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Identification and Optimization of Ecological Restoration Areas Coupled with Ecosystem Service Supply and Demand in the Northern Shaanxi Loess Plateau

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Abstract: Ecological restoration is crucial for maintaining national ecological security. Scientific and reasonable identification of key ecological restoration areas is a difficult problem facing the current national spatial planning. This study evaluated ecosystem service (ES) supply, demand, and their spatio-temporal characteristics in the Northern Shaanxi Loess Plateau (NSLP). A coupling coordination degree (CCD) model was applied to study the interactive relationship between ES supply and demand. The improved ant colony optimization (ACO) model was applied to explore the priority areas of ecological restoration. The results showed that ES supply, demand, and balance had significant spatial differences. Higher ES supply areas were distributed in the south, and higher demand areas were located in the central and northern parts. The balance of ecosystem service exhibited a similar increasing trend to the supply of ES from north to south. Temporally, the supply, demand and balance of ES showed distinct time-varying characteristics across different types of services. Total ES supply decreased from 2000 to 2020, while total ES demand and balance first declined and then rose. Moreover, total ES balance showed a significant decreasing trend in 21.22% of regions in the NSLP. Furthermore, the CCD results showed that about 82% of the regions had a disorder status in 2000, while about 90% of the regions had a coordination status from 2010 to 2020. This also implied that the coupling coordination degree in most regions gradually improved from 2000 to 2020. Finally, four ES enhancement priorities were further identified from the perspectives of enhancing ES supply capacity. Ecological restoration prioritization of different ES enhancements showed significant spatial variations, with the top 15% of the ecological restoration area located in the east–central and west–central regions. The top 5% of total ecosystem services can bring 2,470,400 yuan in ecological benefits. This research can offer scientific and theoretical guidance as well as a reference for decision-makers to undertake ecological restoration efforts.

Keywords: ecosystem service supply and demand; coupling coordination degree; ecological restoration area; ecological benefits; Northern Shaanxi Loess Plateau

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1. Introduction

At present, ecosystem service (ES)-related studies are attracting more and more attention in ecological restoration research [1,2]. The current focus of ecosystem service research is on the balance between supply and demand, which has implications for regional ecosystem management, the construction of ecological security patterns, and the zoning of ecological protection areas [3]. Most research on ES supply and demand focuses on theoretical frameworks, assessment method models, trade-off relationships, and practical applications of ecological protection [4,5]. It is crucial to enhance the exploration of interconnected studies in ecological restoration research, including examining the coupling and influencing factors of ES supply and demand from a multi-scale perspective [6,7], investigating the patterns of spatial transfer of ES supply and demand [8], and refining the parameters for assessment methodology and model optimization. Therefore, by evaluating and analyzing the spatio-temporal characteristics of ecosystem service supply and demand, we can clarify the coupling coordination relationship of ecosystem service supply and demand and identify the main areas where ecosystem services are disorder, so as to provide a basis for decision-making on ecosystem management and ecological restoration policies.

The loss of ecosystem services is a major issue for countries around the world under global change, making the restoration of ecosystem services an explicit goal of ecological restoration programs developed by national governments [9]. The Strategic Plan for Biodiversity 2021–2030 sets out effective actions to reverse global biodiversity loss by 2030 and to put biodiversity on a path of restoration [10]. Furthermore, scholars widely acknowledge the importance of incorporating ecosystem services into the planning of regional ecological restoration [11], which has significant advantages. For example, ecosystem services are a collection of services that can synthesize and interpret multiple pieces of information. Using ecosystem services in ecological restoration assessment not only explicitly considers multiple objectives but also allows for a holistic analysis of results, which can help identify synergies and minimize trade-offs during iterative restoration planning [12]. Some studies have highlighted this need and proposed some framework tools for linking ecological restoration and ecosystem services [13,14]. In general, current scholars have undertaken a lot of meaningful exploration of issues related to ecosystem services and ecological restoration [14–16]. However, research on ecological restoration lacks consideration of the coordination relationship between the supply and demand of ecosystem services, which can not efficiently reflect the interaction between man and nature. Thus, relevant research needs to be strengthened.

Due to the significant impact of both global climate change and human activities, the area of degraded ecosystems is increasing, leading to widespread efforts for ecological restoration in various regions. However, the actual ecological restoration process still faces challenges such as limited funding, so it is difficult to comprehensively restore damaged and degraded areas. Hence, it is essential to establish ecological restoration priorities as a necessary step for conducting ecological restoration in a systematic manner [17]. Currently, methods for determining ecological restoration priority areas mainly include multiple-criteria decision analysis (MCDA) and ecological restoration benefit prioritization methods [18–20]. Among them, MCDA provides an assessment framework to integrate multiple opinions and assessment criteria from stakeholders and experts and assigns weights to objectives according to their importance [18,21]. MCDA also has the advantage of being able to process multiple types of data and perform accurate calculations in various algorithms, especially in combination with Geographic Information Systems (GISs), taking into account the preferences of experts to achieve specific goals [19]. It allows ecological restoration to make great strides in utilizing spatial data at a regional scale and has become the most commonly used methodology for evaluating ecological restoration priorities [22]. For example, Guo et al. (2020) established an integrated decision-making method for terrestrial ecosystem ecological restoration planning based on the MCDA method, which considers different stakeholders to seek ideal ecological restoration solutions [23]. Therefore, the MCDA method can be used to evaluate ecological restoration priority zones integrating ecosystem service enhancement, which can effectively respond to the challenges of ecological restoration and accomplish its objectives.

The Northern Shaanxi Loess Plateau (NSLP) is situated in a region that lies between the Loess Plateau and the Inner Mongolia Plateau in China, characterized by a special terrain, climate, and serious soil erosion, belonging to a typical ecologically fragile area [24]. It has undergone great changes in landscape patterns since ancient times, with significant spatial heterogeneity of landscape and fragile ecosystems, which makes it suitable for ecosystem service research. Meanwhile, with global climate change coupled with the increase in human activities interfering with natural ecosystems, landscape fragmentation is serious, with prominent ecological environment problems [25]. The prominent contradiction between human demand and ES supply necessitates urgent ecological restoration [26]. It is highly important to systematically conduct research on ecological restoration in the NSLP for regional ecological protection. However, the coordination relationship between ecosystem service supply and demand is rarely applied in the ecological restoration of the NSLP. Therefore, taking ecosystem service supply and demand as an entry point, effectively enhancing ES supply capacity is a key scientific issue that needs to be solved in the current ecological restoration of the NSLP.

In this study, we conducted an integrated evaluation of ecosystem service supply, demand, and the degree of coordination between them in the NSLP. Specifically, we utilized the improved ant colony optimization (ACO) model to pinpoint priority areas for ecological restoration by establishing a framework based on feasibility, urgency, and importance. The specific objectives of this research were as follows: (1) quantifying the spatial and temporal fluctuations in ES supply, demand, and balance; (2) investigating the spatial and temporal features of the coordination degree between ES supply and demand; (3) identifying potential ecological restoration areas using ES supply, demand, and its coordination degree; and (4) optimizing priority areas for ecological restoration with a focus on enhancing ecosystem service supply capacity. Through the assessment of ecosystem service supply, demand, and its coordination degree, we aim to provide guidance for the identification and optimization of regional ecological restoration efforts.

2. Materials and Methods

2.1. Study Area

The NSLP has a land area of 79,981.9 km^2, which makes up 38.9% of Shaanxi Province's total area and 12.6% of the Loess Plateau's area, and includes two prefecture-level cities, Yulin and Yan'an. The terrain is oriented northeast and southwest from low to high, with a wind–sand grassland area in the north, a loess hill and gully area in the center, and a beam-shaped low mountainous area in the southern region. The average elevation is approximately 1500 m (Figure 1). The regional climate belongs to the transition zone from a warm temperate continental monsoon semi-humid climate to a temperate semi-arid climate. It is characterized by rainy summers and dry winters, large temperature differences between day and night, and abundant sunshine. The average annual temperature varies from 7 °C to 11 °C, and the average annual precipitation is about 450 mm [27]. In 2020, the resident population was 5,907,400 people, and the urbanization rate was 61.48%, with a total regional GDP of 5691.14 billion [24]. The natural resource endowment of counties/urban areas varies greatly, and the economic development between regions is unbalanced. After nearly 15 years of converting farmland back to forests, the land use pattern in northern

Shaanxi has undergone significant changes as a national key ecological functional area. These changes are evident in the decrease in arable and unused land and the increase in forest lands, grasslands, and watersheds [28].

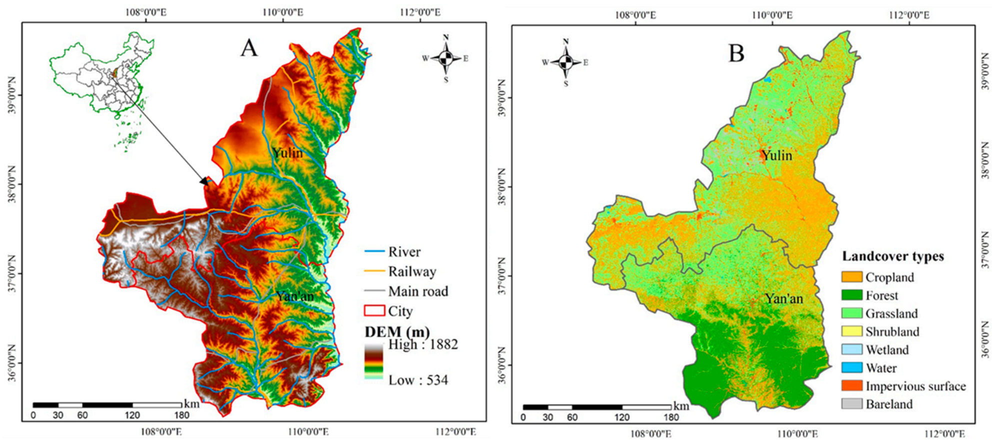

Figure 1. The geographical location's altitude (**A**) and landcover types (**B**) in the NSLP.

2.2. Data Sources and Processing

In this study, a large amount of data were utilized to identify ecological restoration areas in the NSLP. Among them, land use data were acquired from the cloud platform of the Resource Data Center of the Chinese Academy of Sciences. Land use change plays a significant role in influencing human activities. Different types of land cover, such as grassland, forest, farmland, waterbodies, construction land, and barren land, have an impact on the intensity of human activities [29]. The Normalized Difference Vegetation Index (NDVI) data used in this study were obtained from the vegetation instrument of SPOT-4 and SPOT-5 satellites [30]. For human activity data, population density and Gross Domestic Product (GDP) density are important factors reflecting the interaction between human activities and ecosystems [31]. Population density and GDP density data were sourced from the cloud platform of the Resource Data Center of the Chinese Academy of Sciences. Population density data represent the number of people per square kilometer spatially in people/square kilometer. GDP density data represent the total GDP value per square kilometer in space, in units of ten thousand yuan/square kilometer. Road data were obtained from the National Data Center for Agricultural Sciences. Altitude data were also provided by the cloud platform of the Resource Data Center of the Chinese Academy of Sciences [32]. Based on the altitude data, slope was computed using the ArcToolbox tool-3D Analyst tool in ArcGIS Desktop 10.5. Ecosystem service value reflects the advantages of restoring ecosystems and it was obtained from the cloud platform of the Resource Data Center of the Chinese Academy of Sciences [33]. The data sources, resolution, format, and years are listed in Table 1.

