Article

Coordinated State Analysis and Differential Regulation of Territorial Spatial Functions in Underdeveloped Regions: A Case Study of Gansu Province, China

Baopeng Xie, Quanxi Wang, Beiying Huang, Ying Chen, Jie Yang and Peixin Qi

1 College of Management, Gansu Agricultural University, Lanzhou 730070, China; xiebp@gsau.edu.cn (B.X.); HBY970112#163.com (B.H.); qpx0519#163.com (P.Q.)
2 School of Humanities and Law, Northeast University, Shenyang 110169, China; 2010007@stu.neu.edu.cn
3 College of Praticultural Science, Gansu Agricultural University, Lanzhou 730070, China; yangj@gsau.edu.cn
* Correspondence: cheny@gsau.edu.cn; Tel.: +86-1351-9602-540

Abstract: The coordinated development of territorial spatial functions is the main manifestation of the sustainable utilization of territorial resources. Identifying spatial functions and their coordinated relationship has become an important guarantee for regional coordinated development, and is of great significance to the construction of a sustainable land development and protection pattern. This study constructs a classification and function scoring system for Production-Living-Ecological Spaces (PLES) by using land-use data from Gansu Province in 2000 and 2020, and revises the spatial functions of the land to supplement the deficiencies of existing related research by combining socio-economic data (GDP, population density) and ecosystem service value data. In the aforementioned works, the Mechanical Equilibrium Model in physics is referenced to explore the coordinated state among territorial spatial functions. The results show that the high-value areas of production function are mainly distributed in the eastern and central areas of the Loess Plateau, with a strip-like distribution in the Hexi Corridor. The high-value areas of living function are consistent with that in the center of the city. The distribution of high-value areas of ecological function is in line with the topographic distribution pattern of mountainous areas in Gansu Province. The distribution pattern of the coordinated state of land space function in Gansu Province is relatively stable from 2000 to 2020. Simultaneously, the functional dominant area and the promotion area are identified according to the deviation of the coordinated degree of production-living-ecological function. After clarifying the functional characteristics of each county, the author proposes a differentiated regulation strategy of territorial spatial function.

Keywords: Production-Living-Ecological Spaces; functional identification; Mechanical Equilibrium Model; coordinated degree; differential regulation; Gansu Province

1. Introduction

Territorial Space is the unity of Production-Living-Ecological Spaces (PLES). In China, the long-term economic “production-oriented” land use model has led to conflict and chaos in PLES, which has been intensified with the acceleration of urbanization and industrialization. From 1978 to 2020, China’s urbanization level increased from 17.92% to 63.89% [1]. With the rapid urbanization process, this has led to confusion in land spatial development and the reduction of ecological spaces, resulting in a low quality of land spatial use [2], loss of cultivated land [3,4], food security [5], ecosystem degradation [6], etc. At the same time, significant changes have taken place in land space and resource utilization, the proportion of the regional PLES structure tended to be unbalanced [7], and land functions have been involved in time and space [8]. How to gradually optimize the spatial development pattern and promote the synergy of regional spatial functions has
become the focus of regional sustainable development. At present, China has established a five-level territorial space planning system, which aims to achieve an effective control and scientific governance of territorial space and promote the balance and coordination of development and protection. Territorial space planning requires coordinated social and economic development against the background of ecological civilization. It is manifested as the coordinated coexistence of PLEF, and the essence of PLEF is the functional performance of different land subjects on land use. The scientific planning and guidance of different functional spaces need a multi-functional quantitative evaluation and a comprehensive balance analysis. Therefore, identifying the relationship between functional change and functional coordination has become an important guarantee for the coordinated development of the region, which is of great significance to optimize the spatial pattern of land and an important prerequisite for the smooth implementation of land spatial planning.

At present, scholars have conducted extensive research on production-living-ecological functions (PLEF) from different angles, which mainly focus on the definition of concept and connotation [9,10], classification system and quantitative identification [11,12], functional pattern optimization and spatial allocation [13,14], change and influencing factors [15,16]. For example, in terms of spatial classification, some scholars divide it into production land, living land and ecological land based on subjective classification methods [17–19]. Some scholars believe that land space has multi-functional attributes and can be divided into leading functions and secondary functions, including ecological land, ecological production land, production ecological land and living production land [20–23]. Other scholars classify land use functions according to industrial, social and managerial attributes [24]. At the same time, researchers find a scale effect and functional compound characteristics under different research scales, and a unified classification system has not yet been formed. In terms of spatial identification and functional evaluation, qualitative or quantitative methods such as land use classification and distribution [23,25], functional value, calculation function group, location entropy model and spatial multi factor superposition analysis [26,27] are mostly used for functional value evaluation to identify the single or dominant function of land space. In terms of spatial function optimization, a niche suitability evaluation model, a linear programming model and other methods are mostly used to carry out a spatial optimization layout under specific scales, so as to serve the regional land spatial development and optimization layout. In addition, a large number of studies [28] focus on the functional balance of the territory [29]. Focusing on the spatial carrying capacity of production and living ecological land [30,31], this paper studies the spatial optimal layout [32,33], land use transformation and its ecological effect [34], and the spatial development and suitability of urban construction land [35]. Production and living ecological space is not a mutually exclusive spatial unit, but a functional space formed through the interconnection and interaction of different land use modes [36].

Functional interrelation refers to the balance of PLEF. The balance of PLEF is the optimal functional coordination and the minimum negative effect [37]. However, due to the temporal and spatial heterogeneity of PLEF, it is difficult to achieve an actual balance [38], which can only be reflected in the coordination and trade-off relationship of functions [39,40]. At present, scholars have used a coupling coordinated degree model [14,41,42], a spatial correlation analysis [43] and a Pearson parameter correlation analysis [44] to explore the functional synergy and trade-off relationship of PLEF, which has led to significant results. However, although the coupled scheduling model can obtain the coordinated degree of PLEF, it fails to analyze the coupling characteristics. In addition, there is confusion in the research process of the model in terms of principle, formula and result interpretation [43]. Although the method of correlation analysis avoids the confusion problem, most of these methods analyze the pairwise relationship between functions and fail to quantify the coupling relationship of PLEF. Different intensities of production, life and ecological functions lead to the alternating evolution of functional synergy and trade-off.
Measuring the coordinated degree among the PLEF and determining the specific characteristics of functional synergy/trade-off become the key to the coordination of PLEF. The mechanical balance model can be used to obtain the degree of functional coordination. It can reflect more intuitively the characteristics of the functional coordination/trade-off relationship, identify the dominant function and overcome the confusion in the research process. Land spatial planning based on PLEF has become the focus of current land resource management. The land spatial belt is not only an important means to coordinate the multi-objective and multi-functional characteristics of land planning, but also an important guarantee for the top-down organization and management of land spatial planning.

Gansu Province plays an important role in protecting the ecological security of the northwest areas and even of the whole country. Geographically, the Yellow River Basin, in Gansu, spans many national ecological safety zones and constitutes an important ecological barrier for China. To promote the sustainable development of the man–land system in the Yellow River Basin, “Ecological protection and high-quality development of the Yellow River Basin” was promoted as a major national development strategy in 2019. Gansu Province needs to clarify the functional position of each region through the territorial spatial functional zoning and form a development and protection pattern with a reasonable division of labor and complementary advantages. Based on the above considerations, this paper constructs a classification system of PLES and introduces the mechanical equilibrium model in the field of physics, using the land use type data of Gansu Province in 2000 and 2020, and considering the dominant functions and natural attributes of the land. This study quantifies and distinguishes the relationship between spatial functions, tries to measure the coordination of the overall territorial spatial functions, identifies territorial spatial dysfunction areas, and proposes optimized control strategies for problem areas, to alleviate the people in Gansu Province. The scientific basis is provided by the contradiction of land relationship and the optimization of land spatial pattern.

