Article

Change in Landscape Multifunctionality and Its Trade-off–Synergy Relationship in Mined Land

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Abstract: Mining often generates large amounts of inefficiently used land. Clarifying the multifunctional characteristics of mined land and its spatial and temporal evolution is important to environmental protection and promoting the economic and social benefits of mined areas. This article analyzed the conditions of mined land in Jiawang, Jiangsu province, China. The InVEST model was used to assess landscape functions, including those related to water and soil conservation, productivity, habitats, carrying capacity, recreation, and carbon sequestration, to explore the multifunctional changes and trade-off–synergy relationships of the landscape from 2005 to 2020. The results show that (1) ecological restoration of the mined land significantly improved the regional landscape multifunctionality during the study period, with each function enhanced more obviously after restoration was completed in 2012, and (2) the trade-offs and synergistic relationships for landscape multifunctionality varied during the study period because the time series evolved; some trade-offs gradually transformed into synergistic relationships. This study establishes a set of effective systems useful in evaluating the multifunctionality of mined land, and initially evaluated the trade-off–synergistic relationships among eight landscape functions. This will provide ideas supporting the management and restoration of mined land and help in the formulation of spatial planning strategies for ecological restoration.

Keywords: mined land; ecological restoration; InVEST model; landscape multifunctionality

1. Introduction

Mined land includes all areas affected by mining activities. Mines often result in damage to the landscape and its functional structure so that most of the area of mined land cannot be maximized functionally again without ecological restoration [1,2]. The radiating nature of disturbance caused by mining activity means that mine disturbance involves both urbanized land and land designated for future construction as well as non-urbanized land such as agricultural land. In terms of use status, mine land includes both idle and abandoned mined land as well as mined land where mining is actively occurring. In terms of land scale, mine land can be either areas affected by large mining operations and/or areas covering thousands of hectares where underground mines have collapsed or it can be smaller areas of industrial land with offices or areas for daily living including residential areas [3]. The ecosystems of the mined land are often extremely degraded and exceed the restoration capacity of the original ecosystem as a result of the major disturbance caused by human activities [4]. Mining often completely removes the original natural vegetation cover, in a way that the generated tailings sand and waste ore...
occupy a large area of former forest or farmland; this directly affects the productivity and life of the residents around the mine [5], and produces many serious social, economic, and environmental problems [6]. The ecological restoration of the landscape function of mined land after mineral extraction has become an important prerequisite to ensuring the sustainable development of regional economies.

The key to the restoration and sustainable development of mined land is to enhance the functions of the social system, ecosystem, and economic system and to optimize their structures [7]. Maintaining the function of a system is the core issue in the study of sustainable development; when mining activities disrupt the original ecological equilibrium of a region, the successful implementation of ecological restoration projects can delay and stop the degradation of the functioning of the socio-economic-ecological system, and thus re-enhance the overall function of the region [8]. Assessing the specific effects of ecological restoration of mined land can help to guide the planning and development of policies (i.e., regulation) in a region. At this stage, current relevant quantitative approaches have focused on the assessment of changes in the value of ecosystem services. For example, Townsend et al. [9] studied the effects of open-pit mining and reclamation on ecosystem services such as biodiversity and aesthetic landscape in the eastern Appalachian Mountains of the United States based on land cover. In fact, in such mixed areas as mined land, where socioeconomic and natural ecological functions are significantly coupled, human regulation and participation are more necessary in the process of their system succession, and the impact of human activities on ecosystem services is more obvious [10]; therefore, we need a research perspective that can integrate the functional changes in an integrated socioecological system to be able to discuss the specific impacts of ecological restoration on mined land.