Table 1. Data sources, resolution, years, and format.

Data	Data Source	Access Date	Resolution	Time	Format
DEM	http://www.gscloud.cn/	1 September 2023	90 m	-	Raster
Road	http://www.agridata.cn/	1 September 2023	1:250,000	2015	Vector
Population	http://www.gscloud.cn/	10 September 2023	1 km	2020	Raster
GDP	http://www.gscloud.cn/	10 September 2023	1 km	2020	Raster
Land use and cover	http://www.gscloud.cn/	11 September 2023	30 m	2000, 2010, 2020	Raster
NDVI	http://www.vito-eodata.be/	12 September 2023	1 km	2020	Raster
Ecosystem service value	http://www.gscloud.cn/	12 September 2023	1 km	2020	Raster

DEM: Digital Elevation Model, GDP: Gross Domestic Product, NDVI: Normalized Difference Vegetation Index.

2.3. Land Use/Land Cover (LULC) Supply and Demand Matrix Model

The LULC supply and demand matrix model proposed by Burkhard contains 22 ecosystem service types and 44 land use types [34]. To simplify the classification systems, similar land use and ecosystem service types were consolidated from Burkhard's original model. The 44 land use types were merged into 6 categories: farmland, forest, grassland, watershed, construction land, and barren. Similarly, 22 ecosystem service types were merged into 3 groups: provisioning services, regulating services, and cultural services. The supply, demand, and balance matrices of ecosystem services were established as shown in Figure 2.

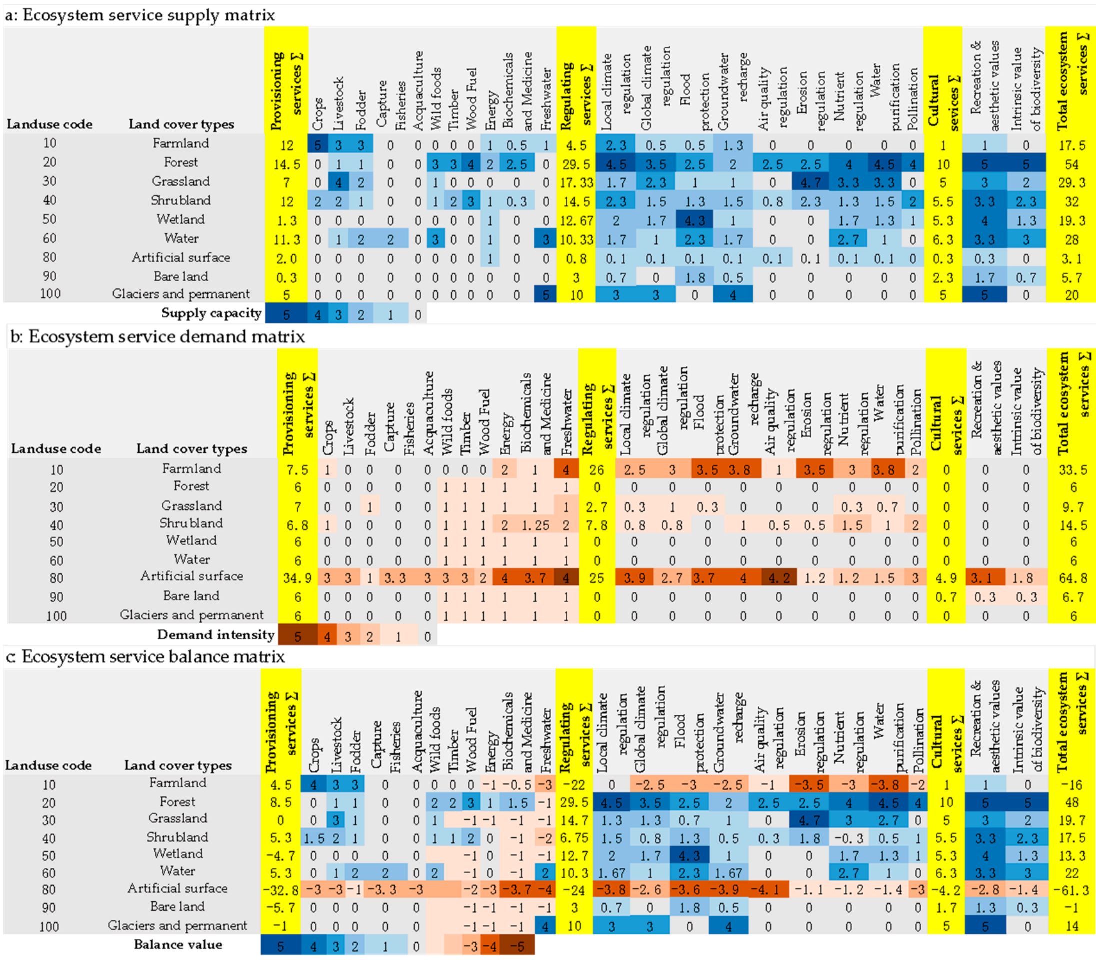

Figure 2. Ecosystem services supply (**a**), demand (**b**), and balance (**c**) matrices across various land cover types from 2000 to 2020.

The ES supply matrix indicates the provisioning capacity of different land cover types to provide various ecosystem services, and the values are quantified as ("0–1": no supply capacity; "1–2": low supply capacity; "2–3": general supply capacity; "3–4": moderate supply capacity; "4–5": high supply capacity) (Figure 2a). The ES demand matrix reflects the actual human demand intensity for the ecosystem services of different land cover types, and the values are quantified as ("0–1": no demand intensity; "1–2": low demand intensity; "2–3": general demand intensity; "3": moderate demand intensity; "4–5": high demand intensity) (Figure 2b). The ES balance matrix is obtained by subtracting ES supply values from ES demand values, reflecting deficits or surpluses of ecosystem service for different land cover types (Figure 2c). The value of ES balance ranges from −5 to 5. The presence of negative values indicates an excess of ES demand over ES supply, while positive values indicate an excess of ES supply over ES demand. A value of zero suggests that ES supply equals ES demand, achieving a balance between the two [3,35]. Therefore, based on matrices for ES supply, demand, and balance, ecosystem services for different land cover types were quantified and mapped by connecting landcover type maps through ArcGIS Desktop 10.5.

To capture the fluctuations in ES supply and demand, we calculated the total values of ES supply, demand, and balance from 1990 to 2020 by multiplying the area of different land use types by their respective quantitative values. To account for variations in ecosystem characteristics across regions, the NDVI was used as a correction factor for ES supply, and ES supply values were calibrated according to Equation (3).

$$\mathrm{ES}_j = \sum_{\mathrm{i}=1}^{6} S_i \times V_{ESi} \quad (1)$$

$$\mathrm{ES\ total} = \sum_{\mathrm{j}=1}^{3} ES_j\ (\mathrm{j} = 1, 2, 3) \quad (2)$$

$$F_{ni} = F_n \times A_i \quad (3)$$

where V_{ESi} is the quantitative value of ecosystem services for land cover type i (i = 1, 2, 3, 4, 5, 6); Si is the area of land cover type i; ESj is ecosystem services value for ES type j; F_{ni} is the adjusted value of ES supply in region i; F_n is the initial value of ES supply; and Ai represents the correction factor. The correction coefficient is defined as the ratio of the NDVI in the study area to the national annual average of the NDVI in that year.

2.4. The Change Trend of Ecosystem Service Supply and Demand

In order to analyze the change trend of ES balance from 2000 to 2020, the ordinary least squares (OLS) method was applied to assess the change rate of ES balance. The formula for calculation is as follows:

$$Slope = \frac{n \times \sum_{j=1}^{n} j \times balance_j - \sum_{j=1}^{n} j \sum_{j=1}^{n} balance_j}{n \times \sum_{j=1}^{n} j^2 - \left(\sum_{j=1}^{n} j\right)^2} \quad (4)$$

where n represents the length of the time series, n = 3 and i is the year number from 1–3 and represents the ES balance value of the ith year. *Slope* > 0 indicated that the ES balance showed an increasing trend; otherwise, it showed a decreasing trend.

The F test was further introduced to assess the significance of the change trend in ES balance. If $F > F0.05(1, n-2)$, the change trend of ES balance is considered significant at a 95% confidence level. $F0.05(1, 1) = 161.448$. Based on this, the F test was calculated and then overlayed the slope value and F value to obtain the change trend of ES balance. The change trend was categorized as follows: significant increase (*Slope* > 0, F > 161.448), increase (*Slope* > 0, F < 161.448), decrease (*Slope* < 0, F < 161.448), or significant decrease (*Slope* < 0, F > 161.448). The formula for calculating the F-test is as follows:

$$F = \frac{R^2(n-2)}{1-R^2} \quad (5)$$

$$r = \frac{\sum_{i=1}^{n}(i-\bar{\iota})\left(X_i - \overline{X}\right)}{\sqrt{\sum_{i=1}^{n}(i-\bar{\iota})^2 \sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}} \quad (6)$$

where n represents the length of the time series, n = 3; R^2 is the correlation coefficient between ES balance and time series at the grid unit; i is the year number of 1–3; $\bar{\iota}$ is the average value of serial number 3; and X_i is the ES balance value in year i. The average value of ES balance from 2000 to 2020 is represented $\overline{X}$. The change trend analysis of ES balance was performed in ArcGIS Desktop10.5.

2.5. Model for Measuring the Degree of Coupling Coordination

Referred to as a physical concept, coupling involves the interaction of two or more systems or forms of motion through various interactions [36]. Coupling analysis is primarily used to examine the connection between human activity and ecosystem services [37]. In this study, we utilized coupling analysis to assess the interplay between ES supply and ES demand using the following calculation formula:

$$C_n = \text{n}\{(u_1.u_2.u_3 \ldots\ldots u_n)|[(u_1 + u_2 + u_3 \ldots\ldots u_n)(u_1 + u_2 + u_3 \ldots\ldots u_n)]\}^{1/n} \quad (7)$$

where C is the coupling degree ($0 \leq C \leq 1$), u_1 is the standardized ES supply ($0 \leq u_1 \leq 1$), and u_2 is the standardized ES demand ($0 \leq u_2 \leq 1$). When $C = 0$, there is no correlation between ES supply and ES demand. When $0 < C \leq 0.3$, they are at low level coupling, with high ES supply and low ES demand. When $0.3 < C \leq 0.6$, they are at an antagonistic stage, and an increase in ES demand leads to changes in land use structure accompanied by a decline in ES supply. When $0.6 < C \leq 0.8$, they are at a running-in stage, and ecosystem damage leads to increased awareness of environmental protection. We should slow down the intensity of human activities, with decreasing ES demand and increasing ES supply. When $0.8 < C < 1$, it indicates a high-level coupling stage where harmony and mutual benefit are achieved between ES supply and ES demand. When $C = 1$, a favorable resonance coupling is attained, leading to the development of a new orderly ecosystem structure and a balance in ecosystem service supply and demand.