2. Theoretical Framework

For a long time, in order to meet the demand for diversified products and services, human beings have made land with multi-functional lands through different ways and intensities of land-use. The realization of the spatial functions of different territories often depends on different types of land use. There is a corresponding relationship between land use types and territorial spatial functions. Different territorial spatial functions can be identified based on the dominant functions of land use types. However, under the joint action of regional, natural, social and economic conditions, the functional values of the same land use type are different. The integrated classification of territorial spatial functions which are based on different land types only considers the actual utilization characteristics of regional land [45], without applicability correction, which affects the accuracy of the evaluation results. Therefore, the identification of different functional spaces should fully consider the differences in the regional natural environment.

PLEF is the performance of land use, and there is a trade-off/synergy effect between the spatial functions [46]. The key to the coordinated development of social economy against an ecological background is the coordinated development of PLEF. Regional territorial space is limited, and mankind’s excessive pursuit of individual land functions has crowded out other functional spaces (ecological functions and food production functions), which is not conducive to the sustainable utilization of regional territorial space. The existing studies have shown that the mechanical balance model can be used to measure the coordinated relationship between the system’s internal subsystems. The model uses the vector forces in three different directions in the Cartesian coordinate system to represent different subsystems, and the resultant force of the vector force and the quadrant of the resultant force are objectives. It reflects the states and characteristics of the system under
the action of multiple directional forces and dynamically recognizes the coordinated degree and matching issues of the system to formulate different control measures for territorial spatial functions [39,47].

Based on the above analysis, this study uses the mechanical equilibrium model to analyze the functional relationship of the territorial spatial in Gansu Province, identifies areas with PLES dysfunction based on the results of coordination judgments and focuses on the regional land use characteristics and coordinated degree level and type to propose different optimization strategies (Figure 1).

![Theoretical framework of coordinated state and regulation of territorial spatial function](image)

**Figure 1.** Theoretical framework of coordinated state and regulation of territorial spatial function.

### 3. Materials and Methods

#### 3.1. Study Area

Gansu Province, which is the only province in China, has three natural geographical regions and is located in inland northwest China. The total area of the province is 42.58 × 10^4 km², which accounts for 4.72% of the total area of China. The terrain consists mainly of mountains and plateaus, taking up about 70% of the total land area of Gansu Province. Gansu Province has jurisdiction over 14 cities (or prefectures) and 87 counties (or county-level cities and districts). The whole province can be divided into five regions: Longzhong region, Hexi Corridor region, Longdong region, Longdongnan region and Gannan region (Figure 2). In addition, it is worth noting that there are 56 nature reserves in Gansu Province, 21 of which are national nature reserves. At the same time, there are 12 national geoparks and 24 provincial geoparks in the province. By the end of 2019, the total population reached 26.47 million, among which the urban population reached 12.84 million and the rural population reached 13.64 million. In 2019, the GDP of Gansu Province was $126.32 billion and the per capita GDP was $4783.55. Among them, the added value of the primary industry, the secondary industry and the tertiary industry were $0.22 billion, $41.50 billion
and $69.67 billion. In 2019, among the 31 provinces (municipalities and autonomous regions) in China, Gansu Province ranked 27th in terms of GDP. The population of Gansu Province accounted for 1.89% of the total population of the country, whereas its GDP accounted for only 0.88% of that of the country.

Figure 2. Location map of Gansu Province in China.

3.2. Data Source and Processing

This paper adopts the land use data (1 km × 1 km) in 2000 and 2020, which are obtained from the Resource and Environment Data Cloud Platform (http://www.resdc.cn/, accessed on 16 November 2021). The data are based on a remote sensing image of Landsat and is generated by artificial visual interpretation. It includes 6 types of land use class 1, such as cultivated land, forest land, grassland, water area, construction land and unused land, and 20 types of land use class 2, such as paddy fields, dry land, forested land and so on, which can meet the needs of this study (Figure 3). The GDP spatial data, population density distribution data and ecosystem service value data used in the revision of territorial spatial functions are obtained from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/, accessed on 16 November 2021), with a spatial resolution of 1 km. In addition, the administrative division comes from the National Basic Geographic Information Center (http://www.ngcc.cn/, accessed on 20 November 2021), and the digital elevation model (DEM) data (90 × 90 m) are obtained from the resource environment data cloud platform (http://www.resdc.cn/, accessed on 16 November 2021) and is used to draw a schematic diagram of the location of the study area.
Figure 3. The spatial distribution of land use in Gansu Province in 2000 and 2020. Note: Cultivated land includes Paddy field, Arid land; Forest land includes Closed forest land, Shrub forest, Sparse forest, Other forest lands; Grassland includes High coverage grassland, Medium coverage grassland, Low coverage grassland; Water includes River channel, Lakes, Reservoir pit, Permanent glacier snow, Beach; Construction land includes Other construction land, Urban land, Rural settlement; Unused land includes Sandy land, Gobi, Saline-alkali land, Wetlands, Bare land, Bare rock gravel and Others.

3.3. Methods

3.3.1. Assessment of Territorial Spatial Function

The integration of territorial spatial functions is based on the land use type. The construction of the classification system of PLES consists in the merging of the dynamic process of the quantity and space of land resources. Scholars have classified types of production-living-ecological land [48] based on the subjective land intention of behavioral subjects and the perspective of natural attributes of the land, covering different land types and reflecting multiple aspects of regional economic and social development pursuit by the production of an economic, livable and ecological environment. However, a spatial evaluation unit has mixed and interwoven functions. One land use type may provide two or more functions that make it difficult to merge land types from the perspective of land use functions.

Therefore, this paper considers the natural attributes of land use and the land use intention satisfied by the subject to carry out the classification of production-living-ecological land, using the above ideas and classification scheme as reference. More specifically, cultivated land is dominated by its agricultural production function and has an ecological function. However, the main purpose of human land is to provide food products for human survival, so it is classified as agricultural production land. The other construction land in the paper refers to the mines, large industrial areas, oil fields, salt fields, quarries and other lands, as well as traffic roads, airports and special land, because their main function is a production function, which is considered as other production land. Urban and rural residential land mainly provides living areas for urban and rural residents, which can be divided into urban and rural living lands. In terms of ecological land, it is more accurate to divide it according to the natural properties of land. For example, forest land and natural grassland mainly play the role of ecological land while undertaking some agricultural and pastoral production functions. Unused land is a natural land cover type, with important landscape ecological functions. After comprehensive consideration, it is finally divided into forestland ecological land, grassland ecological land, water ecological land and other ecological land.
Land use types can be divided into production functions (providing regional space for producing products), living functions (providing regional space for living activities) and ecological functions (providing regional space for ecological services) according to different aspects of human needs. Territorial spatial functions are interrelated and can be transformed, and land use functions are divided into primary and secondary functions under different land uses [49,50]. Based on the land use status classification, the paper refers to the results of the research quantifying the territorial spatial functions [25,51], estimates the equivalent value of ecosystem services [52] and considers the difference and strength of primary and secondary functions that land use can provide. It takes production land as an example, including production land (5 points), semi-production land (3 points), weak production land (1 point) and the functional deficiency (0 points). The same grading process is used for production land and living land (Table 1).