As used in this study, “landscape multifunctionality” can refer to the ability of a landscape to simultaneously support multiple benefits to society based on its interacting ecosystems; the concept of landscape multifunctionality is often described as the joint supplying of multiple ecosystem services at the landscape level [11,12]. As an important tool that can reflect changes in landscapes in complex areas previously disturbed by humans, the quantitative assessment of landscape multifunctionality can effectively guide regional land management and land resource allocation [12,13]. This concept emphasizes human use along with the natural location and attributes of the region; it represents the capacity of the landscape to provide goods and services related to human wellbeing and indirectly reflects the level of development of the region [14,15]. Landscape multifunctionality can provide an effective management tool for socio-economic-ecological services in previously mined lands. Neyret [16] assessed changes in landscape multifunctionality using the level of grassland management as the dependent variable and used this to find trade-offs between how landscape-scale strategies can maximize agricultural production while conserving biodiversity. Baro [17] quantified the impact of landscape multifunctionality in the Barcelona metropolitan area in Spain by identifying clusters of ecosystem services based on supply and demand framework-based ecosystem service clusters to quantify landscape multifunctionality, and used the assessment results to design regional landscape management plans. Irauschek et al. [18] considered wood production, carbon sequestration, biodiversity, and gravity hazard preparedness as key landscape services in the context of the specific status of forests in Central Europe, and predicted the adaptive capacity of multifunctional landscapes to climate change in the Austrian Eastern Alps. Li et al. [19] used landscape multifunctionality as a powerful tool to identify the effects of environmental change and analyzed the relationship between landscape multifunctionality along with spatial and temporal changes in ecological and environmental risks in Beijing over a 10 year period in the region, using the city as a research site. Liang et al. [20] designed a landscape multifunctionality assessment model for the current situation in the region of Suzhou, Jiangsu province, China, quantified the effects of land use transformation, and provided ideas related to a shift in land management paradigm along with the development of spatial planning strategies in support of sustainable land management. In the above
studies, the spatial and temporal differentiation of landscape functions in each study area was expressed by making full use of the coupled socioecological assessment value of landscape multifunctionality. These studies all selected different indicators or were based on different models for the spatial display and expression of a single landscape function according to the characteristics of each respective study area. Most of the existing studies have focused on continents, countries, regional scales, economically developed regions, or rapidly urbanizing regions; nevertheless, the assessment of landscape multifunctionality is also needed in special areas such as mined land. Many studies examined landscape characteristics and post-mining land use effects in mining sites [21,22], but there is still a lack of research on the landscape multifunctionality changes during the whole life cycle of ecological restoration in the mining area.

In the present study, we developed a generalized structure to assess changes in landscape multifunctionality in mined land before and after ecological restoration, and also developed a landscape multifunctionality index to measure integrated socioecological system services. Based on the theoretical study that clarifies the impact of the ecological restoration process on landscape multifunctionality, an InVEST model was applied to assess the changes in landscape multifunctionality in the study area before and after the year of completion of ecological restoration of the mined land system for each period of land use dataset in the study area. Then, combined with the quantification of the trade-off–synergy relationship between the regional landscape functions, the mechanism of the influence of the ecological restoration project on the regional landscape multifunctionality was initially revealed.

2. Study Area

Because the energy structure of China lacks a good supply of oil and gas while being relatively rich in coal, the coal-based energy structure will still exist in the country for a long time. As a result, China has many areas of mined land. Mined land in Jiawang, Xuzhou City, Jiangsu province, China, at 34°17′ to 32°17′N, 117°17′ to 42°E, has a total land area of 617.35 km² and a population of 482,500. The region is an important coal mining area in Jiangsu province, China, containing 38.28 km² of coal mining area; the geographical location is shown in Figure 1. The average elevation of the region is 28.3 m. The local monsoonal warm temperate terrestrial climate has an average annual temperature of 14° C and an average annual precipitation of 922.1 mm. Since the opening of the first mine in 1882, Jiawang has produced about 360 million tons of coal, and the coal industry used to be an important pillar of the regional economy. Before coal mining, the land use type of the region was mainly arable land with flat terrain with a large expanse of high-yielding and high-quality agricultural landscapes. After large-scale and prolonged coal mining, surface subsidence, arable land pollution, and soil degradation occurred in the region, causing serious negative impacts on its social–ecological system functions. In addition, in recent years, Jiawang District has conducted ecological restoration projects with good results, which has led to profound changes in regional socio-economic-ecological system functions and structures after the completion of treatment around 2012; this can be regarded as a typical case of ecological restoration of mined land in China.