The concept of coupling degree is used to assess the level of interaction and influence among systems or elements, but it does not fully capture the extent of coordinated development between them [38]. Therefore, a model known as the coupling coordination degree (CCD) is introduced to serve as a quantitative measure for evaluating the level of coordination between ES supply and demand. Its calculation formula can be expressed as follows:

$$D = (C \times Z)^{0.5} \quad (8)$$

$$Z = \text{a}u_1 + \text{b}u_2 + \text{c}u_3 + \cdots\ldots\ldots\ldots u_n \quad (9)$$

where D is coupling coordination degree and Z is the coordination index of comprehensive ES supply and demand. a and b are the total index values of ES supply and demand, a = b = 0.5. Table 2 provides specific criteria for determining the degree of coupling coordination.

Table 2. Classification criterion for coupling coordination degree.

Stage	Categorization	Standard
Coordinated development	Extreme coordination	$0.8 < D \leq 1$
	Moderate coordination	$0.6 < D \leq 0.8$
Transformative development	Low coordination	$0.5 < D \leq 0.6$
	Low disorder	$0.4 < D \leq 0.5$
Uncoordinated development	Moderate disorder	$0.2 < D \leq 0.4$
	Extreme disorder	$0 \leq D \leq 0.2$

2.6. Identifying Potential Ecological Restoration Areas

To address the degradation of regional ecosystems and restore damaged ecological spaces, this study identified potential ecological restoration areas in the NSLP based on the assessment of ES supply and demand and the coupling coordination degree. The judgment was that areas where ES balance was less than 0 and areas where the coupling between ES supply and demand was moderate and extreme disorder were regarded as ecosystem damage restoration areas (Table 3).

Table 3. Evaluation index system for potential ecological restoration areas.

Evaluation Indicators	Evaluation Status	Judgment Criteria
Ecosystem service supply and demand	Status	The supply capacity of ecosystem services is less than the demand intensity, i.e., the ecosystem service balance is less than 0
	Variations	Significant decrease
The coupling coordination degree between ecosystem service supply and demand	Status	Moderate and extreme disorder areas

2.7. Determining Ecological Restoration Priority Areas

In this study, an evaluation system for ecological restoration priority areas was first constructed from three dimensions of feasibility–urgency–importance in the NSLP, which contained eight indicator layers (Table 4). Among them, feasibility mainly refers to the current favorable conditions for ecological restoration work, which mainly includes three anthropogenic factors of population density, distance to road, and GDP density, as well as two topographic factors of elevation and slope. Generally, areas with dense human habitation have higher levels of economic development and convenient transportation, which can provide sufficient financial support for ecological restoration work. Areas with lower elevations and higher slopes are more conducive to implementing ecological restoration projects. Therefore, population density and GDP density are positive directions for feasibility, while distance to road, elevation, and slope are negative directions for feasibility.

Table 4. Assessment framework system for ecological restoration priority areas in the NSLP.

Target Layer	Dimension Layer	Indicator Layer	Action Direction
Priority area identification	Feasibility	Population density	Positive
		Distance to road	Negative
		GDP density	Positive
		Elevation	Negative
		Slope	Negative
	Urgency	Ecosystem service balance	Negative
		The change trend of ecosystem service balance	Negative
	Importance	Ecosystem service supply	Positive

Urgency refers to the severity of the current ecological problems, including ES balance and its change trend. In general, the deficit and imbalance of ES supply and demand indicate more severe ecological issues, which require prioritizing ecological restoration efforts. The regions where the supply and demand of ecosystem services are in deficit and significantly decreasing indicate that the more serious ecological problems are, the more priority should be given to ecological restoration. Therefore, ecosystem service balance and the change trend of ecosystem service balance are negative directions for urgency. From the perspective of ecosystem service enhancement, the importance is expressed in terms of ES supply capacity. In general, areas with larger ecosystem service supply capacity need to give more priority to ecological restoration. Therefore, ecosystem service supply is a positive direction for importance.

This study established four service scenarios for provisioning services, regulating services, cultural services, and total ecosystem services to optimize and enhance them After optimization indicators were constructed, and the entropy weight method was utilized to determine the weights of the indicator layer and dimension layer.

According to the results of index construction and weight calculation, the improved Ant Colony Optimization (ACO) model was adopted to identify the ecological restoration priority areas. The ACO model was first proposed by Dorigo in the 1990s and has been proven to be an intelligent algorithm for solving multi-objective optimization strategies such as shortest path, land use allocation, and ecological protection zoning [39]. The method incorporates land use suitability and compactness to find the optimal spatial allocation of land use based on an objective function. In this study, the objective function was defined and the spatial optimization for ecological restoration was carried out based on the ACO surface optimization tool in the Geographic Simulation and Optimization System (http://www.geosimulation.cn, accessed on 26 January 2025). The data parameters of the ant colony algorithm mainly include the number of ant colonies, the number of iterations, the number of iterations inspired weight α, the information weight β, and the information evaporation coefficient ρ. The technical flow chart of the study is depicted in Figure 3.

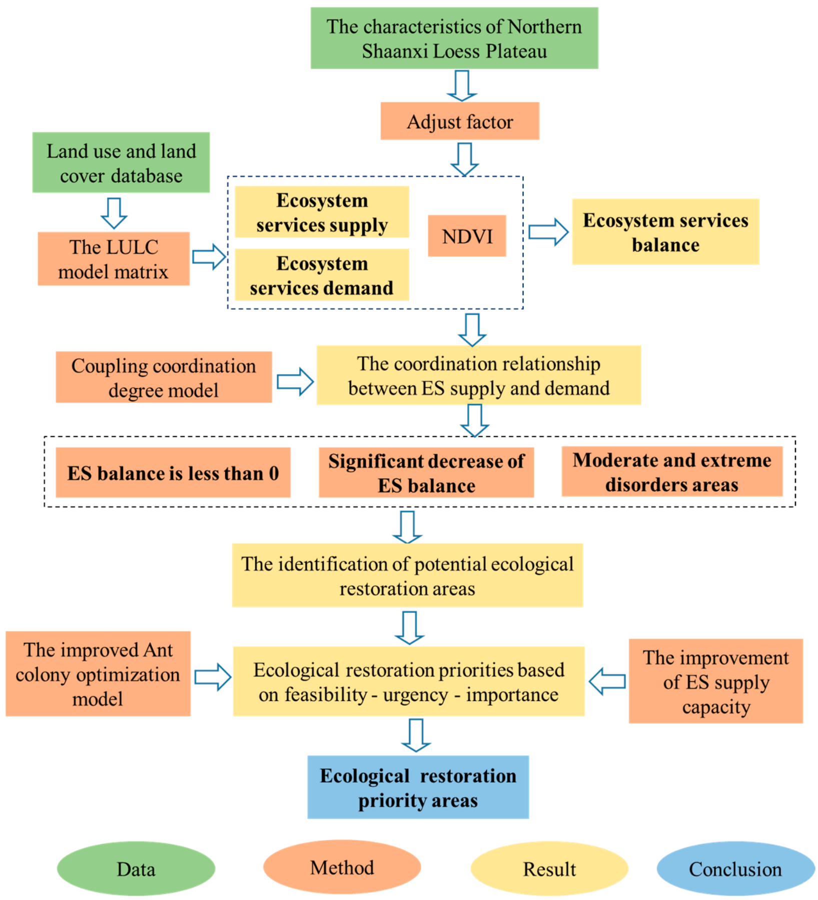

Figure 3. The proposed framework of this study (LULC: land use/land cover, ES: ecosystem service, and NDVI: Normalized Difference Vegetation Index).

3. Results

3.1. Spatial Patterns of Ecosystem Service Supply and Demand in the NSLP

By using the NDVI to correct ES supply, the distributions of ecosystem service supply capacity, demand intensity, and balance from 2000 to 2020 were quantified and mapped (Figure 4). Taking 2020 as an example, there are notable spatial variations in ES supply, demand, and balance in the NSLP. In terms of ES supply capacity, the spatial pattern of provisioning services, regulating services, cultural services, and total ES was consistent, with a roughly southeastern to northwestern increasing trend. Areas with high ES supply capacity were primarily located in the southern part of the region, including Ganquan, Fuxian, Huangling, and Huanglong. Contrarily, areas with low ES supply capacity were predominantly found in the northern part, particularly in the northwestern areas of Wuqi, Dingbian, Jingbian, Yuyang, and Shenmu. In terms of ES demand intensity, the spatial pattern of each ecosystem service generally showed consistency, with high demand intensity areas primarily located in the central and north parts, such as the urban distribution areas of Yuyang, Shenmu, and Baota with more densely populated areas. Conversely, low demand intensity was primarily scattered in the southern regions, such as Huangling, Luochuan, Huanglong, and Fu county. Regarding ES balance, all four types of ES balance exhibited a rising trend from north to south with the deficit areas concentrated in the northern region and surplus areas mainly scattered in the southern part. In addition, we carried out the analyses of the global Moran index to verify the spatial heterogeneity of ecosystem services. In this research, the z-scores of ecosystem service exceeded 1.65 (ES supply capacity, Z = 165.40; ES demand intensity, Z = 140.35; and ES balance, Z = 180.16), indicating that ecosystem service had significant spatial variation.

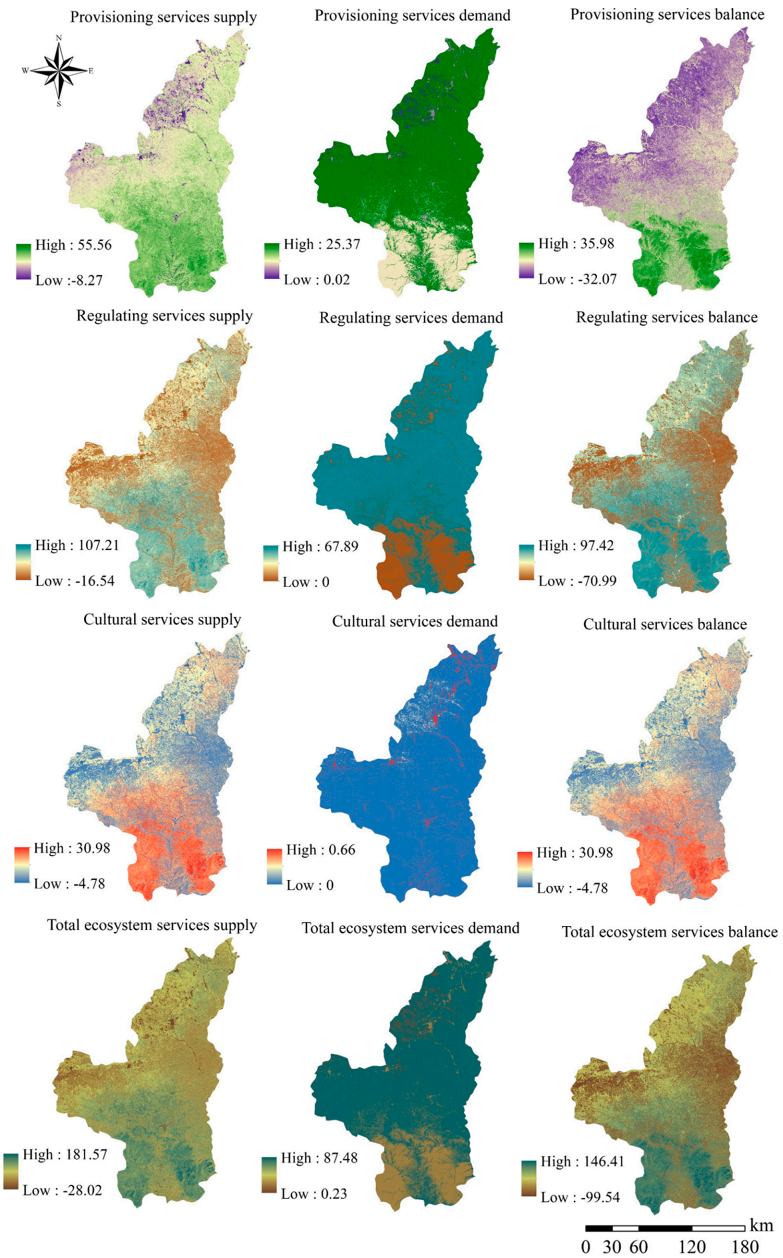

Figure 4. Spatial characteristics of provisioning services, regulating services, cultural services, and total ecosystem service supply, demand, and balance in the NSLP in 2020 ($\times 10^6$ m^2).

