Delimiting Ecological Space and Simulating its Dominant functions in the Perspective of Dynamic Changes in Ecosystem Service Functions: A Case Study in the Qionglai City of Sichuan Province, China

Nengjun Wu1, Yuanxi Li1, Dinghua Ou1, Rui Zhang1, Ziheng Yang1, Qi Zhang1 and Shangqi Gong1

1College of Resources, Sichuan Agricultural University, Chengdu, Sichuan, 611130, China

*Corresponding author’s e-mail: 14340@sicau.edu.cn

Abstract: Demarcating the ecological space scientifically and predicting the spatial change trend of the dominant ecosystem service functions reasonably are of great significance for demarcating the ecological red line, optimizing the pattern of ecological space and promoting the high-quality development of economic and social. This study took Qionglai City as the research area and utilized land-use, satellite remote sensing and other data to demarcate the ecological space from the perspective of the dynamic changes of ecosystem service functions with the support of ESRI ArcGIS and IDRISI. And then we applied the Markov-CA model to simulate the spatial pattern of the dominant ecosystem service functions for the ecological space in 2025 with integrating the change characteristics of the dominant ecosystem service functions. The results showed that: (1) The dynamic change characteristics of ecosystem service functions were obvious. The critical value of comprehensive function value and average annual change rate of ecosystem service functions were 6 and 5% respectively. (2) The ecological space area was 98307hm², which was intensively distributed in the western and central south of the city. Its distribution was consistent with the ecological space range in the local ecological civilization construction plan, which indicated that the ecological space delineation method based on the dynamics of ecosystem service functions is reliable. (3) The dominant ecosystem service functions had shifted and showed strong non-stationarity during 2003-2019, so the dynamicity of the dominant ecosystem service functions should be fully considered in the ecological space zoning management and other related planning. (4) The Markov-CA model was of high simulation accuracy (Kappa coefficient > 0.95), and the simulation results were consistent with the regional ecological function zoning basically. Therefore, the model can be applied to simulate the spatial layout of dominant ecosystem service functions for ecological space in the future. (5) The dominant ecosystem service functions in Qionglai will still undergo mutual conversions during 2019-2025. The ecological space will still maintain the three dominant functions including primary product production, climate regulation and hydrological regulation in 2025, but the area of them will change into 32793hm², 52490hm² and 13024hm² respectively.

1. Introduction
Ecological space is a complex geographical space composed of multiple ecosystems, with the main functions of providing ecological products or ecological services[1-2]. Ecosystem service functions are the natural environmental conditions and utility formed by ecosystems and ecological processes to
maintain human survival[3-4], and it has spatiotemporal dynamics[5] and multifunctionality[6], which makes ecological space often present the same characteristics. Moreover, there must be a function that plays a dominant role among the various ecosystem service functions within a certain ecological space. Therefore, we demarcated ecological space from the perspective of spatiotemporal dynamics for ecosystem service functions and simulated the spatial pattern of dominant functions for ecological space according to the change characteristics of dominant ecosystem service functions. This study may have important theoretical and practical significance for demarcating ecological red lines and ecological space control areas scientifically, constructing and optimizing the pattern of national ecological security.

With the deepening of the national ecological civilization construction strategy, many researchers have carried out a lot of useful explorations including ecological spaces identification and its functional change simulation. In the aspect of ecological space identification, a large number of researches have focused on the methods, which mainly include qualitative research about directly demarcating ecological space based on land use/cover type[7-8] and quantitative research on demarcating ecological space by integrating the importance of ecosystem service functions and the sensitivity of ecological environment[9-10]. Moreover, these researches are mostly static and rarely consider the spatiotemporal dynamics of ecosystem service functions. In the aspect of spatial change simulation, the models used commonly include CA[11-12], CLUE-S[13-14], linear programming model[15-16] and Markov chain[17-18]. CLUE-S and CA models are good at spatial change simulation and can reflect spatial dynamic changes well, but there are certain limitations in quantitative structure simulation. Linear programming model and Markov chain can realize quantitative change prediction well, but have difficulty with simulating spatial variation. Therefore, the composite models integrating quantitative structure and spatial pattern simulation such as Markov-CA[19], DE-CA[20], PSO-CA[21] have been widely used in the field of spatial change simulation, including land use and urban expansion, whereas they have been used seldom in the ecological space change simulation, and applied rarely to the evolution simulation researches of the dominant functions in ecological space. For a long time, the simulation of ecological space changes has mainly focused on the analysis of ecological space evolution[22-23]. In the past two years, there have been a few researches using composite models to simulate ecological spatial changes[24]. Therefore, it is a useful exploration to simulate the dominant functions change of the ecological space by applying the composite models. In a word, there are three main deficiencies in the current researches of delimiting ecological space and simulating its dominant functions. Firstly, the ecological space was delimited mostly by the current ecosystem structure and service function status, while ignoring the spatiotemporal dynamics of the ecological space because of the evolution of ecosystem structure and its dominant service functions. Secondly, the analysis of ecological space evolution mostly focused on quantity and spatial changes, while ignoring the change analysis of dominant ecosystem service functions in the ecological space. Thirdly, the composite models integrating the quantity structure and spatial layout have been applied rarely to the change simulation of the ecological space dominant functions, and the theoretical research results are relatively weak.