We believe that Jiawang is a typical case for this study for at least three reasons: (1) Jiawang is a typical mined land with a simple industrial structure and dense population. To finish the design of land use planning and the construction of sustainable landscape, local and regional authorities first overcame a large number of challenges; (2) after ecological restoration, Jiawang has a variety of natural habitats (wetland park, woodland, grassland, etc.) with high ecological value, and the landscape function has changed significantly; and (3) the starting point for ecological restoration by authorities fits this study, and their policies show a balance of socio-economic-ecological functions in the transition process.
3. Data Sources and Research Methods

3.1. Data Sources

Remote sensing imagery, socioeconomic statistics, and physical geographic data were used in this study to quantitatively assess the landscape multifunctionality and land cover change in the study area. Landsat remote sensing images acquired in 2005, 2010, 2015, and 2020 were used in this study. All images were acquired during April–May of each year during periods without clouds. Socioeconomic statistics and ecological restoration data were obtained from research and historical data provided by the Jiawang District Government. The natural geographic data included rainfall and temperature data (Resource and Environmental Science Research Center, Chinese Academy of Sciences, http://www.resdc.cn, accessed on 24 September 2022), soil data (Food and Agriculture Organization of the United Nations’ Harmonized World Soil Database project data), topographic data, and evapotranspiration data (Spatial Information Alliance, https://cgiarcsi.community, accessed on 24 September 2022).

3.2. Research Method

The logical map of the research method used in this paper is shown in Figure 2. The research methods highlighted in this section include assessment and analysis of landscape multifunctionality, and the measurement of the trade-off–synergy relationship of landscape multifunctionality.

![Figure 2. The logical map of the research method.](image-url)
3.2.1. Assessment and Analysis of Landscape Multifunctionality

The connotations of landscape functions and ecosystem services are similar, but landscape functions emphasize more of the utility of non-ecological functions, and its classification framework containing supply functions, support functions, regulating functions, and cultural functions is considered a feasible analytical tool to cope with land use changes in landscape planning [20]. Based on this, from the perspective of production–life–ecological functions, this paper selects eight landscape functions, including primary production, recreation service, population carrying, carbon sequestration, water production, water purification, soil conservation, and habitat maintenance, which correspond to four aspects of landscape function (supply, support, regulation, and culture) that are representative and easy to calculate. Among the indicators, the level of primary production function uses the annual average net primary productivity response; the recreation service function is estimated by using the recreation opportunity spectrum model; the population carrying function is reflected by the population carrying capacity, which is calculated based on the floor area, volume ratio coefficient, and population carrying coefficient; and the carbon sequestration, water production, water purification, soil conservation, and habitat maintenance functions are calculated by using the InVEST model’s carbon storage and water production. The carbon sequestration, water production, water purification, soil conservation, and habitat maintenance functions are calculated using the carbon storage, water production, nutrient transport, soil loss, and biodiversity conservation modules of the InVEST model. The calculation methods of each landscape function are shown in Table 1. Based on the calculation method of each landscape function, each landscape function is quantitatively assessed for the four periods from 2005 to 2020. The same landscape unit has multiple functions, and this study normalizes each landscape function positively to the interval from 0 to 1. The standardized values of each landscape function on the same landscape unit are accumulated to express the multifunctionality of the landscape unit.

Table 1. Indicators and methods of landscape function evaluation.