3.2. Temporal Changes in Ecosystem Service Supply and Demand in the NSLP

The temporal changes in various ecosystem services from 2000 to 2020 are illustrated in Figure 5. For ES supply capacity, provisioning services, regulating services, cultural services, and total ecosystem services all exhibited a decreasing trend from 2000 to 2020. For ES demand intensity, provisioning services showed a declining trend from 2000 to 2020. Regulating services decreased slowly from 2000 to 2010, but then exhibited an upward trend from 2010 to 2020, exceeding the demand intensity value in 2000. Cultural services increased slightly from 2000 to 2010 but decreased significantly from 2010 to 2020. Total ecosystem services showed an obvious downward trend from 2000 to 2010 and rose again from 2010 to 2020, but it did not exceed the demand intensity value in 2000. For ES balance, provisioning services declined slowly from 2000 to 2010 but slowly increased again from 2010 to 2020. Regulating services did not change significantly from 2000 to 2010 but decreased from 2010 to 2020. Cultural services remained unchanged from 2000 to 2010 and decreased by 4.48% from 2010 to 2020. Total ecosystem services remained basically unchanged from 2000 to 2010 and decreased slightly from 2010 to 2020.

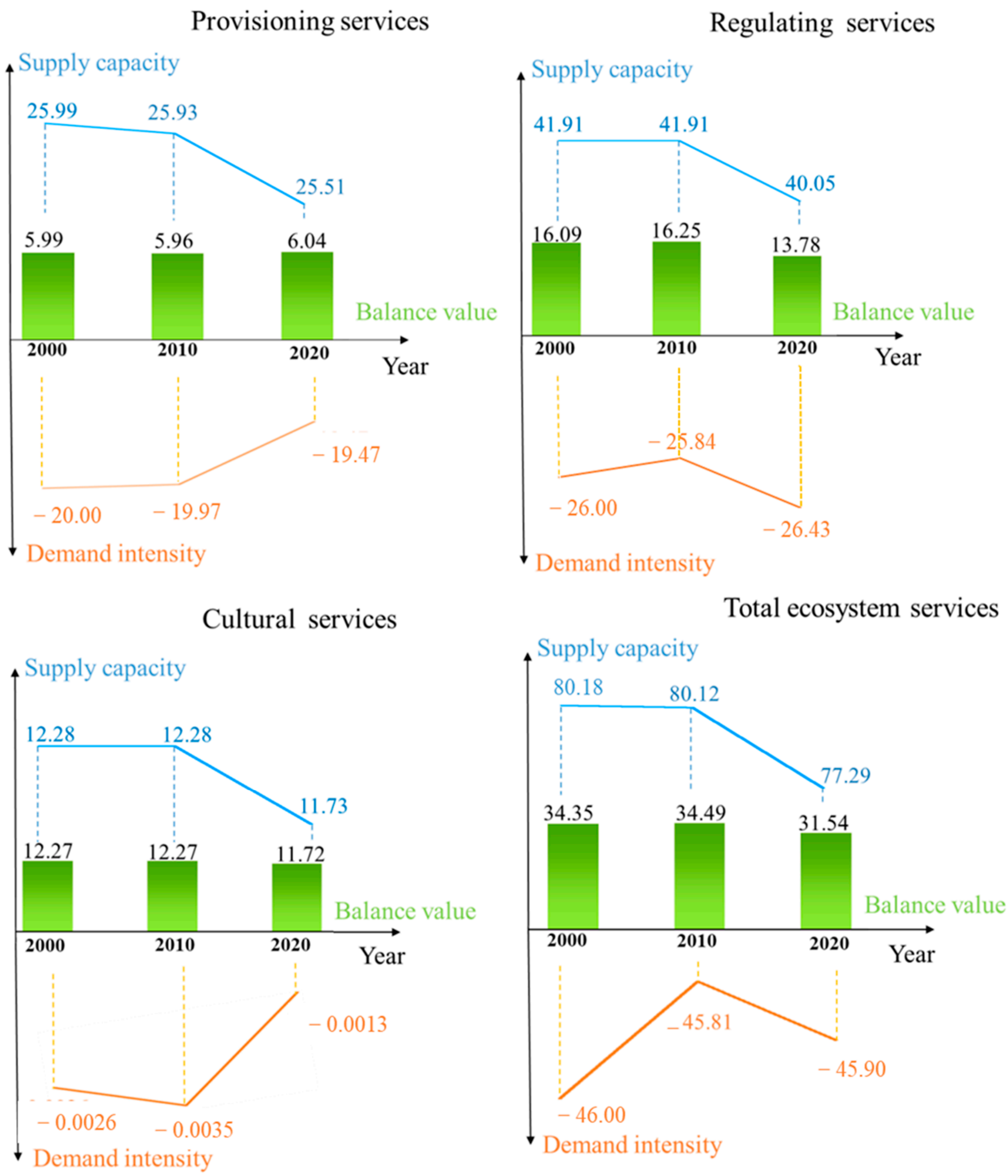

Figure 5. Temporal changes in provisioning services, regulating services, cultural services, and total ecosystem service supply, demand, and balance from 2000 to 2020.

Based on the linear regression analysis method, the spatial change trend of various ecosystem service balance in the NSLP from 1990 to 2020 was analyzed, as shown in Figure 6. The results indicated that the spatial distribution of changes in provisioning services, regulating services, and cultural service balance exhibited similar patterns. More than 65% of the regions showed decreasing trends, primarily located in the central and northern areas, whereas about 30% of the regions showed increasing trends, mainly concentrated in the southern regions. The total ecosystem service balance was mainly characterized by significant decreasing and significant increasing regions, accounting for 21.22% and 78%, respectively. Significant increasing regions were distributed in most parts, and significant decreasing regions were scattered in the northern and central parts. In summary, the primary focus for ecological restoration in the later stage was on areas with significant decreases.

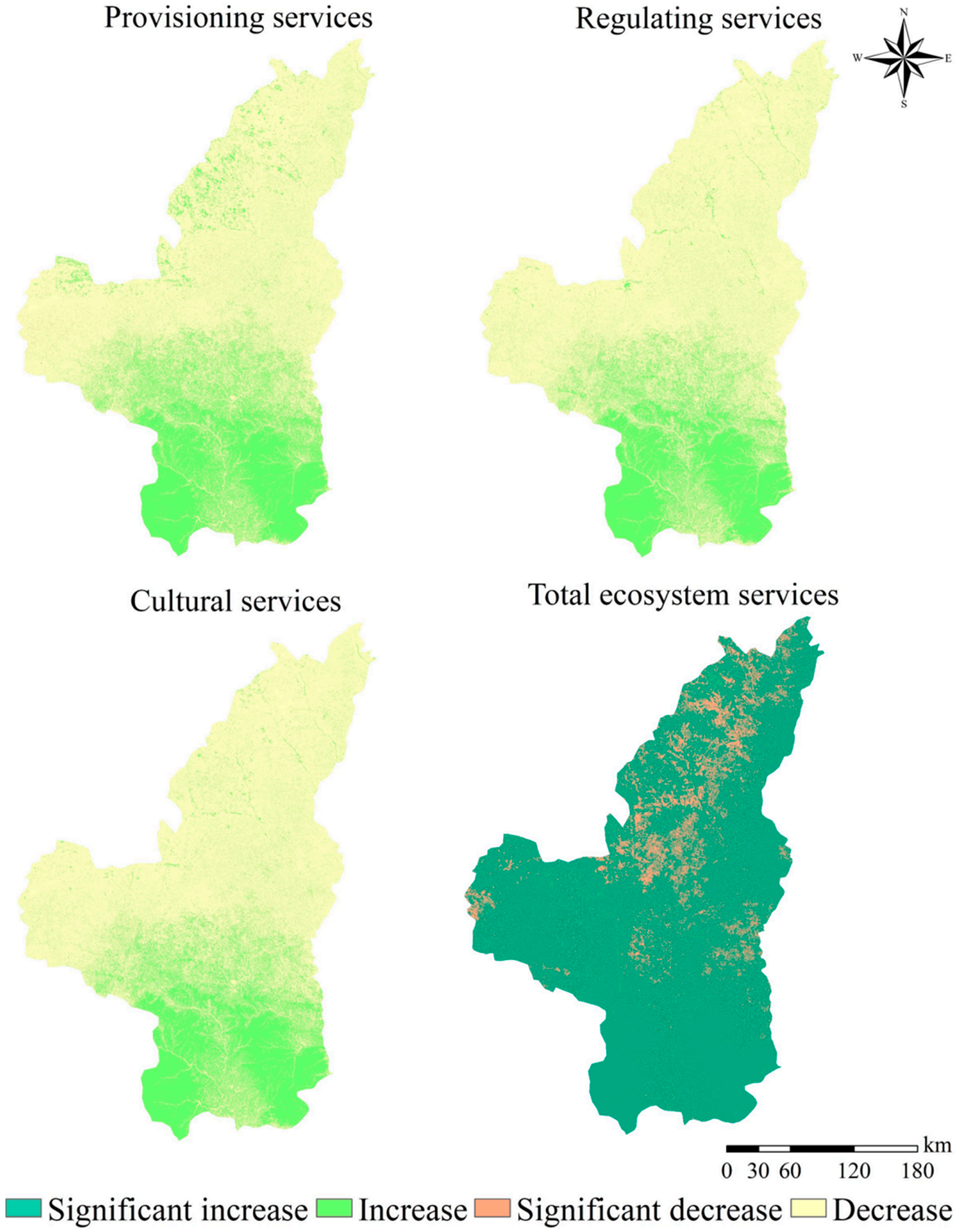

Figure 6. Spatial pattern of the change trend in provisioning services, regulating services, cultural services, and total ecosystem service balance from 2000 to 2020.

