Limitations and Future Research*

The FLUS model showed good effects in regional-scale land-use simulations [81,82]. This model adopts self-adaptive inertia and a competition mechanism based on roulette selection, which can effectively cope with the complexity and uncertainty among the different land use types [54,83]. However, due to the unpredictability of human activities, the fragility of the FPENC, and the changing in policy orientations, the LUC in the study area has great uncertainty. Moreover, land-use distribution is spatially heterogeneous and influenced by different driving factors in different eco-geographic regions [84]. For large-area simulation, such as the FPNEC, we can try to perform it in sub-regions in the future, which might give better results.

This paper designed three alternative land-use scenarios to explore ESs in 2030. Three scenarios (i.e., BAUS, EDS, and EPS) presented the dilemma of the trade-off between economic development and ecological protection faced by FPECN. They provided information for future land use management. However, this study's land use scenario settings were limited to future development in the FPENC. In future research, we can set more scenarios, such as farming land protection and eco-economic balance, to provide more possibilities for future land use management. Furthermore, climate change is another important driver of ecosystem service variation [85]. Climate change should be considered in future research frameworks to provide more practical information for policy decision makers.

## 5. Conclusions

In this study, we developed three alternative scenarios for 2030 to explore the impacts of LUCs on ESs and trade-offs among ESs in the FPENC. According to our estimates, farming land and built-up land area increased while grassland area significantly declined in 2010–2020 in the FPENC. This changing pattern is continued by BAUS and EDS. As a result, crop production and water yield increase, while soil retention, water purification, and carbon storage decrease. Contrarily, EPS increases soil retention, water purification, and carbon storage at the expense of crop production and water yield. Furthermore, EPS has the lowest trade-off between crop production and carbon storage and the highest synergy between crop production and water yield. This study can increase the understanding of trade-offs between development and protection. Our findings can provide supporting information for future regional planning and management in the farming–pastoral ecotone.

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## References

1. Costanza, R.; d'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.V.; Paruelo, J.; et al. The Value of the World's Ecosystem Services and Natural Capital. *Nature* **1997**, *387*, 253–260. [CrossRef]
2. Millennium Ecosystem Assessment. *Millennium Ecosystem Assessment Synthesis Report*; Island Press: Washington, DC, USA, 2005.
3. Brauman, K.A.; Daily, G.C.; Duarte, T.K.E.; Mooney, H.A. The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services. *Annu. Rev. Environ. Resour.* **2007**, *32*, 67–98. [CrossRef]