<table>
<thead>
<tr>
<th>Landscape Function</th>
<th>Connotation</th>
<th>Calculation Method</th>
</tr>
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</table>
| Primary Production | It is the capacity of the landscape to provide food crops for human survival. Characterized by average annual net primary productivity, the higher the average annual net primary productivity, the higher the primary production function. | \( NPP(x,t) = APAR(x,t) \times \varepsilon(x,t) \)  
\( NPP \) is the annual average net primary productivity; \( APAR(x,t) \) denotes the photosynthetically active radiation absorbed by the image element \( x \) in month \( t \), \( \varepsilon(x,t) \) denotes the actual light energy usage of the image element \( x \) in month \( t \). |
| Recreation Service | It is the ability of the landscape to provide recreational services for humans, characterized by the level of recreational opportunities. The higher the opportunity level, the stronger the landscape recreation service function. | \( E_x = G_x + C_x + R_x + L_x \)  
\( E_x \) is the recreation opportunity index of raster \( x \) pairs; \( G_x \) is the opportunity level of raster \( x \) to administrative sites (5 levels, the smaller the distance, the higher the level); \( C_x \) is the opportunity level of raster \( x \) to human landscapes (5 levels, the smaller the distance, the higher the level); \( R_x \) is the opportunity level of raster \( x \) to recreation via roads (5 levels, the smaller the distance, the higher the level); and \( L_x \) is the naturalness level of land use type of raster \( x \) (5 levels: the higher the naturalness level, the higher the level). |
| Population Carrying | It is the ability of the landscape to provide living space for human survival needs. This function is characterized by the habitat carrying capacity, and the higher the habitat carrying capacity, the stronger the function. | \( Rc_i = \frac{S_i \cdot Pr_i}{R_i} \)  
\( Rc_i \) is the habitat carrying capacity in year \( i \); \( Ri \) is the habitat carrying coefficient; \( Pr_i \) is the volume ratio; and \( S_i \) is the residential site footprint. |
Table 1. Cont.

<table>
<thead>
<tr>
<th>Landscape Function</th>
<th>Connotation</th>
<th>Calculation Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Sequestration</td>
<td>It is the ability of an ecosystem to absorb and store carbon through photosynthesis. This function is characterized by carbon stocks; the higher the carbon stock, the greater the capacity for carbon sequestration in the landscape.</td>
<td>( C_{tot} = C_{above} + C_{below} + C_{soil} + C_{dead} )</td>
</tr>
<tr>
<td>Water Yield</td>
<td>It is the ability of a landscape unit to generate runoff per unit area in a certain period of time, characterized by water yield. This indicator can be estimated using the water balance method. The higher the water yield, the stronger the water yield function of the landscape.</td>
<td>( Y_x = \left(1 - \frac{AET}{P_x}\right) \cdot P_x )</td>
</tr>
<tr>
<td>Water Purification</td>
<td>It is the ability of the vegetation and soil within the landscape to mitigate water pollution, characterized by nutrient output. The higher the output, the worse the nutrient purification function of the landscape.</td>
<td>( ALV_x = HSS_x \cdot pol_x )</td>
</tr>
<tr>
<td>Soil Conservation</td>
<td>It is the ability of a landscape to reduce soil erosion and retain soil nutrients and is characterized by the amount of soil loss. The higher the soil loss, the worse the soil retention function.</td>
<td>( USLE_x = R_x \cdot K_x \cdot LS_x \cdot C_x \cdot P_x )</td>
</tr>
<tr>
<td>Habitat Maintenance</td>
<td>It is the ability of a landscape to provide suitable conditions for the sustainable survival of individuals and populations and is characterized by a habitat quality model. The model assesses habitat quality in terms of the maximum stress distance of threat factors, weights, and the habitat suitability and sensitivity of different land use types to each threat factor. The higher the level of habitat quality, the higher the habitat maintenance function of the landscape.</td>
<td>( Q_{sj} = H_j \left[1 - D_{sj}\right] )</td>
</tr>
</tbody>
</table>

Landscape multifunctionality reflects the characteristics of multifunctional organic systems in which each function is interdependent, mutually constrained, and mutually promoted, meaning that this indicator will have a high or low level. High multifunctionality firstly means that the development of the agricultural industry itself has great potential value. In addition, given the fundamental supporting role of the landscape for the whole society, economy, culture, and ecology, the higher multifunctionality means stronger externalities and publicness of the landscape. The level of landscape multifunctionality of the region can be obtained by adding up the eight landscape function scores with equal weights.