3.3. Analysis of Coupling Coordination Degree Between Ecosystem Service Supply and Demand in the NSLP

In order to further explore the coordination relationship between ES supply and demand, the spatial changes of the coupling degree and coordination degree were analyzed in the NSLP. As shown in Figure 7, there were obvious spatial differences in the coupling degree between ES supply and demand. In 2000, the coupling degree in 77.56% of the regions was at an antagonistic stage, mainly located in the central and northern areas. Approximately 22% of the regions were at a low level, mainly distributed in the southern areas. Only 0.15% of the regions were at a running-in stage. In 2010, the coupling degree in most regions was significantly higher than that in 2000. Approximately 37.65% of the regions were at a running-in stage, mainly located in the central and southern areas. Approximately 61.99% of the regions were at a high-level coupling stage, distributed in most of the central and northern regions. By 2020, the coupling relationship was characterized by no correlation, low-level coupling, antagonism, running-in, and high-level coupling, accounting for 0.05%, 0.52%, 2.07%, 21.89%, and 75.47%, respectively. The findings suggested that the coupling relationship in most regions of the NSLP was gradually improving.

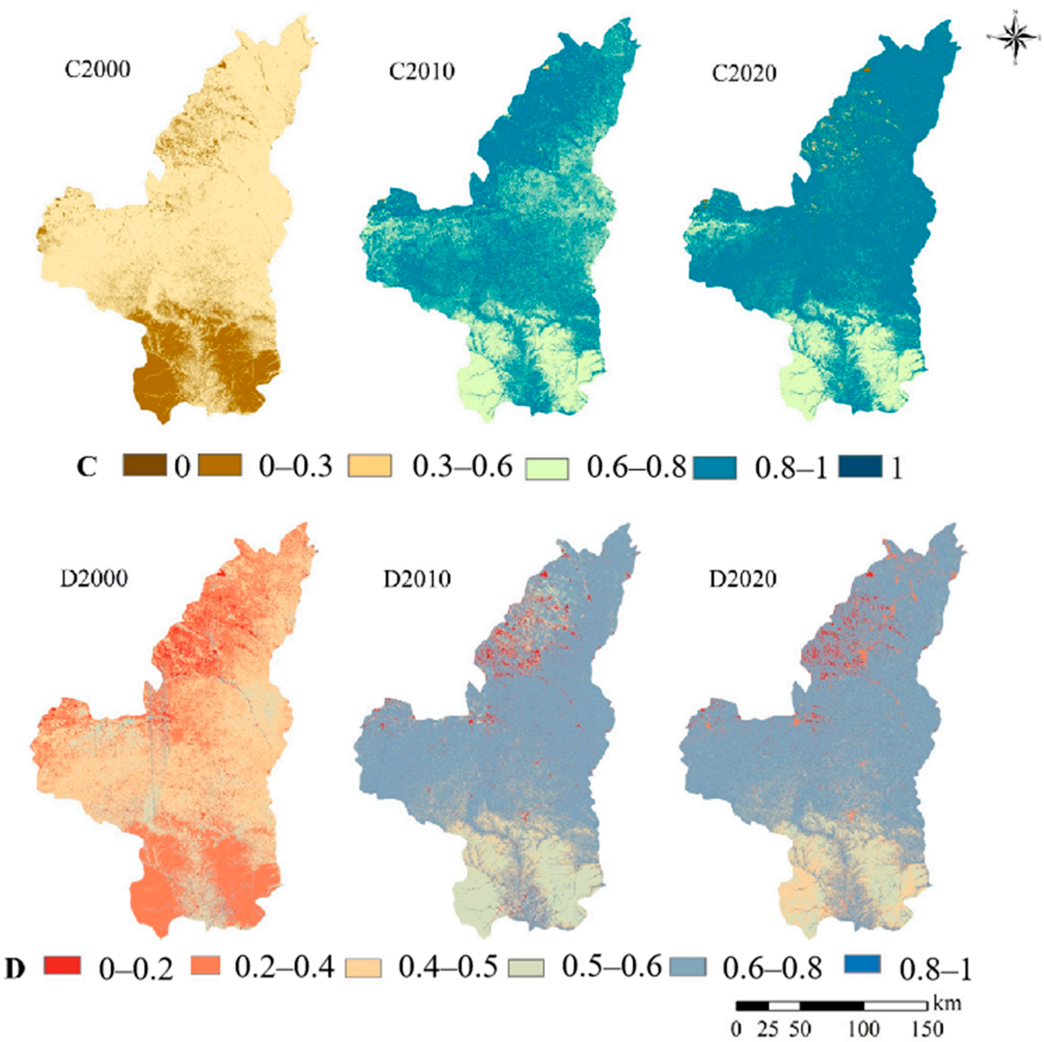

Figure 7. Spatial patterns of the coupling degree and the coupling coordination degree from 2000 to 2020 (C2000, C2010, and C2020 represent the coupling degree in 2000, 2010, and 2020, respectively; D2000, D2010, and D2020 represent the coupling coordination degree in 2000, 2010, and 2020, respectively).

The coupling coordination degree showed a similar change trend with the coupling degree from 2000 to 2020. In 2000, about 82% of the regions had a disorder status in the NSLP. The primary categories of coupling coordination degree consisted of low disorder and moderate disorder, accounting for 41.76% and 36.50%, respectively. The areas of low coordination and moderate coordination accounted for 15.88% and 1.87%, respectively, mainly located in the central and southern parts of the NSLP. In 2010, the coupling coordination degree showed an obvious improvement trend compared with that in 2000. About 90% of the regions had a coordination status in the NSLP. The main types of coupling coordination degree were characterized by moderate coordination, occupying 74.53% of the regions, which was most prevalent in northern and central parts. 15.38% of the regions were at low coordination, primarily concentrated in the southern areas. Moreover, the areas of low disorder, moderate disorder, and extreme disorder accounted for 6.61%, 0.004%, and 3.35%, respectively, mainly distributed in the northern scattered areas. By 2020, the areas of coordination showed a decreasing trend compared with that in 2010, occupying 85% of the regions, while the moderate coordination areas increased by 77.27%. The areas of low disorder, moderate disorder, and extreme disorder accounted for 10.47%, 1.69%, and 2.67%, respectively, mainly located in scattered areas in the north. The contradiction between ES supply and demand in these disorder areas was still very prominent with serious ecological problems, making them crucial for ecological restoration efforts. The findings also implied that the coupling coordination degree in most regions showed an overall improvement trend from 2000 to 2020.

3.4. Identification and Optimization of Ecological Restoration Areas in the NSLP

The potential areas for ecological restoration in the NSLP were mainly identified in the areas of imbalance between ecosystem service supply and demand, a significant decrease in ecosystem service balance, and coupling coordination disorder (Figure 8). The total area of potential restoration areas was identified to be 45,536.4 km^2, accounting for 56.45% of the total study area.

From the perspective of ecosystem service supply capacity enhancement, this study identified ecological restoration priority types for various ecosystem service enhancements based on an ecological restoration evaluation system of feasibility–emergency–importance. Ecological restoration priorities included the top 5%, 5–15%, 15–30%, 30–45%, and 45–100% of the areas (Figure 9). The results showed that ecological restoration prioritization of different ecosystem services enhancement showed significant spatial distribution differences. The spatial patterns of ecological restoration prioritization for various ecosystem services were similar. The top 5% and 15% of ecological restoration areas for various ecosystem services were mainly located in the east-central and west-central regions. The ecological restoration areas of 15–45% were distributed throughout the NSLP, mainly in the central region and parts of the south and north. The ecological restoration areas of 45–100% were distributed in most of the northern and southern parts of the NSLP.

In addition, we counted the ecological benefits of different ecological restoration priorities for each ecosystem service type (Table 5). The top 5%, 15%, 30%, and 45% priority areas of provisioning services can obtain 296,700, 281,900, 282,100, and 284,500 yuan of ecological benefits, accounting for 50.13%, 47.63%, 47.66%, and 48.07% of the total ecological benefits, respectively. The results suggested that the improvement of provisioning services can bring significant ecological benefits by restoring the top 5% of areas. The priority areas of the top 5%, 15%, 30%, and 45% of regulating services restoration can obtain 1,234,200, 1,227,000, 1,310,800, and 1,435,800 yuan of ecological benefits, accounting for 37.20%, 36.99%, 39.51%, and 43.28% of the total ecological benefits, respectively. The results showed that ecological restoration benefits by improving regulating services increased with the expansion of ecological restoration areas, and more areas needed to be restored to obtain ecological benefits. The improvement results of cultural services and total ecosystem services were consistent with those of regulating services. The ecological benefits were cumulative, and the increase in the restoration area would bring more ecological benefits. Based on the above, considering the needs of local ecosystem service improvement, ecological restoration work can be carried out in the future according to the priority of ecological restoration under different types of ecosystem services.

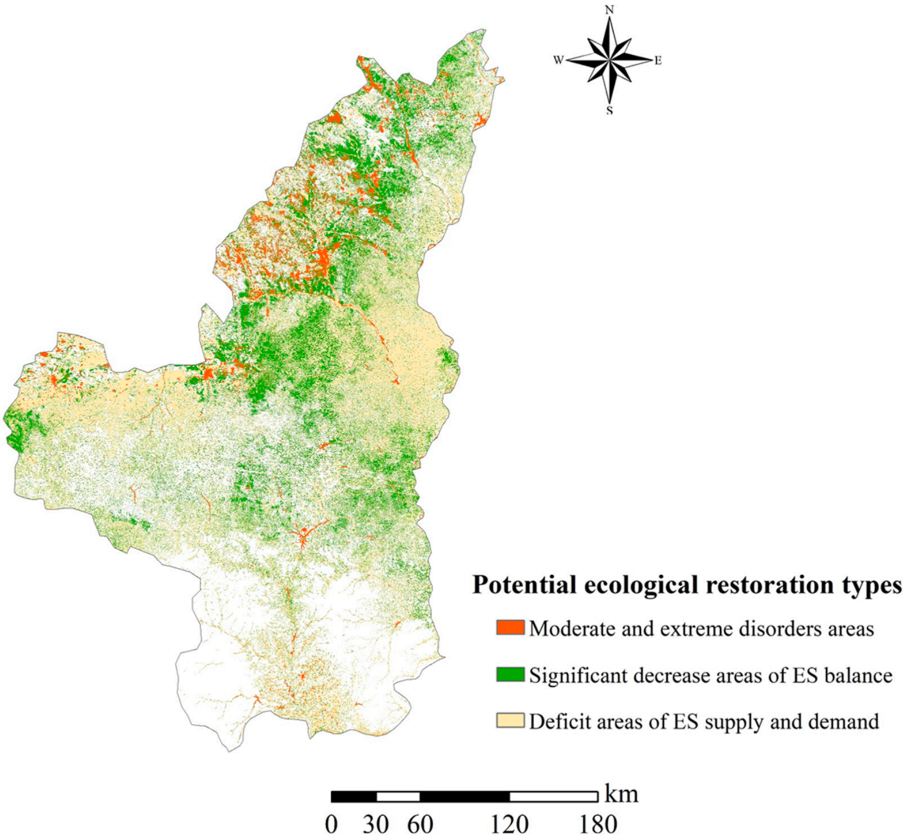

Figure 8. Spatial pattern of potential ecological restoration areas in the NSLP.