4. Mooney, H.; Larigauderie, A.; Cesario, M.; Elmquist, T.; Hoegh-Guldberg, O.; Lavorel, S.; Mace, G.M.; Palmer, M.; Scholes, R.; Yahara, T. Biodiversity, Climate Change, and Ecosystem Services. *Curr. Opin. Environ. Sustain.* **2009**, *1*, 46–54. [CrossRef]
5. Bennett, E.M.; Peterson, G.D.; Gordon, L.J. Understanding Relationships among Multiple Ecosystem Services. *Ecol. Lett.* **2009**, *12*, 1394–1404. [CrossRef]
6. Mitchell, M.G.E.; Suarez-Castro, A.F.; Martinez-Harms, M.; Maron, M.; McAlpine, C.; Gaston, K.J.; Johansen, K.; Rhodes, J.R. Reframing Landscape Fragmentation's Effects on Ecosystem Services. *Trends Ecol. Evol.* **2015**, *30*, 190–198. [CrossRef] [PubMed]
7. Dade, M.C.; Mitchell, M.G.E.; McAlpine, C.A.; Rhodes, J.R. Assessing Ecosystem Service Trade-Offs and Synergies: The Need for a More Mechanistic Approach. *Ambio* **2019**, *48*, 1116–1128. [CrossRef]
8. Tomscha, S.A.; Gergel, S.E. Ecosystem Service Trade-Offs and Synergies Misunderstood without Landscape History. *Ecol. Soc.* **2016**, *21*, 43. [CrossRef]
9. Bai, Y.; Ochuodho, T.O.; Yang, J. Impact of Land Use and Climate Change on Water-Related Ecosystem Services in Kentucky, USA. *Ecol. Indic.* **2019**, *102*, 51–64. [CrossRef]
10. 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]
11. 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*, 100527. [CrossRef]
12. Lang, Y.; Song, W. Quantifying and Mapping the Responses of Selected Ecosystem Services to Projected Land Use Changes. *Ecol. Indic.* **2019**, *102*, 186–198. [CrossRef]
13. Kusi, K.K.; Khattabi, A.; Mhammdi, N.; Lahssini, S. Prospective Evaluation of the Impact of Land Use Change on Ecosystem Services in the Ourika Watershed, Morocco. *Land Use Policy* **2020**, *97*, 104796. [CrossRef]
14. 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] [PubMed]
15. Clerici, N.; Cote-Navarro, F.; Escobedo, F.J.; Rubiano, K.; Villegas, J.C. Spatio-Temporal and Cumulative Effects of Land Use-Land Cover and Climate Change on Two Ecosystem Services in the Colombian Andes. *Sci. Total Environ.* **2019**, *685*, 1181–1192. [CrossRef]
16. Pham, H.V.; Sperotto, A.; Torresan, S.; Acuña, V.; Jorda-Capdevila, D.; Rianna, G.; Marcomini, A.; Critto, A. Coupling Scenarios of Climate and Land-Use Change with Assessments of Potential Ecosystem Services at the River Basin Scale. *Ecosyst. Serv.* **2019**, *40*, 101045. [CrossRef]

17. Arkema, K.K.; Verutes, G.M.; Wood, S.A.; Clarke-Samuels, C.; Rosado, S.; Canto, M.; Rosenthal, A.; Ruckelshaus, M.; Guannel, G.; Toft, J.; et al. Embedding Ecosystem Services in Coastal Planning Leads to Better Outcomes for People and Nature. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 7390–7395. [CrossRef]
18. Gong, J.; Liu, D.; Zhang, J.; Xie, Y.; Cao, E.; Li, H. Tradeoffs/Synergies of Multiple Ecosystem Services Based on Land Use Simulation in a Mountain-Basin Area, Western China. *Ecol. Indic.* **2019**, *99*, 283–293. [CrossRef]
19. Helfenstein, J.; Kienast, F. Ecosystem Service State and Trends at the Regional to National Level: A Rapid Assessment. *Ecol. Indic.* **2014**, *36*, 11–18. [CrossRef]