Table 1. Initial evaluation assignment of territorial space functions.

| Function Types | Land Use Types |
|----------------|---------------|
| **Production function** | Paddy field (3), Arid land (3), Other construction land (3), Urban land (5), Rural settlement (3), Closed forest land (0), Shrub forest (0), Sparse forest (0), Other forest lands (0), High coverage grassland (0), Medium coverage grassland (0), Low coverage grassland (0), River channel (3), Lakes (0), Reservoir pit (1), Permanent glacier snow (0), Beach (0), Sandy land (0), Gobi (0), Saline-alkali land (0), Wetlands (0), Bare land (0), Bare rock gravel (0), Others (0) |
| **Living function** | Paddy field (0), Arid land (0), Other construction land (3), Urban land (5), Rural settlement (5), Closed forest land (0), Shrub forest (0), Sparse forest (0), Other forest lands (0), High coverage grassland (0), Medium coverage grassland (0), Low coverage grassland (0), River channel (0), Lakes (0), Reservoir pit (0), Permanent glacier snow (0), Beach (0), Sandy land (0), Gobi (0), Saline-alkali land (0), Wetlands (0), Bare land (0), Bare rock gravel (0), Others (0) |
| **Ecological function** | Paddy field (3), Arid land (3), Other construction land (0), Urban land (0), Rural settlement (0), Closed forest land (5), Shrub forest (5), Sparse forest (3), Other forest lands (5), High coverage grassland (5), Medium coverage grassland (5), Low coverage grassland (5), River channel (1), Lakes (5), Reservoir pit (1), Permanent glacier snow (5), Beach (5), Sandy land (1), Gobi (1), Saline-alkali land (1), Wetlands (5), Bare land (1), Bare rock gravel (1), Others (1) |

Reviewing the results of the territorial spatial functions, the spatial heterogeneity of the ecological environment in Gansu Province is obvious. At the same time, affected by economic development and comprehensive living conditions, there are differences in the PLEF of the land provided by the same type of land in different regions. Generally speaking, the first difference is that the production function is directly related to the industrial structure and the pursuit of a land-intensive and efficient output. The second is that the service objects of the life functions are mainly the diversified needs of human beings, and the pursuit of convenience and livability. The third is that the better the ecological condition, the stronger the ecological function service capacity of the land space [45,53]. Therefore, this paper revises the production \( X_1 \), life \( X_2 \) and ecological \( X_3 \) function values of the territorial spatial function in Gansu Province, using the unit development intensity GDP, population density and ecosystem service value indicators.

\[
X_i = X'_i \times (TS_i - Min_i) / (Max_i - Min_i)
\]

(1)

In formula (1): \( X_i \) is the function value of the territorial space where \( i \) is 1, 2 and 3, representing the production function, living function and ecological function. \( X'_i \) is the initial function value of the territorial space. \( TS_i \), \( TS_2 \) and \( TS_3 \) are the grid unit values of the unit development intensity GDP, population density and ecosystem service value, respectively. \( Max_i \) and \( Min_i \) represent the maximum and minimum values of the functional correction index.
3.3.2. Measure Model of Coordinated Degree of Territorial Spatial Function

PLEF is the functional expression of land use by different land subjects. There is an interactive symbiotic relationship between functions. The essence of sustainable development and the utilization of land space is to realize the coordination of the three functions. Previous studies have shown that the mechanical balance model can be used to measure the coordinated relationship between subsystems within the system. The model represents different subsystems with three vector forces in different directions in the Cartesian coordinated system, objectively reflects the state and characteristics of the system under the action of multiple directional forces with the resultant force and the quadrant of the resultant force, and dynamically identifies the coordinated degree and matching problem of the system. Compared with the traditional system coupling coordinated degree model, this model can not only directly reflect the coordinated level of each subsystem from the evaluation results, but also identify its functional “short board” from the deviation direction of the coordinated degree [47,54].

This study constructs a discrimination model for the coordination of territorial and spatial functions, and abstracts production, life and ecological functions into three vector forces in different directions, using the mechanical balance model. If all of the three forces reach the expected goal, the combined force is zero, which means that the PLEF develops in a balanced manner. At that time, the point of action of the resultant force can be called the equilibrium point, that is, the point O in the figure; on the contrary, the resultant force makes \( F \) deviate from the equilibrium point \( O \), which means that the PLEF is in an unbalanced state. Therefore, the characteristics of the coordinated relationship between land and space functions can be studied (the conceptual model is shown in Figure 4) according to the magnitude of the resultant force \( F \) and the deviation angle \( \theta \). In the process of calculating the resultant force—the resultant force of \( OA \) and \( OB \), in other words—\( F_1 \) is calculated first. Then, the resultant force (\( F \)) of \( F_1 \) and \( OC \) is calculated in the same way, and so is the angle between \( F \) and the X axis. The formulas are as follows:

\[
F_1 = \sqrt{OA^2 + OB^2 + abs(2 \times OA \times OB) \times \cos(\angle XOA - abs \angle XOC)} \quad (2)
\]

\[
\alpha = \arcsin \frac{absOB \times \sin(\angle XOA - \alpha - abs \angle XOC)}{F_1} \quad (3)
\]

\[
\alpha = \arcsin \frac{absOB \times \sin(\angle XOA - \alpha - abs \angle XOC)}{F_1} \quad (4)
\]

\[
F = \sqrt{F_1^2 + OC^2 + abs(2 \times F_1 \times OC) \times \cos(\angle XOA - \alpha - abs \angle XOC)} \quad (5)
\]

\[
\angle FOB = \arcsin \frac{F_1 \times \sin(\angle XOA - \alpha - abs \angle XOC)}{F} \quad (6)
\]

\[
\beta = \angle XOB - \angle FOB \quad (7)
\]
Figure 4. The conceptual model of the territorial spatial deviation level.

There are significant differences in the functions of the different main functional areas. The key developed zones often have more production and living functions. The key ecological function areas and main agricultural production areas have an outstanding performance in ecological and agricultural production functions. Therefore, this study takes the average function value of the ground (the value of the living function, ecological function or production function per unit area of land) as the basic indicator, to enhance the comparability between different function values of the main functional areas, and the identification is based on the mechanical equilibrium model. The detailed steps are as follows:

(1) The evaluation method of land space function value calculates the initial value and the correction value of various land space functions, and the land area of county units in Gansu Province based on the proportional relationship between the total value of regional land space function and the land quantity of corresponding function types, which are average the living function value, land average ecological function value and land average production function value.

(2) Compare the land average function value of the county unit with the standard value of the corresponding function in the area and obtain the strength of the soil space function of each county. According to the principle that the functions of adjacent units are similar, and the county units in different regions are different due to differences in the natural environment and human activities, the relative standard determination method in the sustainable development assessment is used as reference, and the functional average of all county units in the prefecture-level city is the standard value [48].