Table 5. Restoration areas and benefits of different ecological restoration priorities under provisioning services, regulating services, cultural services, and total ecosystem services.

ES Types	Stage	Area (km^2)	Benefit (yuan)	Proportion of Total Ecological Benefits (%)
Provisioning services	5%	375.5	296,700	50.13%
	15%	1122	281,900	47.63%
	30%	2247.5	282,100	47.66%
	45%	3366.5	284,500	48.07%
Regulating services	5%	375.5	1,234,200	37.20%
	15%	1122	1,227,000	36.99%
	30%	2247.5	1,310,800	39.51%
	45%	3366.5	1,435,800	43.28%
Cultural services	5%	375.5	72,800	32.27%
	15%	1122	73,800	32.71%
	30%	2247.5	81,100	35.95%
	45%	3366.5	90,200	39.98%
Total ecosystem services	5%	375.5	2,470,400	38.01%
	15%	1122	2,412,200	37.11%
	30%	2247.5	2,565,500	39.47%
	45%	3366.5	2,779,100	42.76%

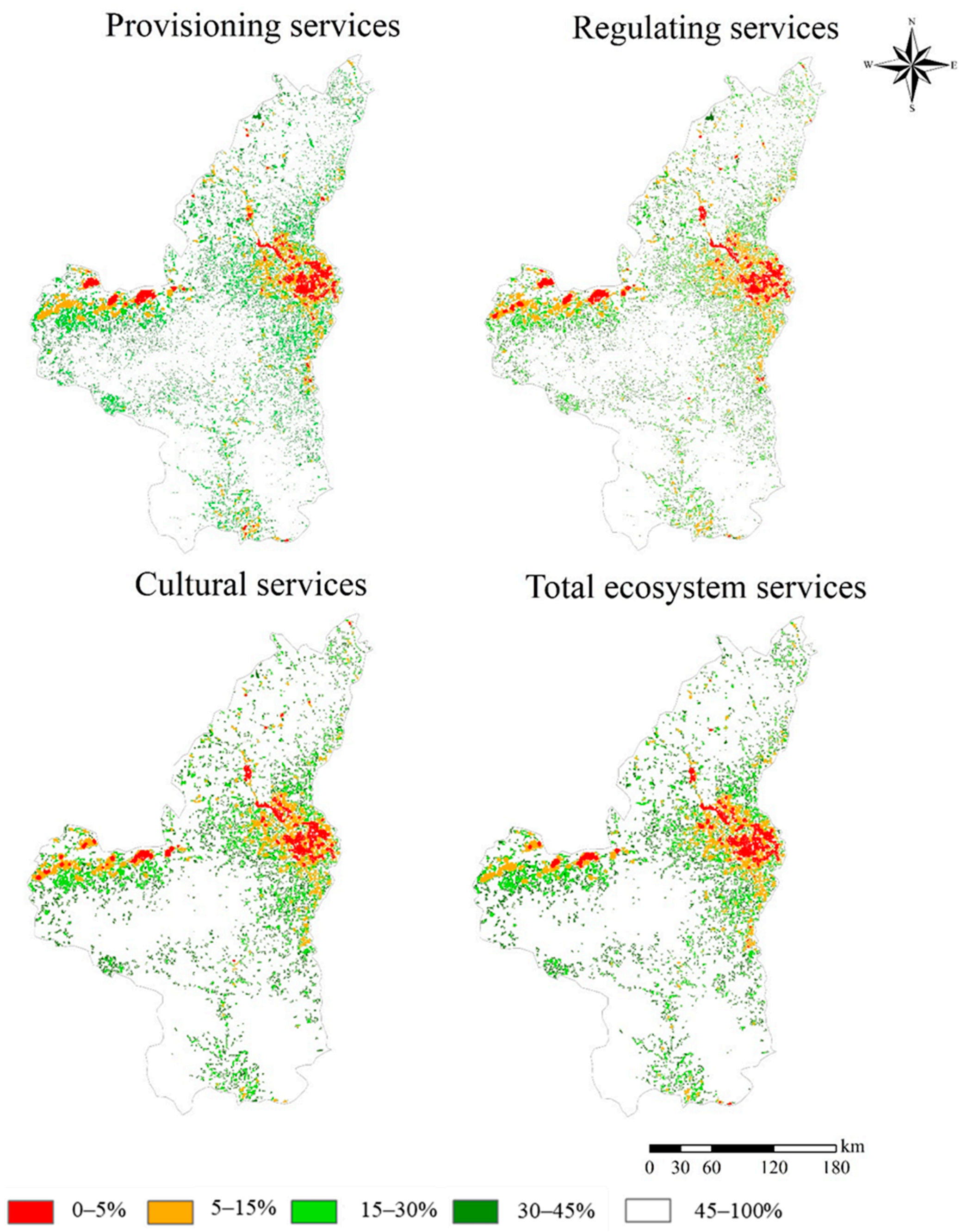

Figure 9. Spatial patterns of ecological restoration priority areas of provisioning services, regulating services, cultural services, and total ecosystem services in the NSLP.

4. Discussion

4.1. Spatio-Temporal Change Analysis of Ecosystem Service Supply and Demand in the NSLP

This study deeply explored the temporal changes and spatial distribution of ES supply capacity and demand intensity. Spatially, there were significant differences in ES supply capacity and demand intensity, with a decrease in ES supply capacity from north to south. Temporally, the overall fluctuation in total ES supply capacity decreased, and total ES demand intensity showed a fluctuating decline. Approximately 21% of the regions showed a degrading trend. Therefore, the regions with significant degradation in the NSLP should be regarded as key areas for ecological restoration aimed at improving ES supply capacity [40]. Natural and human factors are the main driving force of ES evolution [41]. Climate and land use change are the most influential factors for ES supply [42,43]. The precipitation and temperature in the NSLP show a decreasing trend from south to north, consistent with the distribution of ES supply. Moreover, the spatial heterogeneity of ES supply was also attributed to the distribution of land use types, which was consistent with previous research results [28,43]. The change in land use pattern not only changes the structure and function of the ecosystem but also causes a change in the interaction mode between the regional ecosystem and the external environment, thus causing a change in ecosystem services. The southern part of the NSLP was mainly distributed with forests and grasslands characterized by high supply and low demand distribution, while the northern part was mainly distributed with farmland, construction land, and unused land characterized by low supply and high demand distribution [44].

According to the spatial heterogeneity theory of ES demand, different stakeholders have significant differences in their preferences for ES demand. The differences in economic level, educational level, residence location, cognition level, and other factors of the beneficiaries lead to an impact on ES demand [45]. Socio-economic development and population growth are the most direct driving factors [46]. With the increase in population and the improvement of people's living standards, human demand for resources is gradually increasing. It is suggested that the increase in human activity intensity may be the primary reason for the increase in ES demand [47]. In addition, with the increase in the population, the total demand for ES increases, and the existing living space cannot be met. Ecological or semi-ecological land needs to be transformed into residential areas to meet the living space of human beings. In general, the spatio-temporal evolution of ecosystems is the result of a combination of factors. A deep understanding of the driving forces of ecosystem service changes and their relationships is the basic condition for formulating effective policies and measures.

4.2. Coupling Coordination Analysis of Ecosystem Service Supply and Demand in the NSLP

The coupling mechanism of ecosystem service supply and demand involves the coordination relationship between humans and ecosystems. Previous research has primarily focused on the impact of changes in land use on ecosystem services [48], with limited exploration of the coupling coordination relationship between ES supply and demand in the NSLP [44,47]. This study utilized the coupling coordination degree model to analyze the characteristics of the coupling coordination between ES supply and demand. Over time, there was an observed improvement trend in the coupling coordination degree of ES supply and demand from 2000 to 2010, with slight changes from 2010 to 2020. Spatially, the coordination degree had significant spatial heterogeneity [49]. More than 75% of the regions showed high-level coupling, mostly located in the central and northern parts, indicating a relatively high overall coupling degree between ES supply and demand. The results for coupling coordination degree showed that more than 77% of the regions were moderately coordinated, suggesting that the relationship was relatively coordinated in most areas of the NSLP. The central and southern regions of the study area had a higher concentration of coordination areas, while the northern parts were mainly characterized by imbalanced areas. This suggests that ecological restoration strategies should be tailored to the specific regional conditions in ecosystem restoration and management.

The relationship between ES supply and human demand intensity is mutually restricted and influenced. The change of one factor will bring about the change of another factor, and the influence of human activities is an important factor [50]. If human beings regulate their behavior reasonably, human activities and ecosystem services will maintain a good coupling state. On the contrary, deforestation and overgrazing by humans will lead to ecological destruction and deterioration of ecosystem services [51]. However, improving the coordination between human activities and ecosystem services is a gradual process that requires long-term efforts. Decision makers should attach great importance to ecological environment protection and ES supply-demand balance. Sustainable development strategies are necessary to achieve this coordination for mutual benefits.

4.3. Optimization of Ecological Restoration Areas in the NSLP

With the rapid expansion of population and economy in the NSLP, human activities have significantly increased their impact on the ecological environment [25]. The vulnerability and sensitivity of the ecosystem to climate change and human interference have led to widespread attention being given to ecological issues in the NSLP [52,53]. Ecological restoration refers to the conscious renewal and repair of degraded, damaged, or destroyed ecosystems in an attempt to restore degraded ecosystems to their original state, or at least to a lasting "self-sustaining" state that can last [54]. In recent years, ecological restoration has emerged as a crucial aspect of conservation efforts. It offers a proactive approach to environmental protection and the sustainable management of ecosystems by focusing on the rehabilitation of degraded ecosystems and biodiversity [55]. However, ecological restoration needs to address more complex challenges, not only in the face of unprecedented climate change but also in the efforts to restore ecosystems in a landscape increasingly shaped and limited by human activities. Meanwhile, regional ecological restoration initiatives should be tailored to address the varying degrees of ecological issues in different areas. In addition, ecological restoration is a long-term dynamic succession process, which should be dominated by natural restoration and supplemented by artificial restoration [56]. However, the process of natural restoration requires a slow restoration process of several years or even decades, and ecological restoration work is imminent. Therefore, we identified areas in the NSLP with damaged, severely degraded, and dysfunctional ecosystems as priority sites for ecological restoration based on the supply and demand of ecosystem services.

The potential ecological restoration areas identified above were extensive, covering approximately 56% of the total NSLP area. However, considering the constraints of capital, manpower, climate, terrain, and other factors, it is not feasible to restore all of these areas [57]. Therefore, it is important to prioritize the most urgent, feasible, and significant areas for ecological restoration in order to maximize ecological benefits while minimizing costs. This study proposes an assessment system of ecological restoration priority areas based on feasibility, urgency, and importance. From the perspective of enhancing ecosystem service supply capacity, ecological restoration priority areas of the NSLP were identified by using the improved ant colony algorithm optimization model. The findings can serve as theoretical guidance and as a reference for the government to carry out ecological restoration work.