3.2.2. The Measurement of the Trade-off–Synergy Relationship of Landscape Multifunctionality

Due to the diversity of landscape functions and the uneven spatial distribution, the relationship between landscape functions appears to be dynamic, manifesting itself in the form of trade-offs and synergies of mutual gains. A trade-off refers to the situation where the supply of some types of ecosystem services decreases due to the increase in the use
of other types of ecosystem services [23], while synergy refers to the situation where two or more ecosystem services are enhanced simultaneously [24]. In this study, the results of four periods of landscape function evaluation in Jiawang District from 2005 to 2020 were substituted into SPSS software. Spearman correlation analysis was applied to calculate the correlation coefficients among landscape functions in the study area, and then the temporal trends of trade-off–synergy in terms of multifunctionality were analyzed on this basis.

\[ r_s(X_i, Y_i) = 1 - \frac{6 \sum_{i=1}^{n} (P_i - Q_i)^2}{n(n^2 - 1)} \]  

(1)

4. Results

4.1. Spatial Characteristics of Change in Land Use Structure

The total land area of the study area was about 617.35 km\(^2\). The land use was mainly based on construction land (composed of both urban and rural construction land) and arable land. After using the geographic information data processed through ArcGIS analysis, the land use types of the study area in different periods were obtained (Figure 3). Please note that, unlike countries that often use land zoning laws to control private lands, essentially all land in China is owned by the government. The concept of construction land in China is similar to land zoning elsewhere; however, it is the government that designates planned land use for construction land and not private landowners or the zoning laws of the local government. Construction land in China can be land that is designated for future construction.

Because large-scale ecological restoration of the region was completed around 2012, the land use type conversion in Figure 4 is used to better reflect the specific changes in the land use structure of Jiawang District during the period from 2005 to 2020.

<table>
<thead>
<tr>
<th>Year</th>
<th>Before conversion</th>
<th>After conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005–2010</td>
<td><img src="image1" alt="Map" /></td>
<td><img src="image2" alt="Map" /></td>
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<tr>
<td>2010–2015</td>
<td><img src="image3" alt="Map" /></td>
<td><img src="image4" alt="Map" /></td>
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<tr>
<td>2015–2020</td>
<td><img src="image5" alt="Map" /></td>
<td><img src="image6" alt="Map" /></td>
</tr>
<tr>
<td>2005–2020</td>
<td><img src="image7" alt="Map" /></td>
<td><img src="image8" alt="Map" /></td>
</tr>
</tbody>
</table>

Legend:
- Unchanged Area
- Farmland
- Woodland & Grassland
- Unused Land
- Eco-water
- Construction Land


By observing the illustration of the distribution of land use in each year in Figure 3, it can be found that the construction land in Jiawang is mainly concentrated in the old city in the west and maintains an expansion trend; woodland and grassland are mainly scattered in the mountains and riverside, and ecological water surface is concentrated in the Pan'an
Lake area, both of which expanded in the 2015 and 2020 periods. The source of the area transferred to each of the above categories is mainly farmland.

In Figure 4, it can be observed that land use in the study area changed significantly from 2005 to 2020. The area of construction land and ecological water surface increased significantly while the spatial extent of other land uses decreased significantly during this interval. This was mainly a result of changes in land use after the systematic restoration of mined land in a land treatment project that has been conducted in Jiawang District since 2010, which led to the transformation of the poorly functioning untreated collapsed land in the domain to ecological waters. At the same time, the economic and social development of Xuzhou City has driven a significant expansion of the construction of land area. During 2010–2015, a large amount of unused land in Jiawang District, including mostly collapsed land or barren farmland disturbed by collapse, was transferred to land use as ecological waters, which was the result of the completion of the collapsed land treatment project in this area in 2012; the change of surface cover of mined land was therefore quite significant. Since 2015, the designation of land as construction land in the region has caused a continuous radiation of construction land in the entire area, while the unused land has been developed and used intensively. In general, the urban development areas in the region were mainly located in the central part of the region in a southerly direction, and the area of construction land has increased significantly over the past 20 years. Before 2010, the land use changes in Jiawang District were characterized by the redesignation of farmland as construction land and ecological waters. Population growth, rapid industrialization, and urbanization were the main driving forces causing the structural changes in land use in the district. After 2010, the conversion rate of farmland to other land use types declined under the influence of policies such as those related to farmland and ecological land protection.