20. Vlek, P.L.G.; Khamzina, A.; Azadi, H.; Bhaduri, A.; Bharati, L.; Braimoh, A.; Martius, C.; Sunderland, T.; Taheri, F. Trade-Offs in Multi-Purpose Land Use under Land Degradation. *Sustainability* **2017**, *9*, 2196. [CrossRef]
21. Yang, S.; Zhao, W.; Liu, Y.; Wang, S.; Wang, J.; Zhai, R. Influence of Land Use Change on the Ecosystem Service Trade-Offs in the Ecological Restoration Area: Dynamics and Scenarios in the Yanhe Watershed, China. *Sci. Total Environ.* **2018**, *644*, 556–566. [CrossRef]
22. Li, B.; Chen, D.; Wu, S.; Zhou, S.; Wang, T.; Chen, H. Spatio-Temporal Assessment of Urbanization Impacts on Ecosystem Services: Case Study of Nanjing City, China. *Ecol. Indic.* **2016**, *71*, 416–427. [CrossRef]
23. Milnar, M.; Ramaswami, A. Impact of Urban Expansion and In Situ Greenery on Community-Wide Carbon Emissions: Method Development and Insights from 11 US Cities. *Environ. Sci. Technol.* **2020**, *54*, 16086–16096. [CrossRef] [PubMed]
24. Ma, L.; Guo, J.; Velthof, G.L.; Li, Y.; Chen, Q.; Ma, W.; Oenema, O.; Zhang, F. Impacts of Urban Expansion on Nitrogen and Phosphorus Flows in the Food System of Beijing from 1978 to 2008. *Glob. Environ. Chang.* **2014**, *28*, 192–204. [CrossRef]
25. Elias, E.; Dougherty, M.; Srivastava, P.; Laband, D. The Impact of Forest to Urban Land Conversion on Streamflow, Total Nitrogen, Total Phosphorus, and Total Organic Carbon Inputs to the Converse Reservoir, Southern Alabama, USA. *Urban Ecosyst.* **2013**, *16*, 79–107. [CrossRef]
26. Chamberlain, D.; Kibuule, M.; Skeen, R.; Pomeroy, D. Trends in Bird Species Richness, Abundance and Biomass along a Tropical Urbanization Gradient. *Urban Ecosyst.* **2017**, *20*, 629–638. [CrossRef]
27. Li, G.; Fang, C.; Li, Y.; Wang, Z.; Sun, S.; He, S.; Qi, W.; Bao, C.; Ma, H.; Fan, Y.; et al. Global Impacts of Future Urban Expansion on Terrestrial Vertebrate Diversity. *Nat. Commun.* **2022**, *13*, 1628. [CrossRef]
28. Swetnam, R.D.; Fisher, B.; Mbilinyi, B.P.; Munishi, P.K.T.; Willcock, S.; Ricketts, T.; Mwakalila, S.; Balmford, A.; Burgess, N.D.; Marshall, A.R.; et al. Mapping Socio-Economic Scenarios of Land Cover Change: A GIS Method to Enable Ecosystem Service Modelling. *J. Environ. Manag.* **2011**, *92*, 563–574. [CrossRef]
29. Teague, A.; Russell, M.; Harvey, J.; Dantin, D.; Nestlerode, J.; Alvarez, F. A Spatially-Explicit Technique for Evaluation of Alternative Scenarios in the Context of Ecosystem Goods and Services. *Ecosyst. Serv.* **2016**, *20*, 15–29. [CrossRef]
30. Gao, J.; Li, F.; Gao, H.; Zhou, C.; Zhang, X. The Impact of Land-Use Change on Water-Related Ecosystem Services: A Study of the Guishui River Basin, Beijing, China. *J. Clean. Prod.* **2017**, *163*, S148–S155. [CrossRef]
31. Ma, S.; Qiao, Y.P.; Jiang, J.; Wang, L.J.; Zhang, J.C. Incorporating the Implementation Intensity of Returning Farmland to Lakes into Policymaking and Ecosystem Management: A Case Study of the Jianghuai Ecological Economic Zone, China. *J. Clean. Prod.* **2021**, *306*, 127284. [CrossRef]