4.4. Limitations and Future Works

In this research, we assessed the supply and demand of ES and identified areas for ecological restoration in the NSLP. This can offer theoretical support for regional ecological protection and restoration. However, there were limitations in this study. Firstly, land use supply and demand models were utilized to quantify ES supply, demand, and balance in the NSLP. This method has been widely used in ecosystem service assessment, but there were still some uncertainties. For example, this method has stronger subjectivity and uncertainty mainly based on the cognitive level of experts, reflecting their knowledge, experience, and attitudes, which may lead to discrepancies in the estimation results [35,58]. Moreover, using only land use data may ignore the effects of other ecological and social factors, such as ecological conditions and population density, resulting in estimation errors [29,59]. Based on the above uncertainties, we computed the sensitivity coefficients (CS) to validate the reasonableness of the method and results. The sensitivity results indicated that the CS values for all land use types were less than 1, suggesting that the research method and assessment results were reasonable and reliable in the NSLP (Table 6). Therefore, in future studies, we should consider the regional situation comprehensively and incorporate all uncertainties to obtain credible ecosystem service assessment results. Despite the many shortcomings mentioned above, the model still has certain advantages for social and environmental management at larger spatial scales as well as technical support for areas with scarce data [60]. It helps to identify areas most in need of protection and restoration, especially those where the capacity to provide ecosystem services is severely reduced.

Table 6. The changes in the sensitivity coefficient for different land use types in the NSLP.

Year \ Land Types	Farmland	Forest	Grassland	Shrubland	Wetland	Water	Settlement	Barren
2000	−0.671	−0.934	−1.124	−0.014	−0.002	−0.003	−0.010	−0.151
2010	−0.425	−0.771	−1.329	−0.018	0	−0.003	−0.013	−0.116
2020	−1.886	−1.235	−1.619	−0.017	0	0	−0.084	−0.301

Adjustment quantity: ±50%.

Secondly, the temporal and spatial changes of ES supply and demand will be affected by external driving factors, which will lead to changes in the structure and process of ecosystem services. However, the driving factors of ES supply, demand, and balance change were not explored in the NSLP. Exploring the influencing factors of ecosystem services can effectively explain the temporal and spatial changes in ES supply and demand. Therefore, a deep understanding of the driving forces of ecosystem service changes and their relationships is the basic condition for formulating effective policies and measures in future studies. Thirdly, we explored the coupling coordination degree between ES supply and demand at a raster scale. Previous research has demonstrated significant scaling effects in the coordination relationship between ES supply and human demand [61,62], such as the comparison of provincial scale, city scale, county scale, and grid scale. However, the coupling coordination in the NSLP was not considered at different scales. This implied that the conversion process from a small scale to a large scale was similar to the peak cutting and valley filling process, in which the high value was cut and the low value was filled, meaning that the coupling coordination degree tended to be stable [61,63]. Therefore, different management strategies at different scales should be adopted in ecosystem management to coordinate the connection between ES supply and human demand.

Finally, many factors were considered to identify ecological restoration priority areas in the NSLP, but some other natural and human factors may also influence the distribution of priority areas, such as natural disasters, tourism, mineral resource exploitation, and ecological engineering construction [64]. Vegetation, soil, and water resources in the restoration area may be damaged by natural disasters like floods, earthquakes, and debris flow, which can impact the effectiveness of restoration efforts [65]. The impact of human activities on ecosystem services is a significant source of uncertainty. Different human activities have varying effects on the function and stability of ecosystem services. Therefore, it is important to comprehensively consider the influencing factors of ecological restoration in future efforts. Furthermore, ecological restoration requires substantial investment in terms of human resources, materials, and finances, making it essential to clarify the objectives and effectively evaluate the benefits of such restoration work.

5. Conclusions

In this study, we first used the LULC matrix approach to quantify the spatio-temporal trends of ecosystem service supply and demand in the NSLP from 2000 to 2020. We observed an increasing trend in the mean ES balance, with lower values mainly found in the northern regions. Moreover, the total ES balance in the northern and central parts exhibited significant decreasing trends. These unbalanced and degraded regions are important areas for ecological restoration. Furthermore, we explored the coordination relationship between ecosystem service supply and demand. Most regions of the NSLP showed improving trends in coupling coordination degrees from 2000 to 2020. Of note, 4.36% of regions showed moderate disorder and extreme disorder, mainly located in the northern scattered areas. These disordered areas would also require ecological restoration efforts. Finally, we identified four ecosystem service enhancement priorities from the perspective of enhancing ecosystem service supply capacity. The spatial distribution of ecological restoration priority areas varied significantly across different types of ecosystem services. The top 15% of ecological restoration priority areas can bring significant ecological benefits. These findings are crucial for studying changes in ecosystem services and providing effective guidance for future ecological restoration efforts.

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References

1. Fu, B.; Liu, Y.; Meadows, M.E. Ecological restoration for sustainable development in China. *Natl. Sci. Rev.* **2023**, *10*, nwad033. [CrossRef] [PubMed]
2. Yang, Q.; Liu, G.; Casazza, M.; Dumontet, S.; Yang, Z. Ecosystem restoration programs challenges under climate and land use change. *Sci. Total Environ.* **2022**, *807*, 150527. [CrossRef] [PubMed]
3. Yang, Z.; Xu, X.; Li, J.; Liang, C. Progress and prospects of research on ecosystem service flow. *J. Ecol. Rural Environ.* **2023**, *39*, 827–838.
4. Wang, J.; Zhou, W. Ecosystem service flows: Recent progress and future perspectives. *Acta Ecol. Sin.* **2019**, *39*, 4213–4222.
5. Li, Z.; Li, S.; Cao, Y.; Wang, S.; Liu, S.; Zhang, Z. Supply and demand of ecosystem services:Basic connotation and practical application. *J. Agric. Resour. Environ.* **2022**, *39*, 456–466.
6. Boesing, A.L.; Prist, P.R.; Barreto, J.; Hohlenwerger, C.; Maron, M.; Rhodes, J.R.; Romanini, E.; Tambosi, L.R.; Vidal, M.; Metzger, J.P. Ecosystem services at risk: Integrating spatiotemporal dynamics of supply and demand to promote long-term provision. *One Earth* **2020**, *3*, 704–713. [CrossRef]
7. Li, J.H. Identification of ecosystem services supply and demand and driving factors in Taihu Lake Basin. *Environ. Sci. Pollut. Res.* **2022**, *2*, 17263. [CrossRef]
8. Huang, M.; Xiao, Y.; Xu, J.; Liu, J.; Wang, Y.; Gan, S.; Lv, S.; Xie, G. A review on the supply-demand relationship and spatial flows of ecosystem services. *J. Resour. Ecol.* **2022**, *13*, 925–935.
9. Rey Benayas, J.M.; Newton, A.C.; Diaz, A.; Bullock, J.M. Enhancement of biodiversity and ecosystem services by ecological restoration: A meta-analysis. *Science* **2009**, *325*, 1121–1124. [CrossRef] [PubMed]
10. Liu, S.; Dong, Y.; Wang, F.; Liu, H.; Yu, L. Cost-benefit research and potential solutions of ecological restoration programs in China. *Trans. Earth Environ. Sustain.* **2023**, *1*, 68–79. [CrossRef]

11. Liu, S.; Dong, Y.; Wang, F.; Liu, H.; Zhao, Y. Application of ecosystem service valuation in ecological restoration. *Chin. J. Eco-Agric.* **2023**, *31*, 1343–1354.
12. Verutes, G.M.; Arkema, K.K.; Clarke-Samuels, C.; Wood, S.A.; Rosenthal, A.; Rosado, S.; Canto, M.; Bood, N.; Ruckelshaus, M. Integrated planning that safeguards ecosystems and balances multiple objectives in coastal Belize. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* **2017**, *13*, 1–17. [CrossRef]
13. Carlucci, M.B.; Brancalion, P.H.S.; Rodrigues, R.R.; Loyola, R.; Cianciaruso, M.V. Functional traits and ecosystem services in ecological restoration. *Restor. Ecol.* **2020**, *28*, 1372–1383. [CrossRef]
14. Li, Z.; Ma, L.; Chen, X.; Wang, X.; Bai, J. Zoning and management of ecological restoration from the perspective of ecosystem service supply and demand: A case study of Yuzhong County in Longzhong Loess Hilly Region, China. *Land* **2023**, *12*, 992. [CrossRef]
15. Feng, S.; Liu, X.; Zhao, W.; Yao, Y.; Zhou, A.; Liu, X.; Pereira, P. Key areas of ecological restoration in Inner Mongolia based on ecosystem vulnerability and ecosystem service. *Remote Sens.* **2022**, *14*, 2729. [CrossRef]
16. Liu, T.; Yu, L.; Chen, X.; Wu, H.; Lin, H.; Li, C.; Hou, J. Environmental laws and ecological restoration projects enhancing ecosystem services in China: A meta-analysis. *J. Environ. Manag.* **2023**, *327*, 116810. [CrossRef] [PubMed]
17. Liu, Y.; Liu, S.; Wang, F.; Liu, H.; Li, M.; Sun, Y.; Wang, Q.; Yu, L. Identification of key priority areas under different ecological restoration scenarios on the Qinghai-Tibet Plateau. *J. Environ. Manag.* **2022**, *323*, 106–112. [CrossRef] [PubMed]
18. Barton, D.N.; Sundt, H.; Bustos, A.A.; Fjeldstad, H.-P.; Hedger, R.; Forseth, T.; Kohler, B.; Aas, O.; Alfredsen, K.; Madsen, A.L. Multi-criteria decision analysis in Bayesian networks—Diagnosing ecosystem service trade-offs in a hydropower regulated river. *Environ. Model. Softw.* **2020**, *124*, 104604. [CrossRef]
19. Demir, S.; Demirel, O.; Okatan, A. An ecological restoration assessment integrating multi-criteria decision analysis with landscape sensitivity analysis for a hydroelectric power plant project: The Tokat-Niksar case. *Environ. Monit. Assess.* **2021**, *193*, 818. [CrossRef]
20. Zhang, W.; Xu, D. Benefits evaluation of ecological restoration projects based on value realization of ecological products. *J. Environ. Manag.* **2024**, *352*, 120139. [CrossRef]
21. Watrobski, J.; Jankowski, J.; Ziemba, P.; Karczmarczyk, A.; Ziolo, M. Generalised framework for multi-criteria method selection. *Omega-Int. J. Manag. Sci.* **2019**, *86*, 107–124. [CrossRef]
22. Paletto, A.; Pieratti, E.; De Meo, I.; Agnelli, A.E.; Cantiani, P.; Chiavetta, U.; Mazza, G.; Lagomarsino, A. A multi-criteria analysis of forest restoration strategies to improve the ecosystem services supply: An application in Central Italy. *Ann. For. Sci.* **2021**, *78*, 7. [CrossRef]
23. Guo, K.; Zhang, X.C.; Liu, J.M.; Wu, Z.; Chen, M.; Zhang, K.; Chen, Y. Establishment of an integrated decision-making method for planning the ecological restoration of terrestrial ecosystems. *Sci. Total Environ.* **2020**, *741*, 139852. [CrossRef] [PubMed]
24. Liu, X.; Huang, M.; Lei, W. Spatiotemporal evolution of land use in ecologically fragile areas of the Loess Plateau of northern Shaanxi province. *J. China Agric. Resour. Reg. Plan.* **2023**, *44*, 47–57.
25. Zhang, J.; Chen, H.; Ma, Y.; Liu, D.; Liang, X.; Chen, W. Identification of priority areas for ecological restoration based on ecological security and landscape elements. *Environ. Sci. Pollut. Res.* **2023**, *30*, 35307–35325. [CrossRef] [PubMed]
26. Xiao, Y.; Huang, M.; Xie, G.; Zhen, L. Evaluating the impacts of land use change on ecosystem service values under multiple scenarios in the Hunshandake region of China. *Sci. Total Environ.* **2022**, *850*, 158067. [CrossRef] [PubMed]
27. Wen, X.; Wang, J.; Han, X.; Ma, L. Where are the trade-offs in multiple ecosystem services in the process of ecological restoration? a case study on the vegetation restoration area in the Loess Plateau, Northern Shaanxi. *Land* **2024**, *13*, 70. [CrossRef]
28. Shi, W.; Zhao, W.; Yan, T.; Liu, X.; Xu, D. Land use structure of typical county with conversion of farmland to forests in loess areas of Northern Shaanxi. In Proceedings of the International Workshop on Green Energy, Environment and Sustainable Development (G2ESD), Weihai, China, 28–30 August 2020.
29. Sun, Y.; Liu, S.; Shi, F.; An, Y.; Li, M.; Liu, Y. Spatio-temporal variations and coupling of human activity intensity and ecosystem services based on the four-quadrant model on the Qinghai-Tibet Plateau. *Sci. Total Environ.* **2020**, *743*, 140721.
30. Sun, Y.X.; Liu, S.L.; Dong, Y.H.; Dong, S.K.; Shi, F.N. Effects of multi-time scales drought on vegetation dynamics in Qaidam River Basin, Qinghai-Tibet Plateau from 1998 to 2015. *Theor. Appl. Climatol.* **2020**, *141*, 117–131. [CrossRef]
31. Sun, Y.X.; Liu, S.L.; Liu, Y.X.; Dong, Y.H.; Li, M.Q.; An, Y.; Shi, F.N.; Beazley, R. Effects of the interaction among climate, terrain and human activities on biodiversity on the Qinghai-Tibet Plateau. *Sci. Total Environ.* **2021**, *794*, 148497. [CrossRef] [PubMed]
32. Sun, Y.; Liu, S.; Liu, C.; Sun, J.; Liu, Y.; Wang, F. Interactive response and spatial heterogeneity of alpine grassland biodiversity to soil, topography, climate, and human factors on the Qinghai-Tibet Plateau. *Land Degrad. Dev.* **2023**, *34*, 4488–4502. [CrossRef]
33. Jiang, W.; Wu, T.; Fu, B. The value of ecosystem services in China: A systematic review for twenty years. *Ecosyst. Serv.* **2021**, *52*, 101365. [CrossRef]
34. Burkhard, B.; Kroll, F.; Nedkov, S.; Muller, F. Mapping ecosystem service supply, demand and budgets. *Ecol. Indic.* **2012**, *21*, 17–29. [CrossRef]