(3) The calculated force intensities of the average land life function, land average ecological function and land average production function are abstracted into 3 equal-angle ($2\pi/3$ respectively) components of different directions at intervals, and the solution is based on the resultant force. The method obtains the strength and direction of the comprehensive force of PLEF and uses polar coordination to express it as $(F, \theta)$. According to the combination of the positive and negative vector relationships between the PLEF, a vector feature table of each quadrant (Table 2) is formed to measure the quadrant and the vector direction of the evaluation unit, that is, the range of angle $\theta$, to analyze the territorial spatial function coordination status.
Table 2. The characteristics of different coordination types.

| Quadrant | Angel         | Force Characteristics | Characteristic Description                                                                 |
|----------|---------------|-----------------------|-------------------------------------------------------------------------------------------------|
| I        | $[11\pi/6, 0]$, $[0, \pi/6]$ | $\pm$ $-$ $+$         | The production function is higher than the established standard value, and the ecological function is lower than the established standard value. The direction of the force of the living function is both positive and negative. The living function is higher than the established standard value, and the ecological function is lower than the established standard value. The direction of the force of the production function is both positive and negative. |
| II       | $[\pi/6, \pi/2]$ | $+$ $-$ $\pm$         | The production function is higher than the established standard value, and the ecological function is lower than the established standard value. The direction of the force of the living function is both positive and negative. The living function is higher than the established standard value, and the production function is lower than the established standard value. The direction of the force of ecological function is both positive and negative. |
| III      | $[\pi/2, 5\pi/6]$ | $+$ $\pm$ $-$         | The production function is higher than the established standard value, and the ecological function is lower than the established standard value. The direction of the force of ecological function is both positive and negative. The production function is higher than the established standard value, and the production function is lower than the established standard value. The direction of the force of ecological function is both positive and negative. |
| IV       | $[5\pi/6, 7\pi/6]$ | $\pm$ $+$ $-$         | The production function is higher than the established standard value, and the ecological function is lower than the established standard value. The direction of the force of the production function is both positive and negative. The ecological function is higher than the established standard value, and the production function is lower than the established standard value. The direction of the force of the living function is both positive and negative. |
| V        | $[7\pi/6, 3\pi/2]$ | $-$ $+$ $\pm$         | The production function is higher than the established standard value, and the production function is lower than the established standard value. The direction of the force of the production function is both positive and negative. The ecological function is higher than the established standard value, and the living function is lower than the established standard value. The direction of the force of the production function is both positive and negative. |
| VI       | $[3\pi/2, 11\pi/6]$ | $-$ $\pm$ $+$         | The production function is higher than the established standard value, and the ecological function is lower than the established standard value. The direction of the force of the ecological function force is both positive and negative. The production function is higher than the established standard value, and the production function is lower than the established standard value. The direction of the force of the ecological function force is both positive and negative. |

Note: The signs $+$, $-$ and $\pm$ indicate that the direction of the force is positive, negative and uncertain, respectively. The distribution of LF, EF and PF is the living function, ecological function and production function in the territorial space.

4. Results

4.1. Single Function Evaluation of Territorial Space

4.1.1. Spatial-Temporal Pattern of Production Function

The high-value areas of Gansu’s production function are mainly distributed in the Loess Plateau in the central and eastern part of Gansu, and the zonal distribution areas are located in Zhangye City and Wuwei City, in the Hexi Corridor region (Figure 5). The production functions with low area are Gannan Plateau, Qilian Mountains and Jiuquan City. Among them, the central and eastern areas are the key dry farming areas and major agricultural production areas. It is characterized by extensive planting, thin harvesting and rain-fed agriculture, the cultivated land is widely distributed and the agricultural production functions are prominent. The Hexi region is characterized by island massive oasis agriculture, and Zhangye City is located in the main area of the Heihe river basin, which has high production functions in oasis agriculture. In addition, the Hexi Corridor is used to connect cities, providing certain production functions, which is consistent with the distribution of high-value areas of production functions. As urban construction land invades cultivated land and ecological land, the area of production improvement is more consistent with the distribution of high-value areas in production space. However, due to the implementation of the policy of compensating for the balance of cultivated land, urban expansion requires the cultivation of cultivated land and the replenishment of the same area of cultivated land. From 2000 to 2020, Gansu Province has expanded the production space by reclaiming grassland, low hills and gentle slopes.
4.1.2. Spatial-Temporal Pattern of Living Function

In 2000 and 2020, the high-value area of living space in Gansu Province is basically in line with the location of urban centers, which are in line with the current situation of land distribution in rural residential areas (Figure 6). Due to the significant difference in natural conditions, the population density of the province is largely different. In the Hexi area, there are large land areas, and the population density is lower than the average level of Gansu province. The distribution characteristics of population are unbalanced and concentrated in an oasis with superior hydrothermal soil conditions. The high value of living space is distributed around Lanzhou City, Jiayuguan City and Qingyang City, which is consistent with the spatial-temporal pattern of key development zones in Gansu Province. Some regions vigorously carry out rural residential renovation works to reduce the area of rural residential areas, and to reduce the living space to a certain extent, this is why the high-value area of living functions shows the trend of functional improvement.

4.1.3. Spatial-Temporal Pattern of Ecological Function

The ecological distribution shows a trend along with the provincial boundary, which is consistent with the mountainous terrain distribution pattern in Gansu Province (Figure 7). The high-value areas of function are located in Ganann plateau, the mountains in the south of Gansu Province, Qilian Mountain ridge as well as Jiuquan City. The forest vegetation of these areas is relatively good, which is the ecological barrier of ecological security and plays an important role in Gansu province. Hexi Corridor area is characterized by island block oasis agriculture. Jiuquan City is one of the most serious desertification areas in the province due to its drought and lack of rain, harsh water and heat conditions and fragile ecological environment.

![Figure 5. Spatial-temporal pattern of production functions in 2000 and 2020.](image)
4.2. Coordinated Degree of Territorial Spatial Function

4.2.1. Type of Coordinated Degree of Territorial Spatial Function

The resultant force $F$ of each county is calculated according to Equations (2)–(5) to measure the functional coordination of PLEF which is divided into 4 types in descending order using the natural discontinuity method, including the highly coordinated type ($0.03 \leq F \leq 0.64$), approximately coordinated type ($0.64 < F \leq 1.60$), transitional type ($1.60 < F \leq 7.02$) and disordered type ($7.02 < F \leq 18.07$). Among them, the synergy state includes highly coordinated and approximately coordinated, and the trade-off state includes transitional type and disordered type.

The distribution pattern of PLEF coordination in Gansu Province is relatively stable (Figure 8), and the number of coordination areas (highly coordinated type and approximately coordinated type) is obviously redundant. In 2000, the number of synergies and tradeoffs was 71 and 12, and by 2020 the number of synergies and tradeoffs was 69 and 14, indicating that the coordinated degree of PLEF in Gansu Province was high. However,
from 2000 to 2020, some counties in Gannan and Longnan changed from a high degree of coordination to a basic type of coordination, and the degree of coordination decreased, mainly because with the social and economic development of the above two regions, the construction space and production space occupied part of the ecological space, resulting in the decline of the degree of coordination. The balance areas are mainly municipal government stations, such as Suzhou District of Jiuquan City, Chengguan District of Lanzhou City, Linxia city and Liangzhou District of Wuwei city. These areas are economic development centers with a large population density and a large demand for construction land. The living and production functions exceed the ecological functions, showing a strong balance state. In the past 20 years, most counties and districts in Jiuquan City have changed from synergy type to trade-off type. Therefore, on the whole, the coordinated degree of Sansheng function in Gansu Province has decreased.