32. Sharma, S.K.; Baral, H.; Laumonier, Y.; Okarda, B.; Purnomo, H.; Pacheco, P. Ecosystem Services under Future Oil Palm Expansion Scenarios in West Kalimantan, Indonesia. *Ecosyst. Serv.* **2019**, *39*, 100978. [CrossRef]
33. Srichaichana, J.; Trisurat, Y.; Ongsomwang, S. Land Use and Land Cover Scenarios for Optimum Water Yield and Sediment Retention Ecosystem Services in Klong U-Tapao Watershed, Songkhla, Thailand. *Sustainability* **2019**, *11*, 2895. [CrossRef]
34. Sun, S.; Shi, Q. Global Spatio-Temporal Assessment of Changes in Multiple Ecosystem Services under Four IPCC SRES Land-Use Scenarios. *Earth's Future* **2020**, *8*, e2020EF001668. [CrossRef]
35. Peng, J.; Hu, X.; Wang, X.; Meersmans, J.; Liu, Y.; Qiu, S. Simulating the Impact of Grain-for-Green Programme on Ecosystem Services Trade-Offs in Northwestern Yunnan, China. *Ecosyst. Serv.* **2019**, *39*, 100998. [CrossRef]
36. Bai, Y.; Ouyang, Z.; Zheng, H.; Li, X.; Zhuang, C.; Jiang, B. Modeling Soil Conservation, Water Conservation and Their Tradeoffs: A Case Study in Beijing. *J. Environ. Sci.* **2012**, *24*, 419–426. [CrossRef]
37. Wu, Y.; Tao, Y.; Yang, G.; Ou, W.; Pueppke, S.; Sun, X.; Chen, G.; 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]
38. Tian, Y.; Wang, S.; Bai, X.; Luo, G.; Xu, Y. Trade-Offs among Ecosystem Services in a Typical Karst Watershed, SW China. *Sci. Total Environ.* **2016**, *566–567*, 1297–1308. [CrossRef]
39. Sun, X.; Zhang, Y.; Shen, Y.; Randhir, T.O.; Cao, M. Exploring Ecosystem Services and Scenario Simulation in the Headwaters of Qiantang River Watershed of China. *Environ. Sci. Pollut. Res.* **2019**, *26*, 34905–34923. [CrossRef]
40. Li, Z.; Cheng, X.; Han, H. Analyzing Land-Use Change Scenarios for Ecosystem Services and Their Trade-Offs in the Ecological Conservation Area in Beijing, China. *Int. J. Environ. Res. Public Health* **2020**, *17*, 8632. [CrossRef]
41. Shi, W.; Liu, Y.; Shi, X. Contributions of Climate Change to the Boundary Shifts in the Farming-Pastoral Ecotone in Northern China since 1970. *Agric. Syst.* **2018**, *161*, 16–27. [CrossRef]
42. Chen, X.; Zhang, H.; Yao, X.; Zeng, W.; Wang, W. Latitudinal and Depth Patterns of Soil Microbial Biomass Carbon, Nitrogen, and Phosphorus in Grasslands of an Agro-Pastoral Ecotone. *Land Degrad. Dev.* **2021**, *32*, 3833–3846. [CrossRef]

43. Yang, Y.; Wang, K.; Liu, D.; Zhao, X.; Fan, J. Effects of Land-Use Conversions on the Ecosystem Services in the Agro-Pastoral Ecotone of Northern China. *J. Clean. Prod.* **2020**, *249*, 119360. [CrossRef]
44. Chen, C.; Huang, D.; Wang, K. Risk Assessment and Invasion Characteristics of Alien Plants in and Around the Agro-Pastoral Ecotone of Northern China. *Hum. Ecol. Risk Assess. Int. J.* **2015**, *21*, 1766–1781. [CrossRef]
45. Wang, X.; Li, Y.; Chen, Y.; Lian, J.; Luo, Y.; Niu, Y.; Gong, X.; Yu, P. Temporal and Spatial Variation of Extreme Temperatures in an Agro-Pastoral Ecotone of Northern China from 1960 to 2016. *Sci. Rep.* **2018**, *8*, 8787. [CrossRef]