In general, the land use structure of Jiawang District underwent a large-scale spatial transformation within 15 years, mainly from farmland to construction land, with a high speed and rapid extent of the transformation until the change tended to slow down after 2015. Overall, the land use change in Jiawang District during 2010–2015 was characterized by the replacement of farmland and unused land by residential areas, construction land, and ecological waters, with more drastic changes compared with 2005–2010 and 2015–2020. It is noteworthy that when comparing the distribution of collapsed areas in Jiawang, the land types such as farmland and construction lands transferred between 2005 and 2020 were concentrated in the areas affected by mining collapse in the region, and ecological restoration transformed the inefficiently used land types into a new condition. Population growth, ecological protection policies, and urbanization were the main drivers of land use structure changes in the region during this period. After 2015, with the completion of the regional ecological restoration process, the social, economic, and ecological conditions in the region shifted to a new steady state, and the rate of land transferred out of farmland in the region declined to some extent.

4.2. Changes in Landscape Function

Using the InVEST model operation, we obtained the change in landscape function of each region between 2005 and 2020 (Figure 5).
Figure 5 shows that the changes in each landscape function indicated in the study area before and after the changes of ecological restoration basically showed a positive trend. Among them, the progress of agricultural technology caused a gradual increase in the value of the primary production function of the area during the study period. As the ecological restoration project advanced, natural and human-modified landscapes, such as Pan’an Lake Wetland Park, were built, leading to the increasing recreation service function of the study area. The population carrying capacity was affected by the increase in population and the increase in building volume ratio due to urban expansion, and the carrying capacity gradually increased. The level of carbon sequestration function varied significantly over time, which was mainly a result of the number of land types with strong carbon storage function in the study area during the 20 year study. This occurred because the area of
farmland and woodland remained stable, while the area of ecological waters and other land types continued to increase. The water production capacity of the study area was reflected through water production, and its change was consistent with the precipitation in the region, with the peak occurring in 2005. After 2015, the water production capacity showed a trend of initially decreasing and then increasing, with a large gap between years in the water production capacity of the area. From 2005 to 2010, the urban development of the study area was very uneven. The area of human-disturbed land increased, and the area of farmland increased to previous levels while the woodland decreased considerably, leading to an increase in the output of nitrogen and phosphorus; thus, the water purification function continued to weaken. In the two phases of data after 2012, the promotion of ecological restoration in the study area led to a gradual decrease in the output of nitrogen and phosphorus along with an incremental increase in the water purification function in the study area. The level of soil conservation function continued to increase, indicating that after the ecological restoration of mined land, the intensity of soil loss in the area had gradually decreased. The habitat maintenance function had also been significantly weakened by the expansion of designated construction land and gradually increased after the implementation of mined land restoration. The habitat maintenance function was also significantly weakened by the expansion of construction land but it gradually rebounded after the ecological restoration project was completed.

4.3. Landscape Multifunctionality Trade-off–Synergy Relationship

Figure 6 shows results of the correlation coefficients among the landscape functions in the study area during 2005–2020. This figure shows that since the areas with high carbon sequestration and habitat maintenance functions are concentrated in mountain and plain forest areas with high forest cover, the two overlap spatially with correlation coefficients greater than 0.7; therefore, the synergistic relationship is obvious. In addition, the gathering areas of settlements with high habitat carrying capacity in the study area have high ground hardening, high water production, and low soil loss, making the correlation coefficients between habitat carrying capacity along with water production and soil maintenance greater than 0.3. Therefore, the synergistic relationship between them is also relatively significant. Obvious trade-offs existed between the landscape functions of RS-HM, PP-WP, and CS-WY groups. Among them, the correlation of the relationship between RS and HM functions was less than \(-0.5\), indicating that the settlement agglomeration areas with higher population carrying functions have weakening effects on carbon sequestration and habitat maintenance functions. Meanwhile, the relationships between PP-WP and CS-WY were less than \(-0.2\) and \(-0.3\), respectively, indicating that the primary production and water purification functions in the study area are spatially separated, which is mainly caused by the fact that agricultural fertilization results in a higher amount of nitrogen and phosphorus in water than in other areas. In addition, the poor water production capacity in areas with higher carbon sequestration function is a result of the large amount of water required for vegetation growth.