4.2.2. Type of Coordinated Degree of Territorial Spatial Function

The deviation angle $\theta$ is calculated by the mechanical balance model, and the functional deviation characteristics are analyzed in the quadrant where the deviation angle is located. The results show that $\theta$ angles are distributed in 6 quadrants (Figure 9). According to the characteristics of different coordinated types (Table 2), this paper divides the territorial spatial function into 3 types.

Quadrants I and VI are the leading areas of ecological functions. The regional socio-economic development lags behind, and the ecological functions are relatively prominent. From 2000 to 2020, the overall ecological functions of Gansu Province were higher than the production and living functions. Most counties are the leading areas of ecological functions, which is related to the regional geography and natural environment of Gansu Province. However, from 2000 to 2020, the number of public areas of the leading areas of ecological functions decreased by 2. In 2000, nine counties in Gansu Province were in quadrant I. these counties had a high ecological function value and low living function value. By 2020, the number of counties and cities in quadrant I increased to 11. The number of counties and cities in quadrant VI decreased from 27 to 23, and the life function was improved due to the process of urbanization, making some counties turn from quadrant VI to quadrant V and become the leading areas of life function.

Quadrant II and quadrant III are the leading areas of production function, indicating that production function is higher than ecological and living functions, respectively. In 2000, there were 17 counties in quadrant II. These counties had a rapid economic development, a high production function and a low ecological function value. By 2020, they were reduced to 13, 3 counties of which would be transformed into quadrant III and I into quadrant I. It shows that the ecological function has been improved. In 2000, 12 counties were in quadrant III. The production function of these counties was good, but the urbanization level was backward, and the living function was weak. By 2020, the number of counties of this type had been reduced to 8, indicating that the living function or ecological function of the four counties can be improved and surpass the production function. Overall, the ecological construction and urbanization process have continuously improved the ecological and living functions, and reduced the leading areas of production functions in Gansu Province.

Quadrant IV and V are the dominant areas of life function. The living function of this area offsets the impact of the production function and the ecological function. In 2000 and 2020, the living function of 25 counties was higher than the production function, mainly in the counties where the municipal government was located, and their surrounding counties and districts were Lanzhou City and Tianshui city, etc. The number of counties with higher living function than ecological function increased from 4 in 2000 to 9. Overall, the increase or decrease in the number of life function advantage areas in Gansu Province shows that the life function of Gansu Province has improved significantly in the past 20 years.
4.2.3. Strategies for Adjusting and Controlling Differences in Territorial Space

According to the coordinated type of territorial spatial function, in the required improvement areas, it proposes an optimization strategy (Table 3).

Production function dominance (living function and ecological function improvement zones): This area is dominated by production functions, but has weak living and ecological functions. It is mainly distributed in the municipal districts of Hexi and Lanzhou. These areas have a high land-use intensity, a high population density and a rapid expansion of construction land, resulting in low living and ecological functions. This type of area should be improved by optimizing the urban land use structure, promoting the economical and intensive use of construction land, controlling the occupation of ecological land by construction land and fully tapping the potential of the existing land in the city, increasing the supply of ecological land such as parks and green corridors, etc., to improve the ecological function.
Living function dominance (production function and ecological function improvement zones): The typical characteristics of this type of area are high living functions and low ecological functions. They are mainly distributed in the central towns and surrounding areas of various districts and counties. These counties and cities are mainly focused on agricultural production, with relatively low production functions. The range is more stable. As in the living ecological improvement area dominated by production functions, the first step is to improve the ecological functions by increasing ecological land. The second step is to optimize the layout of living space and ecology, and improve the internal ecological environment of the region. In addition, compared with high-production and low-ecological areas, the level of economic development in this type of area is not outstanding, and it is not appropriate to take relevant measures that restrict the production function.

Ecological function dominance (living function and production function improvement zones): The ecological function of this type of area is relatively high, but the production function is relatively low, which is in line with the key ecological function areas delineated by the main function areas of Gansu Province. While maintaining the non-decrease of the ecological function, this type of area needs to combine regional characteristics to develop characteristic industries, such as tourism and rural tourism. At the same time, through the continuous improvement of public infrastructure conditions in the region, the quality of residents’ lives will be improved, and regional production functions will be enhanced. In addition, in the process of high-quality economic development and the improvement of public service facilities, it is still necessary to pay attention to the protection of the ecological environment to prevent the degradation of ecological functions in the Gannan Mountains and Qilian Mountains, and soil erosion in the Loess Plateau.

Table 3. Optimization strategies of territorial spatial function zones.

| Function Zones                                      | Representative Zones                                                                 | Optimization Strategy                                                                 |
|-----------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Production function dominant (living function and   | Lanzhou-Baiyin, Jiuquan-Jiayuguan, Ganzhou-Linze, Jinchang-Wuwei, Pingliang-Qingyang  | Optimize urban land use structure and increase ecological land supply                  |
| ecological function improvement zones)             | municipal district                                                                     | Fully tap the potential of the existing land use in the city, and promote the economical and intensive use of construction land |
|                                                     | Tiancheng (Tianshui-Chengxian, Huixian) area                                            | Persist in ecological protection, increase the supply of public services and optimize the industrial structure |
| Living function dominant (production function and   | Agricultural Industrial Belt along the Yellow River (Linxia City, Yongjing County, etc.) | Increase ecological land and enhance ecological functions                              |
| ecological function improvement zones)             | Main production areas of Hexi agricultural products (Gaotai County, Guazhou County, etc.) | Optimize the layout of living space and ecological space, and improve the overall ecological environment within the region |
|                                                     | Main production areas of Longdong agricultural products (Heshui County, Chongxin County, etc.) |                                                                                       |
| Ecological function dominant (living function and   | Important water supply ecological function areas of the Yellow River in Gannan (Xiahe County, Kangle | According to the characteristics of regional natural resources, develop characteristic industries, such as tourism and rural tourism industry |
| production function improvement zones)             | Country, Kangle County, etc.)                                                         | Continuously improve the public infrastructure conditions in the region, improve the quality of life of residents and enhance regional production functions |
|                                                     | Qilian Mountain Glacier and Water Conservation Ecological Function Zones (Subei County, Shandan County, Gulang County, etc.) |                                                                                       |
5. Discussion

5.1. Insights into the Spatial Heterogeneity and the Interaction of Territorial Spatial Function

Gansu Province is a key ecological protection and development area in China. The judgment and classification of the coordination of its PLEF are of great significance to achieve a high-quality development. In essence, the uncoordinated development of production, life and ecological functions is a complex process of trade-offs influenced by physical geography and socio-economic factors, which can occur through a variety of possible mechanisms [55]. The formation and evolution of the spatial pattern of land use are characterized by complexity, comprehensiveness and dynamic variability, and are subject to the combined effects of natural constraints, humanistic driving forces and human–land interaction [56,57]. Regional local factors (such as topography, climate, resource endowment and economic location) constitute the prerequisites for changes in the spatial function of the land in Gansu Province, and have an important influence on the spatial pattern of the land. In addition, external driving factors (such as urbanization, spatial planning and land management policies) determine the direction and intensity of the evolution of territorial spatial functions. Micro-topography, high in the west and low in the east, complex and diverse geomorphic patterns, as well as the transition from east to west and the transition of climate and vegetation succession in Gansu Province make the regional production, living and ecological spatial patterns showing obvious regional differences. In fact, spatial incompatibilities of land use caused by different demands are the roots of the trade-offs.