35. Burkhard, B.; Müller, A.; Müller, F.; Grescho, V.; Anh, Q.; Arida, G.; Bustamante, J.V.; Van Chien, H.; Heong, K.L.; Escalada, M.; et al. Land cover-based ecosystem service assessment of irrigated rice cropping systems in southeast Asia—An explorative study. *Ecosyst. Serv.* **2015**, *14*, 76–87. [CrossRef]
36. Liu, Y.; Li, R.; Song, X. Analysis of coupling degrees of urbanization and ecological environment in China. *J. Nat. Resour.* **2005**, *20*, 105–112.
37. Yang, Z.; Zhan, J.; Wang, C.; Twumasi-Ankrah, M.J. Coupling coordination analysis and spatiotemporal heterogeneity between sustainable development and ecosystem services in Shanxi Province, China. *Sci. Total Environ.* **2022**, *836*, 155625. [CrossRef] [PubMed]
38. Qi, Y.; Farnoosh, A.; Lin, L.; Liu, H. Coupling coordination analysis of China's provincial water-energy-food nexus. *Environ. Sci. Pollut. Res.* **2022**, *29*, 23303–23313. [CrossRef] [PubMed]
39. Ai, B.; Ma, S.; Wang, S. Land-use zoning in fast developing coastal area with ACO model for scenario decision-making. *Geo-Spat. Inf. Sci.* **2015**, *18*, 43–55. [CrossRef]
40. Posner, S.; Getz, C.; Ricketts, T. Evaluating the impact of ecosystem service assessments on decision-makers. *Environ. Sci. Policy* **2016**, *64*, 30–37. [CrossRef]
41. Chen, Y.; Qiao, X.; Yang, Y.; Zheng, J.; Dai, Y.; Zhang, J. Identifying the spatial relationships and drivers of ecosystem service supply-demand-demand matching: A case of Yiluo River Basin. *Ecol. Indic.* **2024**, *163*, 112122. [CrossRef]
42. Wang, X.; Yao, W.; Feng, X.; Jia, Z.; Zhang, X.; Ma, J.; Zhou, J.; Tu, Y.; Sun, Z. Changes and driving factors of ecosystem services supply and demand on the Tibetan plateau. *Acta Ecol. Sin.* **2023**, *43*, 6968–6982.
43. Zhou, X.; Zhou, Y. Spatio-temporal variation and driving forces of land-use change from 1980 to 2020 in Loess Plateau of Northern Shaanxi, China. *Land* **2021**, *10*, 982. [CrossRef]
44. Chen, H.; Gong, J. Supply and demand pattern of ecosystem services and its change in the Loess Plateau of Northern Shaanxi Province. *Res. Soil Water Conserv.* **2021**, *28*, 226–232.
45. Yang, M.; Zhao, X.; Wu, P.; Hu, P.; Gao, X. Quantification and spatially explicit driving forces of the incoordination between ecosystem service supply and social demand at a regional scale. *Ecol. Indic.* **2022**, *137*, 108764. [CrossRef]
46. 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]
47. Wang, D.; Liang, Y.; Peng, S.; Yin, Z.; Huang, J. Integrated assessment of the supply-demand relationship of ecosystem services in the Loess Plateau during 1992–2015. *Ecosyst. Health Sustain.* **2022**, *8*, 2130093. [CrossRef]
48. Jing, L.; Zhiyuan, R. Variations in ecosystem service value in response to land use changes in the Loess Plateau in Northern Shaanxi Province, China. *Int. J. Environ. Res.* **2011**, *5*, 109–118.
49. Manning, P.; Cutler, G.C. Ecosystem functioning is more strongly impaired by reducing dung beetle abundance than by reducing species richness. *Agric. Ecosyst. Environ.* **2018**, *264*, 9–14. [CrossRef]
50. Feng, Y.X.; Li, G.D. Interaction between urbanization and eco-environment in the Tibetan Plateau. *J. Geogr. Sci.* **2021**, *31*, 298–324. [CrossRef]
51. Bryan, B.A.; Ye, Y.; Connor, J.D. Land-use change impacts on ecosystem services value: Incorporating the scarcity effects of supply and demand dynamics. *Ecosyst. Serv.* **2018**, *32*, 144–157. [CrossRef]
52. Chang, S.; Dai, Z.; Wang, X.; Zhu, Z.; Feng, Y. Landscape pattern identification and ecological risk assessment employing land use dynamics on the Loess Plateau. *Agronomy* **2023**, *13*, 2247. [CrossRef]
53. Zhao, F.; Wang, N.; Liu Je Zhou, Z. Effects of vegetation type and topography on vegetation restoration after pipeline construction in the Northern Shaanxi Loess Plateau, China. *Ecol. Res.* **2023**, *38*, 177–187. [CrossRef]
54. Sun, J.; Yang, Y.S.; Cheng, X.G.; Jing, M. Discussion on ecological restoration. In Proceedings of the 3rd International Yellow River Forum, Dongying, China, 16–19 October 2007.
55. Lang, S.; Hu, S.; Li, M.; Qian, H.; Pu, Y.; Zhang, S.; Li, T.; Jia, Y. Ecological restoration measures improved carbon sequestration of desertification grassland ecosystem in Alpine Area. *Environ. Sci. Technol.* **2021**, *44*, 149–157.
56. Feng, L.; Guo, M.; Wang, W.; Shi, Q.; Guo, W.; Lou, Y.; Zhu, Y.; Yang, H.; Xu, Y. Evaluation of the effects of long-term natural and artificial restoration on vegetation characteristics, soil properties and their coupling coordinations. *Sci. Total Environ.* **2023**, *884*, 163828. [CrossRef] [PubMed]
57. Zhang, Z.; Li, T.; Li, L.; Li, S.; Rong, Y.; Bao, R.; Fu, X.; Tang, M.; Wu, G. Integrating ecosystem service importance and ecological sensitivity to identify priority areas for ecological conservation and restoration in Miyun Reservoir Basin. *Int. J. Sustain. Dev. World Ecol.* **2023**, *30*, 925–937. [CrossRef]
58. Sun, Y.; Liu, S.; Dong, Y.; An, Y.; Shi, F.; Dong, S.; Liu, G. Spatio-temporal evolution scenarios and the coupling analysis of ecosystem services with land use change in China. *Sci. Total Environ.* **2019**, *681*, 211–225. [CrossRef]
59. Tao, Y.; Wang, H.N.; Ou, W.X.; Guo, J. A land-cover-based approach to assessing ecosystem services supply and demand dynamics in the rapidly urbanizing Yangtze River Delta region. *Land Use Policy* **2018**, *72*, 250–258. [CrossRef]

60. Schroeter, M.; Stumpf, K.H.; Loos, J.; van Oudenhoven, A.P.E.; Boehnke-Henrichs, A.; Abson, D.J. Refocusing ecosystem services towards sustainability. *Ecosyst. Serv.* **2017**, *25*, 35–43. [CrossRef]
61. Yang, M.H.; Gao, X.D.; Zhao, X.N.; Wu, P.T. Scale effect and spatially explicit drivers of interactions between ecosystem services-a case study from the Loess Plateau. *Sci. Total Environ.* **2021**, *785*, 147389. [CrossRef]
62. Cui, F.Q.; Tang, H.P.; Zhang, Q.; Wang, B.; Dai, L. Integrating ecosystem services supply and demand into optimized management at different scales: A case study in Hulunbuir, China. *Ecosyst. Serv.* **2019**, *39*, 100984. [CrossRef]
63. Xu, S.N.; Liu, Y.F.; Wang, X.; Zhang, G.X. Scale effect on spatial patterns of ecosystem services and associations among them in semi-arid area: A case study in Ningxia Hui Autonomous Region, China. *Sci. Total Environ.* **2017**, *598*, 297–306. [CrossRef]
64. Dang, H.; Lu, Y.; Guo, J.; Wu, X. Identifying priority conservation areas in regional ecological networks using attack scenario simulation. *Glob. Ecol. Conserv.* **2023**, *46*, e02602. [CrossRef]
65. Huang, H.; Yang, S.; Tian, Y.; Xie, Z. The debris flow disaster land use and ecological restoration measures inWenchuan earthquake hard-hit disaster areas: A case study in the small watershed of Duba River. *J. Nat. Resour.* **2020**, *35*, 106–118.