46. Zhou, Z.; Sun, O.J.; Huang, J.; Li, L.; Liu, P.; Han, X. Soil Carbon and Nitrogen Stores and Storage Potential as Affected by Land-Use in an Agro-Pastoral Ecotone of Northern China. *Biogeochemistry* **2007**, *82*, 127–138. [CrossRef]
47. Liu, J.; Chen, H.; Yang, X.; Gong, Y.; Zheng, X.; Fan, M.; Kuzyakov, Y. Annual Methane Uptake from Different Land Uses in an Agro-Pastoral Ecotone of Northern China. *Agric. For. Meteorol.* **2017**, *236*, 67–77. [CrossRef]
48. Liu, M.; Jia, Y.; Zhao, J.; Shen, Y.; Pei, H.; Zhang, H.; Li, Y. Revegetation Projects Significantly Improved Ecosystem Service Values in the Agro-Pastoral Ecotone of Northern China in Recent 20 Years. *Sci. Total Environ.* **2021**, *788*, 147756. [CrossRef]
49. Yang, Y.; Wang, K.; Liu, D.; Zhao, X.; Fan, J.; Li, J.; Zhai, X.; Zhang, C.; Zhan, R. Spatiotemporal Variation Characteristics of Ecosystem Service Losses in the Agro-Pastoral Ecotone of Northern China. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1199. [CrossRef]
50. Wang, Z.; Jiang, J.; Ma, Q. The Drought Risk of Maize in the Farming-Pastoral Ecotone in Northern China Based on Physical Vulnerability Assessment. *Nat. Hazards Earth Syst. Sci.* **2016**, *16*, 2697–2711. [CrossRef]
51. Wang, Z.; Jiang, J.; Liao, Y.; Deng, L. Risk Assessment of Maize Drought Hazard in the Middle Region of Farming-Pastoral Ecotone in Northern China. *Nat. Hazards* **2015**, *76*, 1515–1534. [CrossRef]
52. Xu, X. Spatial Distribution of GDP in China with Kilometer Grid Dataset. *Resour. Environ. Sci. Data Regist. Publ. Syst.* **2017**. [CrossRef]
53. Xu, X. Spatial Distribution of Chinese Population in Kilometer Grid Dataset. *Resour. Environ. Sci. Data Regist. Publ. Syst.* **2017**. [CrossRef]
54. Liu, X.; Liang, X.; Li, X.; Xu, X.; Ou, J.; Chen, Y.; Li, S.; Wang, S.; Pei, F. A Future Land Use Simulation Model (FLUS) for Simulating Multiple Land Use Scenarios by Coupling Human and Natural Effects. *Landsc. Urban Plan.* **2017**, *168*, 94–116. [CrossRef]
55. Liao, W.; Liu, X.; Xu, X.; Chen, G.; Liang, X.; Zhang, H.; Li, X. Projections of Land Use Changes under the Plant Functional Type Classification in Different SSP-RCP Scenarios in China. *Sci. Bull.* **2020**, *65*, 1935–1947. [CrossRef]
56. Li, X.; Chen, G.; Liu, X.; Liang, X.; Wang, S.; Chen, Y.; Pei, F.; Xu, X. A New Global Land-Use and Land-Cover Change Product at a 1-Km Resolution for 2010 to 2100 Based on Human–Environment Interactions. *Ann. Am. Assoc. Geogr.* **2017**, *107*, 1040–1059. [CrossRef]
57. Li, J.; Chen, X.; Kurban, A.; Van de Voorde, T.; De Maeyer, P.; Zhang, C. Coupled SSPs-RCPs Scenarios to Project the Future Dynamic Variations of Water-Soil-Carbon-Biodiversity Services in Central Asia. *Ecol. Indic.* **2021**, *129*, 107936. [CrossRef]
58. Liang, X.; Liu, X.; Li, X.; Chen, Y.; Tian, H.; Yao, Y. Delineating Multi-Scenario Urban Growth Boundaries with a CA-Based FLUS Model and Morphological Method. *Landsc. Urban Plan.* **2018**, *177*, 47–63. [CrossRef]
59. Libang, M.; Shuwen, N.; Lina, Y. Scenarios Simulation of Land Use/Cover Pattern in Dunhuang City, Gansu Province of Northwest China Based on Markov and CLUE-S Integrated Model. *Chin. J. Ecol.* **2012**, *31*, 1823–1831.