Faced with core issues such as ensuring food security, protecting ecological security and maintaining the stability of economic development, the central and local governments have implemented a series of policies such as land management, ecological environmental protection and macroeconomic regulation, which have had a profound impact on the development and protection of territorial space. Since the Reform and Opening-up, with the continuous advancement of the Development of China’s Western Region policy, the national strategic focus has shifted to economic construction. The rapid development of industrialization and urbanization has driven major changes in land use patterns, resulting in a decline in the quality of the ecological environment in Gansu Province [58]. In recent years, China’s One Belt One Road/The Belt and Road Initiative was introduced, and the strategy of the Ecological Protection and High-quality Development in the Yellow River Basin was implemented. In 2019, rare development opportunities and favorable policies have been ushered in Gansu Province, and more attention has been paid to ecology while developing its economy. Environmental protection and construction, namely the continuous implementation of environmental projects such as the protection of natural forest resources, returning farmland to forests and grasslands, the construction of the Three-North Shelter Forest Program and the protection and restoration of key ecological function areas will restrain the continued deterioration of the quality of the ecological environment.

Besides, we have noticed that, except for the urbanization development areas in Gansu Province, the main agricultural production areas have strong ecological functions and have been defined as ecological protection areas in the regional planning, resulting in a high degree of conflict. This kind of uncoordinated development of land and space functions is reasonable, because ecological maintenance is the original function of land use and is not subject to human interference.

5.2. Implications for Sustainable Territorial Land Spatial Development and Management

This study uses the mechanical balance model to analyze the coordinated state between regional spatial functions, which is consistent with the social and economic development and geographical environment endowment of Gansu Province. It is an effective way to identify the leading functions. Importantly, it can identify the trade-offs and syn-
ergies of territorial spatial functions, realize the comprehensive functional zoning of ter-
ritorial space and clearly define key ecological functional areas, urbanization develop-
ment areas and main agricultural product production areas, which is of great significance
to the sustainable protection and development of territorial space.

In order to deal with the unbalanced performance of spatial functions in different
regions, appropriate land use policies and countermeasures should be formulated accord-
ing to the actual situation and socio-economic development stage of Gansu Province (Ta-
ble 3). With the advancement of urbanization and the improvement of production and
living functions, the PLEF turns to synergy. However, if the ecological environment is not
protected in the promotion process, there will be a high-stage trade-off between produc-
tion and living functions beyond ecological functions. Therefore, in the future develop-
ment process, it is necessary to adjust the direction of function evolution, change the ori-
entation of only pursuing production and living functions, and adjust the industrial struc-
ture, promote social and economic transformation and development, strictly control the
occupation of ecological space by production and living space, arrange ecological corri-
dors between clustered cities, improve ecological security and maintain ecological func-
tions. In order to ensure the implementation of the above regional policies and programs
in Gansu Province, it is also necessary to explore the mutual feedback mechanism between
land spatial function transformation and land resource management [54]. In the future,
we should continue to practice the concept of ecological civilization and strive to build a
land use spatial pattern integrating mountains, rivers, forests, fields, lakes, grass and sand
in Gansu Province. Specifically, it is necessary to plan and protect the ecological land in
key ecological functional areas and ensure the regional ecological security pattern, includ-
ing the water conservation area in Gannan plateau, the soil and water conservation area
in Longdong Loess Plateau and the ecological barrier area in Qilian Mountain. At the same
time, urbanization development areas should make intensive use of production land, im-
prove the utilization efficiency of land resources and meet the needs of regional economic
development. Finally, we should vigorously promote the improvement of urban and rural
living space and the construction of supporting infrastructure, so as to make Gansu Prov-
ince embark on the sustainable development road of good ecology, production develop-
ment and rich life. In short, we must adhere to the national and provincial multi-functional
zoning strategy, innovate the multi-functional intensive land use mechanism and realize
the coordinated development of sustainable utilization of land resources and ecological
environment protection.

5.3. Uncertainties and Challenges for Further Research

This study analyzes the coordination of PLEF in Gansu Province and the regulation
of functional divisions. The evaluation and revision of territorial functions can objectively
reflect the temporal and spatial differentiation characteristics of territorial spatial func-
tions, facilitate the definition and identification of regional dominant functions and pro-
vide a theoretical basis for the scientific compilation of territorial and spatial planning.
Compared with the traditional coupling coordinated degree model, the mechanical equi-
librium model used in this study not only quantifies the coordination degree, but also
accurately identifies the coordinated degree type, which is more reasonable and compre-
hensive [54]. The results of the coordinated state analysis and zoning control can provide
practical guidance for the future space optimization of the region, to realize the effective
control and scientific governance of regional land space [59].

However, this research still has shortcomings in the process of theoretical construc-
tion and empirical testing: (1) Due to the limitations of data collection and quantitative
methods, only PLEF is used for spatial quantitative evaluation, while other detailed func-
tions (such as water conservation function in ecological function areas, life support func-
tions in urbanized areas and agricultural products) are not used for spatial quantitative
evaluation. The production function of cultivated land in the production area is not taken
into consideration. In the future, the evaluation system of land space function can be appropriately refined to meet the needs of land space development and protection. (2) Calculating the value of land space function, the authors comprehensively consider that the function of the same land type may be different in different regions and select the index with the regional difference to correct the initial value of the function. However, only one correction index is selected for each land space function. In future research, the correction index that can reflect the strength of the land space function should be strengthened, including food production potential, quality of life and ecosystem health, etc., so that the evaluation results are in line with the actual situation of the region. (3) To meet the needs of the actual main functional zoning scale, this research aims to analyze the coordinated status of land and space functions on the county scale, and the spatial scale needs to be refined to solve specific problems in land use practice.

6. Conclusions

The coordination of the functions of land and space is the requirement and purpose of realizing the sustainable development and utilization of land and resources. Gansu Province is a key ecological protection and development area in China, where the judgment and classification of the coordination of its PLEF are of great significance to achieve high-quality development. Therefore, this study takes Gansu Province as a research case, introduces the equilibrium model of mechanics in the field of physics and conducts a quantitative analysis and judgment on the relationship between land and space functions. The authors arrived at the following conclusions:

(1) The high-value areas of production function areas in Gansu Province are mainly distributed in the Loess Plateau areas in the central and eastern of Gansu Province, while others are distributed in bands in the Hexi Corridor area. The low-value areas of production functions are distributed in the Gannan Plateau, Jiuquan City and Qilian Mountain. The high-value areas of living functions are as similar as the scope of the urban center, distributed around Lanzhou City, Jiayuguan City and Qingyang City, which is consistent with the pattern of key development zones in Gansu Province. The distribution pattern of the high-value area of ecological functions is in line with the distribution pattern of mountain terrain in Gansu Province.

(2) The distribution pattern of the coordinated state of land space function in Gansu Province is relatively stable. The county units at the coordination level are dominated by the Longzhong regions and the Hexi Corridor regions. Those at the approximately coordinative type are concentrated on the Gannan regions, the Longdong regions and some counties in the Qilian Mountains. The county units at the confliction level are mainly distributed around the municipal districts.