From the changes in correlation coefficients among the groups of landscape functions in Jiawang District from 2005 to 2020, the inter-annual changes of trade-off–synergy relationships among the landscape functions were small. The synergistic relationship between each function and the habitat maintenance function increased over time, indicating that ecological restoration of mined land has alleviated the conflict between different land use types; the depth of landscape functions of a certain land type was continuously explored.

4.4. Changes in the Level of Landscape Multifunctionality

Landscape multifunctionality represents the characteristics of a multifunctional organic system including interdependence, mutual constraints, and mutual promotion of each function, so there are strong and weak points. First, strong multifunctionality means a high potential value exists for the development of the region itself. Second, given the fundamental supporting role of the landscape to the whole society, economy, culture, and
ecology, stronger multifunctionality means stronger externality and publicness of the landscape. The level of landscape multifunctionality of the region can be obtained by adding up the eight landscape function scores with equal weights (Figure 7).

Figure 6. Correlations among landscape functions in Jiawang from 2005 to 2020.

Figure 7. Overall change in regional landscape multifunctionality level from 2005 to 2020.
In terms of temporal changes, the intervals of landscape multifunctionality level in 2005, 2010, 2015, and 2020 were 0.45–5.22 (mean 3.41), 0.78–5.42 (3.53), 0.92–5.58 (3.81), and 0.95–5.56 (3.89), respectively. In terms of the change between the interval and the mean value, the landscape multifunctionality in the study area has changed significantly over the 30 year period, with an overall increase of 14.08%.

5. Discussion
5.1. Insights into the Change in Landscape Multifunctionality of Mined Land under Ecological Restoration

The contribution of coal mining and ecological restoration to land use change in mining areas is different. Coal mining leads to subsidence and consequently waterlogging, while the construction of industrial plazas has left a lot of abandoned industrial and mining land, and these land types tend to have a negative contribution as the landscape function after mining is close to 0. In contrast, the ecological restoration of the river dredging project has created a water system and the land has been levelled to create agricultural land, which has greatly enhanced the landscape function of the area, making a positive contribution. Along with the pre–during–post ecological restoration process in the study area, it can be found that scientifically sound and reasonable ecological restoration can substantially increase the level of landscape multifunctionality in the land and improve the natural and social conditions of the area. The enhancement of landscape multifunctionality was achieved through comprehensive measures taken during the ecological restoration process. Before ecological restoration was completed (2005 and 2010), human activity disturbance still had a strong influence within the region. At that time, natural ecological succession had a minimal effect in transforming some natural ecosystems into artificial ecosystems such as transforming mined land into land that could be used as farmland and construction land. For a long time, the irregular urban land boundaries, untreated mining pollution, and crude attempts to develop farmland in the region had led to a stable but low level of landscape multifunctionality in the region, while the core ecological spatial positioning in the region was blurred.

After the completion nodes of ecological restoration had past (2015 and 2020 phases), Jiawang adjusted the spatial distribution of each landscape type. This enhanced the stability of the environment within the landscape, optimized the landscape structure of the study area, and better realized the economical and intensive use of land resources. These efforts comprehensively and systematically improved the living standard of local residents through the mode of intensification and elimination of disturbed landscape types of previously mined land. Specifically, after the ecological restoration program was completed, the area of land used as an ecological landscape in the region has been gradually expanded. The transformation of coal mine subsidence sites into wetland parks has led to improved ecological conditions in the study area, which has had a significant positive effect on the supply of water resources, capacity for hydrological regulation, and the maintenance of desired habitats in the region. In addition, while acquiring and changing these ecological landscape functions, the region conducted the relocation and concentration of mine overburden and infrastructure re-construction during the relocation process, while finishing and merging agricultural and garden lands, so that the regional food production, biodiversity, and other landscape functions that should have been affected by the declining ecological conditions were simultaneously enhanced. The population carrying capacity and primary production functions of the region improved continuously, which indicates the trend of concentration of population carrying capacity and the intensification of agricultural production in the region was in the process of comprehensive improvement. Meanwhile, several functions gradually evolved and improved, including the habitat maintenance function, the population carrying function, and the water production and water purification function. This developed from a trade-off relationship to a more synergistic relationship, which is due to the active industrial transformation and was guided by the idea of ecologically sound agricultural practices and the intensive development of rural construction land in the
process of mined land management in the region. The case study in this paper organically integrates the evaluation results of individual factors through the analysis of changes in landscape multifunctionality throughout the life cycle of ecological restoration in mining areas, and carries out a spatially integrated evaluation. By comparing and analyzing the correlation characteristics between different functions, a systematic evaluation of landscape multifunctionality in mined land can be achieved.