60. Fu, Q.; Hou, Y.; Wang, B.; Bi, X.; Li, B.; Zhang, X. Scenario Analysis of Ecosystem Service Changes and Interactions in a Mountain-Oasis-Desert System: A Case Study in Altay Prefecture, China. *Sci. Rep.* **2018**, *8*, 12939. [CrossRef]
61. Chen, T.; Peng, L.; Wang, Q. Response and Multiscenario Simulation of Trade-Offs/Synergies among Ecosystem Services to the Grain to Green Program: A Case Study of the Chengdu-Chongqing Urban Agglomeration, China. *Environ. Sci. Pollut. Res.* **2022**, *29*, 33572–33586. [CrossRef]
62. Cong, W.; Sun, X.; Guo, H.; Shan, R. Comparison of the SWAT and InVEST Models to Determine Hydrological Ecosystem Service Spatial Patterns, Priorities and Trade-Offs in a Complex Basin. *Ecol. Indic.* **2020**, *112*, 106089. [CrossRef]
63. Sánchez-Canales, M.; López Benito, A.; Passuello, A.; Terrado, M.; Ziv, G.; Acuña, V.; Schuhmacher, M.; Elorza, F.J. Sensitivity Analysis of Ecosystem Service Valuation in a Mediterranean Watershed. *Sci. Total Environ.* **2012**, *440*, 140–153. [CrossRef] [PubMed]
64. Guo, M.; Ma, S.; Wang, L.J.; Lin, C. Impacts of Future Climate Change and Different Management Scenarios on Water-Related Ecosystem Services: A Case Study in the Jianghuai Ecological Economic Zone, China. *Ecol. Indic.* **2021**, *127*, 107732. [CrossRef]
65. Sharp, R.; Douglass, J.; Wolny, S.; Arkema, K.; Bernhardt, J.; Bierbower, W.; Chaumont, N.; Denu, D.; Fisher, D.; Glowinski, K.; et al. *InVEST 3.11.0.post56+ug.gfa89dd9 User's Guide*; The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund. 2020. Available online: https://invest-userguide.readthedocs.io/_/downloads/en/3.9.0/pdf/ (accessed on 17 March 2022).
66. Erfu, D.; Xiaoli, W.; Jianjia, Z.; Dongsheng, Z. Methods, Tools and Research Framework of Ecosystem Service Trade-Offs. *Geogr. Res.* **2016**, *35*, 1005–1016.
67. Luo, R.; Yang, S.; Wang, Z.; Zhang, T.; Gao, P. Impact and Trade off Analysis of Land Use Change on Spatial Pattern of Ecosystem Services in Chishui River Basin. *Environ. Sci. Pollut. Res.* **2022**, *29*, 20234–20248. [CrossRef] [PubMed]
68. Yang, Y.; Li, M.; Feng, X.; Yan, H.; Su, M.; Wu, M. Spatiotemporal Variation of Essential Ecosystem Services and Their Trade-off/Synergy along with Rapid Urbanization in the Lower Pearl River Basin, China. *Ecol. Indic.* **2021**, *133*, 108439. [CrossRef]

69. Zhou, J.; Zhang, F.; Xu, Y.; Gao, Y.; Xie, Z. Evaluation of Land Reclamation and Implications of Ecological Restoration for Agro-Pastoral Ecotone: Case Study of Horqin Left Back Banner in China. *Chin. Geogr. Sci.* **2017**, *27*, 772–783. [CrossRef]
70. Tang, H.; Chen, Y.; Li, X. Driving Mechanisms of Desertification Process in the Horqin Sandy Land-a Case Study in Zhalute Banner, Inner Mongolia of China. *Front. Environ. Sci. Eng. China* **2008**, *2*, 487–493. [CrossRef]
71. Ke, X.; Wang, L.; Ma, Y.; Pu, K.; Zhou, T.; Xiao, B.; Wang, J. Impacts of Strict Cropland Protection on Water Yield: A Case Study of Wuhan, China. *Sustainability* **2019**, *11*, 184. [CrossRef]
72. Li, J.; Zhang, C.; Zhu, S. Relative Contributions of Climate and Land-Use Change to Ecosystem Services in Arid Inland Basins. *J. Clean. Prod.* **2021**, *298*, 126844. [CrossRef]