(3) Different regions should optimize the land use structure and functional spatial layout and adjust the industrial structure according to the planning and development requirements of the main functional areas in combination with the levels and types of PLEF coordination. It is worth noting that for areas where the production-life ecological function is at the level of resistance to knots and imbalances, measures should be classified and implemented from the dimensions of comprehensive land consolidation, ecological restoration, natural resource supervision and comprehensive evaluation to enhance PLEF coordination.

**Author Contributions:** Writing—review and editing, B.X.; writing—original draft, Q.W.; supervision, J.Y. and B.H.; resources, Y.C., P.Q.; funding acquisition, Y.C. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Gansu Agricultural University’s publicly introduced doctoral research start-up fund (GAU-KYQD-2017-34).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.
**Data Availability Statement:** Not applicable.

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

**References**

1. Fang, C. Important progress and prospects of China’s urbanization and urban agglomeration in the past 40 years of reform and opening-up. *Econ. Geogr. 2018*, 8, 1–9.

2. Li, Q.; Fang, C.; Wang, S. Suitability evaluation and regulation of rural residential land in Yixing City based on the grey target model. *Areal Res. Dev. 2016*, 5, 163–169.

3. Liu, Y.; Wang, J.; Long, H. Analysis of arable land loss and its impact on rural sustainability in Southern Jiangsu Province of China. *J. Environ. Manag. 2010*, 91, 646–653.

4. Radwan, T.; Blackburn, G.; Whyatt, J.; Atkinson, P. Dramatic loss of agricultural land due to urban ex-pansion threatens food security in the Nile Delta, Egypt. *Remote Sens. 2019*, 11, 332.

5. Fan, X.; Liu, J.; Chen, Z.; Zhao, L.; Wei, H. Changes of land use and functions of ecosystem service: A case study in China. *Pol. J. Environ. Stud. 2019*, 28, 73–82.

6. Yang, H.; Chen, W.; Liang, Z. Relationship of PM2.5 concentration and land use type in Nanchang City based on LUR simulation. *Trans. Chin. Soc. Agric. Eng. 2017*, 6, 232–239.

7. Liao, L.; Dai, W.; Chen, J.; Chen, J.; Huang, W.; Jiang, F.; Hu, Q. Spatial conflict between ecological-production-living spaces on Pingtian Island during rapid urbanization. *Resour. Sci. 2017*, 10, 1823–1833.

8. Verburg, P.; Steeg, J.; Veldkamp, A.; Willemen, L. From land cover change to land function dynamics: A major challenge to improve land characterization. *J. Environ. Manag. 2009*, 3, 1327–1335.

9. Cao, R.; Zhang, A.; Cai, Y.; Xie, X. How imbalanced land development affects local fiscal condition? A case study of Hubei Province, China. *Land Use Policy 2020*, 99, 105086.

10. Wang, C.; Tang, N. Spatio-temporal characteristics and evolution of rural Production-Living-Ecological space function coupling coordination in Chongqing Municipality. *Geogr. Res. 2018*, 37, 1100–1114.

11. Liu, J.; Liu, Y.; Li, Y. Classification evaluation and spatial-temporal analysis of “Production-Living-Ecological” spaces in China. *Acta Geogr. Sin. 2017*, 72, 1290–1304.

12. Xie, G.; Zhen, L.; Zhang, C. Assessing the multifunctionalities of land use in China. *J. Resour. Ecol. 2010*, 1, 311–318.

13. Li, B.; Zeng, C.; Dou, Y. Change of human settlement environment and driving mechanism intraditional villages based on Living-Production-Ecological space: A case study of Lanxi village, Jiangyong county, Hunan province. *Prog. Geogr. 2018*, 37, 677–687.

14. Zhang, L.; Zheng, X.; Meng, C. Spatio-temporal difference of coupling coordination degree of land use functions in Hunan province. *China Land Sci. 2019*, 33, 85–94.

15. Wang, J.; Chen, H.; Shi, Q. Research on spatiotemporal differentiation and influencing factors of land use multi-functional areas of Shaanxi province. *Chin. J. Agric. Resour. Reg. Plan. 2019*, 40, 101–108.

16. Eng, J.; Chen, X.; Liu, Y. Spatial identification of multifunctional landscapes and associated influencing factors in the Beijing-Tianjin-Hebei Region, China. *Appl. Geogr. 2016*, 74, 170–181.

17. Geng, S.; Zhu, W.; Shi, L. A functional land use classification for ecological, production and living spaces in the Taihang Mountains. *J. Resour. Ecol. 2019*, 3, 246–255.

18. Cheng, L.; Zhou, S.; Zhou, B.; Lv, L.; Cheng, T. Characteristics and driving forces of regional land use transi-tion based on the leading function classification: A case study of Jiangsu Province. *Economic Geogr. 2015*, 2, 155–162.

19. Groot, R. Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, mul-ti-functional landscapes. *Lands. Urban Plan. 2006*, 3–4, 175–186.

20. Zhang, H.; Xu, E.; Zhu, H. An ecological-living-industrial land classification system and its spatial distribution in China. *Resour. Sci. 2015*, 7, 1332–1338.

21. Yu, L.; Song, A.; Zheng, Y.; Jian, Q.; Zhang, P. The ecological-living-industrial land classification system and the analysis of its spatial distribution—Case of Changli County. *Chin. J. Agric. Resour. Reg. Plan. 2017*, 2, 89–96.

22. Cai, E.; Jing, Y.; Liu, Y.; Yin, C.; Gao, Y.; Wei, J. Spatial-temporal patterns and driving forces of ecological-living-production land in Hubei Province, Central China. *Sustainability 2018*, 10, 66.

23. Xia, M.; Feng, X.; Xia, J.; Zou, W. Delineation of production-living-ecological space in Lishui District of Nanjing based on land multi-functions and suitability. *Trans. Chin. Soc. Agric. Eng. (Trans. CSAE) 2021*, 16, 242–250.

24. Zou, L.; Wang, J.; Hu, X. An classification systems of production-living-ecological land on the county level: Theory building and empirical research. *China Land Sci. 2018*, 8, 59–66.

25. Liao, G.; He, P.; Gao, X.; Deng, L.; Zhang, H.; Feng, N.; Zhou, W.; Deng, O. The productio-living-ecological land classification system and its characteristics in the Hilly area of Sichuan Province, Southwest China based on identification of the main functions. *Sustainability 2019*, 11, 1600.

26. Li, G.; Fang, C.L. Quantitative function identification and analysis of urban ecological-production-living spaces. *Acta Geogr. Sin. 2016*, 1, 49–65.

27. Liu, D.; Ma, X.; Gong, J.; Li, H. Functional identification and spatiotemporal pattern analysis of production-living-ecological space in watershed scale: A case study of Bailongjiang Watershed in Gansu. *Chin. J. Ecol. 2018*, 5, 1490–1497.
28. Bian, Z.; Cheng, X.; Yu, M.; Li, H.; Cui, W. The Proportionality of the functions of production, life and ecology in connection zone between shenyang and fushen. Chin. J. Agric. Resour. Reg. Plan. 2016, 12, 84–92.