In addition, the research direction of this study is very important because a realistic demand exists for ecological restoration to study the mechanism of regulation and enhancement of landscape multifunctionality in mined land. The prerequisite for effective regulation of landscape functions is to reveal the trade-off–synergy relationships among landscape functions. Existing studies are relatively mature in the quantitative assessment of this relationship, but the mechanism of landscape multifunctionality enhancement needs further study. In the case of this study, the influence on the trade-off–synergy relationship of regional landscape functions was realized in the study area through an analysis of the results of ecological restoration measures. Before and after ecological restoration, multiple groups of landscape functions in the region evolved from trade-off to synergistic relationships, or the phenomenon of an enhanced synergistic relationship appeared.

Therefore, enhancing landscape multifunctionality through collaborative management can be considered an effective way to realize the sustainable development of mined land. In view of the special socio–economic–ecological problems in the post-coal era, Jiawang’s ecological restoration model of “production intensification-living centralization-landscape ecology” can be practiced in different countries and in various mined land areas. Under the condition of limited land resources, human beings’ various demands for economy, society, and environment determine that landscape restoration will inevitably develop in the direction of multifunction and complexity. This paper provides a case study to help decisionmakers, urban planners, and other urban specialists deal with similar situations. From the perspective of the socioecosystem, landscape planning and management must comprehensively consider the spatial correlation between natural processes and socioeconomic processes and their interactions in landscape. At the same time, decisionmakers need to try to enhance the synergistic relationship between functions. When there is a strong trade-off between two functions, policymakers are required to evaluate the relationship between development and conservation more comprehensively. It will be necessary to continue to deepen the exploration of ecological and diversified land use patterns and accumulate experience in the rational and optimal allocation of resources. This will allow land managers to more effectively improve the level of landscape multifunctionality and maintain the healthy operation of the social–ecological system in mined landscapes.

5.2. Future Work

In response to a series of existing socio–economic–ecological problems in mined land, it is necessary to continue to deepen the exploration of ecological and diversified ecological restoration models, so as to effectively improve the multifunctional level of mined landscapes on a regional scale. In the future, it will still be necessary to study the quantitative modeling of the transformation relationships and trends among the landscape functions during the steady-state period after ecological restoration, so as to regulate the structure and function of the mined land landscape more precisely. In the next step of the study, we can draw on the analysis of economic costs in the trade-off–synergy relationship to achieve an optimal decision on the layout of the landscape.

6. Conclusions

In this study, the mined landscape of Jiawang District was selected as the study area. Eight landscape functions, namely, primary production, recreation services, population carrying capacity, carbon sequestration, water production, water purification, soil conservation, and habitat maintenance, were comprehensively assessed, and the changes in landscape multifunctionality from 2005 to 2020 were revealed. It is important to clarify the
evolutionary trend of landscape functions before and after ecological restoration and the changes in their interrelationships for regional landscapes and sustainable land use.

The study shows that (i) the ecological restoration of mined land had a significant positive effect on regional landscape multifunctionality; the level of landscape multifunctionality in 2020 increased by 22.41% compared with that in 2005. (ii) Among the landscape functions, more obvious synergistic relationships existed among the CS-HM, PC-WY, and PP-CS functions at different times, while the CS-WY, PP-WP, and RS-HM functions maintained obvious trade-off relationships. Most of the synergistic relationships were strengthened through ecological restoration, in which the relationships among PC-HM, WY-HM, and WP-HM gradually evolved from trade-offs to synergistic relationships. It can be said that the land use changes created by scientifically sound and reasonable ecological restoration can substantially improve the landscape multifunctionality of mined land and improve the natural and social conditions of the region. Research on the adaptive management of regional landscapes and landscape sustainability assessment should be strengthened in the future.

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