73. Qiu, J.; Huang, T.; Yu, D. Evaluation and Optimization of Ecosystem Services under Different Land Use Scenarios in a Semiarid Landscape Mosaic. *Ecol. Indic.* **2022**, *135*, 108516. [CrossRef]
74. Zhu, W.; Zhang, J.; Cui, Y.; Zhu, L. Ecosystem Carbon Storage under Different Scenarios of Land Use Change in Qihe Catchment, China. *J. Geogr. Sci.* **2020**, *30*, 1507–1522. [CrossRef]
75. Procházková, E.; Kincl, D.; Kabelka, D.; Vopravil, J.; Nerušil, P.; Menšík, L.; Barták, V. The Impact of the Conservation Tillage "Maize into Grass Cover" on Reducing the Soil Loss Due to Erosion. *Soil Water Res.* **2020**, *15*, 158–165. [CrossRef]
76. Vogel, E.; Deumlich, D.; Kaupenjohann, M. Bioenergy Maize and Soil Erosion-Risk Assessment and Erosion Control Concepts. *Geoderma* **2016**, *261*, 80–92. [CrossRef]
77. Li, Q.; Zhang, X.; Liu, Q.; Liu, Y.; Ding, Y.; Zhang, Q. Impact of Land Use Intensity on Ecosystem Services: An Example from the Agro-Pastoral Ecotone of Central Inner Mongolia. *Sustainability* **2017**, *9*, 1030. [CrossRef]
78. Yang, X.; Chen, H.; Gong, Y.; Zheng, X.; Fan, M.; Kuzyakov, Y. Nitrous Oxide Emissions from an Agro-Pastoral Ecotone of Northern China Depending on Land Uses. *Agric. Ecosyst. Environ.* **2015**, *213*, 241–251. [CrossRef]
79. Liu, D.; Chen, J.; Ouyang, Z. Responses of Landscape Structure to the Ecological Restoration Programs in the Farming-Pastoral Ecotone of Northern China. *Sci. Total Environ.* **2020**, *710*, 136311. [CrossRef]
80. Chen, J.; John, R.; Sun, G.; Fan, P.; Henebry, G.M.; Fernández-Giménez, M.E.; Zhang, Y.; Park, H.; Tian, L.; Groisman, P.; et al. Prospects for the Sustainability of Social-Ecological Systems (SES) on the Mongolian Plateau: Five Critical Issues. *Environ. Res. Lett.* **2018**, *13*, 123004. [CrossRef]
81. Wang, Q.; Guan, Q.; Lin, J.; Luo, H.; Tan, Z.; Ma, Y. Simulating Land Use/Land Cover Change in an Arid Region with the Coupling Models. *Ecol. Indic.* **2021**, *122*, 107231. [CrossRef]
82. Tan, Z.; Guan, Q.; Lin, J.; Yang, L.; Luo, H.; Ma, Y.; Tian, J.; Wang, Q.; Wang, N. The Response and Simulation of Ecosystem Services Value to Land Use/Land Cover in an Oasis, Northwest China. *Ecol. Indic.* **2020**, *118*, 106711. [CrossRef]
83. Hu, S.; Chen, L.; Li, L.; Zhang, T.; Yuan, L.; Cheng, L.; Wang, J.; Wen, M. Simulation of Land Use Change and Ecosystem Service Value Dynamics under Ecological Constraints in Anhui Province, China. *Int. J. Environ. Res. Public Health* **2020**, *17*, 4228. [CrossRef] [PubMed]
84. Li, M.; Liu, S.; Wang, F.; Liu, H.; Liu, Y.; Wang, Q. Cost-Benefit Analysis of Ecological Restoration Based on Land Use Scenario Simulation and Ecosystem Service on the Qinghai-Tibet Plateau. *Glob. Ecol. Conserv.* **2022**, *34*, e02006. [CrossRef]
85. Ghimire, U.; Shrestha, S.; Neupane, S.; Mohanasundaram, S.; Lorphensri, O. Climate and Land-Use Change Impacts on Spatiotemporal Variations in Groundwater Recharge: A Case Study of the Bangkok Area, Thailand. *Sci. Total Environ.* **2021**, *792*, 148370. [CrossRef] [PubMed]