29. Cui, J.; Gu, J.; Sun, J.; Luo, J. The spatial pattern and evolution characteristics of the production, living and eco-logical space in Hubei Provence. China Land Sci. 2018, 8, 67–73.

30. Fang, C.; Bao, C.; Zhang, C. Analysis on the changing condition and the evolutive scene of the ecology-production-living carrying capacity in arid area: A case study in Yuli District in the Lower Reaches of Tarim River. Acta Ecol. Sin. 2003, 9, 1915–1923.

31. Zhang, C.; Fang, C. Driving mechanism analysis of ecological-economic-social capacity interactions in oasis systems of arid lands. J. Nat. Resour. 2002, 2, 181–187.

32. Zhu, Y.; Yu, B.; Zeng, J.; Han, Y. Spatial optimization from three spaces of production, living and ecology in national restricted zones: A case study of Wufeng County in Hubei Province. Econ. Geogr. 2015, 4, 26–32.

33. Xi, J.; Wang, S.; Zhang, R. Restructuring and optimizing production-living-ecology space in rural settlements: A case study of Gougezhuang Village in Yesanpo tourism attraction in Hebei Province. J. Nat. Resour. 2016, 3, 425–435.

34. Zhang, L.; Liu, G.; Wei, J.; Liu, Y. The effects of “ecological-production-living” land use transformation on associated ecological service value: A case study of Yingkou City. Chin. J. Ecol. 2019, 3, 838–846.

35. Wu, Y.; Yang, Y.; Yang, L.; Zhang, C.; You, Z. Land spatial development and suitability for city construction based on ecological-living-industrial space: Take Ningbo City as an example. Resour. Sci. 2016, 11, 2072–2081.

36. Aubry, C.; Ramamonjisoa, J.; Dabat, M. Urban agriculture and land use in cities: An approach with the mul-ti-functionality and sustainability concepts in the case of Antananarivo (Madagascar). Land Use Policy 2012, 2, 429–439.

37. Wang, M.; Zhou, Z.; Feng, H. Coordinated development of urban agricultural multi-functionality of Xi’an Metropolitan Zone. Arid. Land Geogr. 2015, 38, 858–866.

38. Jia, X.; Fu, B.; Feng, X. The tradeoff and synergy between ecosystem services in the grain-for-green areas in Northern Shaanxi, China. Ecol. Indic. 2014, 43, 103–113.

39. Zhang, Y.; Long, H.; Tu, S. Spatial identification of land use functions and their tradeoffs/synergies in China: Implications for sustainable land management. Ecol. Indic. 2019, 107, 1100–1114.

40. Liu, C.; Xu, Y.; Huang, A. Spatial identification of land use multifunctionality at grid scale in farming-pastoral area: A case study of Zhangjiakou city, China. Habitat Int. 2018, 76, 48–61.

41. Zhou, D.; Xu, J.; Zhu, L. Conflict coordination? Assessing land use multi-functionalization using production-living-ecology analysis. Sci. Total Environ. 2017, 577, 136–147.

42. Liu, P.; Chen, R.; Yang, C. Study on layout optimization of rural settlements based on coordination of Production-Living-Eco logical space. Res. Soil Water Conserv. 2017, 24, 283–288.

43. Li, X.; Fang, B.; Yin, R. Spatial-temporal change and collaboration/trade-off relationship of “Production-Living-Ecological” functions in county area of Jiangsu province. J. Nat. Resour. 2019, 34, 2363–2377.

44. Fan, Y.; Jin, X.; Gan, L. Spatial identification and dynamic analysis of land use functions reveals distinct zones of multiple functions in Eastern China. Sci. Total Environ. 2018, 642, 33–44.

45. Zhou, H.; Jin, P.; Xia, W.S. Functional zoning of territorial space in provincial level based on the production-living-ecological functions: A case of Henan Province. China Land Sci. 2020, 34, 10–17.

46. Zhang, Y.; Chen, Y.; Wang, J.; Ye, J.; Zhang, B. Coordinate degree and differential optimizing “production-living-ecological” function in the Yellow River Basin. Trans. Chin. Soc. Agric. Eng. 2021, 37, 251–261.

47. Kang, Q.; Guo, Q.; Ding, Y.; Zang, Y. Trade offs/synergies analysis of “Production-Living-Ecological” functions in Shaxi province. J. Nat. Resour. 2021, 36, 1195–1207.

48. Yang, Q.; Duan, X.; Wang, L.; Jin, Z. Land use transformation based on ecological-production-living-spaces and associated eco-environment effects: A case study in the Yangtze River Delta. Sci. Geogr. Sin. 2018, 1, 97–106.

49. Pérez-Soba, M.; Petit, S.; Jones, L.; Bertrand, N.; Briquel, V.; Omelide-Zorini, L.; Contini, C.; Helming, K.; Farrington, J.H.; Mossello, M.T. Land use functions—A multifunctionality approach to assess the impact of land use changes on land use. In Sustainability Impact Assessment of Land Use Changes; Springer: Berlin/Heidelberg, Germany, 2008; pp. 375–404.

50. Chen, J.; Shi, P.J. Discussion on functional land use classification system. Beijing Norm. Univ. 2005, 5, 536–540.

51. Jin, X.; Lu, Y.; Lin, J.; Qi, X.; Li, X. Research on the evolution of spatiotemporal patterns of production-living-ecological space in an urban agglomeration in the Fujian Delta region, China. Acta Ecol. Sin. 2018, 12, 4286–4295.

52. Xie, G.; Zhang, C.; Zhang, L.; Chen, W.; Li, S. Improvement of the Evaluation Method for Ecosystem Service Value Based on Per Unit Area. J. Nat. Resour. 2015, 8, 1243–1254.

53. Huang, J.; Lin, H.; Qi, X. A literature review on optimization of spatial development pattern based on ecological-production-living space. Prog. Geogr. 2017, 3, 378–391.

54. Zhou, R.; Lin, M.; Gong, J.; Wu, Z. Spatiotemporal heterogeneity and influencing mechanism of ecosystem services in the Pearl River Delta from the perspective of LUCC. J. Geogr. Sci. 2019, 9, 831–845.

55. Jiao, G.; Yang, X.; Huang, Z.; Zhang, X.; Lu, L. Evolution characteristics and possible impact factors for the changing pattern and function of “Production-Living-Ecological” space in Wuyuan county. J. Nat. Resour. 2021, 36, 1252–1267.

56. Shi, Z.; Deng, W.; Zhang, S. Spatial pattern and spatio-temporal change of territory space in Hengduan Mountains region in recent 25 years. Geogr. Res. 2018, 37, 607–621.

57. Song, Y.; Xue, D.; Xia, S.; Mi, W. Change characteristics and formation mechanism of the territorial spatial pattern in the Yellow River Basin from 1980 to 2018, China. Geogr. Res. 2021, 40, 1445–1463.
58. Dong, J.; Zhang, Z.; Da, X.; Zhang, W.; Feng, X. Eco-environmental effects of land use transformation and its driving forces from the perspective of “production-living-ecological” Spaces: A case study of Gansu Province. *Acta Ecol. Sin.* **2021**, *41*, 5919–5928.

59. Fu, X.; Wang, X.; Zhou, J.; Ma, J. Optimizing the production-living-ecological space for reducing the ecosystem services deficit. *Land* **2021**, *10*, 1001.