To address the problems mentioned above, we took Qionglai City as the research area, firstly demarcated the ecological space based on the spatiotemporal dynamic changes of the comprehensive ecosystem service functions during 2003-2019, then identified the dominant ecosystem service functions of the ecological space and analyzed their change characteristics, and lastly simulated the dominant function spatial pattern of ecological space in 2025 with the Markov-CA composite model. The results of this study may provide a useful theoretical basis and method reference for demarcating the ecological red line, optimizing the ecological space protection pattern and realizing sustainable development.

2. Methods and Materials

2.1 Study area

Qionglai City, located in the southwest of Chengdu, Sichuan Province, between 30°12′N~30°33′N and 103°04′E~103°45′E. The city's total administrative area is 1377km², covering 1 street, 19 towns, and 4
townships (figure 1). Its terrain gradually slopes from the northwest to the southeast, with the highest elevation of 1991m and the lowest elevation of 451m. There are plain, mountains, hills and other landform types. The city is rich in vertical and horizontal rivers, with a total length of 271.25km. Qionglai City is a subtropical moist zone, with an average annual temperature of 16.3℃, rainfall of 1117.3mm, sunshine hours of 1107.9h, and evaporation of 28.04mm. The main soil types are gray, gray-brown alluvial and purple soil. The forest vegetation type is subtropical evergreen broad-leaved forest.

2.2 Data source and processing
The basic study data were the land use data of Qionglai City in odd years during 2003-2019. The land use data in 2009 was the data of the second national land survey of Qionglai City, classifying the land according to the GBT 21010-2007 Current Land Use Classification. The land use data of 2011, 2013, 2015, 2017, and 2019 were the annual land use change survey data of Qionglai City, which adopted the same classification system as the data of 2009. The land use data of 2003, 2005 and 2007 with that the land use patch had changed were modified one by one with the support of ESRI ArcGIS according to the second national land survey data of Qionglai City in 2009, and compared with the satellite images of Google Earth in the corresponding years. In addition, in order to determine the regional vegetation types, we also referred to the spatial distribution data of China's 1:1 million vegetation types. Due to the inconsistent coordinates of the land use, satellite imagery, and vegetation type data, we firstly unified the geographic coordinates of the data into WGS-84 coordinates and the projection into UTM projection by ESRI ArcGIS. At the same time, we transformed the land use vector data into raster data with the unified raster size of 100m×100m. Then, we divided the ecosystem types of Qionglai City into 7 categories: farmland, forest, grassland, wetland, water area, desert, and settlement by referring to authoritative research results[6,25-26] and combining with the status of the regional ecosystem, and lastly we merged the preliminary processed land use raster data according to the corresponding relationship shown in Table1 with the support of ESRI ArcGIS, so that obtained the ecological system type distribution raster data of Qionglai City during 2003-2019.
Table 1. Correspondence between ecosystem types and land use types.

| Ecosystem Type | Land Use Type                                      |
|----------------|--------------------------------------------------|
| Farmland       | Water field, Irrigated land, Dry land            |
| Forest         | Woodland, Scrubland, Other woodland, Orchard, Tea garden, Other garden land |
| Grass          | Other grass                                      |
| Wetland        | Inland beach                                     |
| Waters         | River water surface, Pond water surface, Reservoir water surface, Ditches |
| Desert         | Sand, Bare ground                                |
| Settlement     | Mining land, Scenic spots and special land, Railway land, Highway land, Facility agricultural land |

2.3 Research method

2.3.1 Dynamic identification of the ecological space

The processes and steps of ecological space identification considering the spatiotemporal dynamics of ecosystem service functions are as follows:

1) Establishing the evaluation units of ecosystem service functions for ecological space. The grid size of the evaluation units was determined to be 100m×100m after referring to the Guidelines for the Demarcation of Ecological Protection Red Line and considering the study area scope and the amount of data operation comprehensively. Then, we constructed the grid vector data of evaluation units for the ecosystem service functions of ecological space with the support of ESRI ArcGIS Create Fishnet tool. There were 139738 unit grids in the study area.

2) Calculating the ecosystem service function value of the evaluation units. The equivalent factor method has the characteristics of simple application and easy comparison of results, which is suitable for the spatiotemporal dynamic evaluation of the ecosystem service function value[27-28]. The equivalent of ecosystem service value can be directly used as a "measurement" of the size for ecosystem service functions without calculating the specific economic value of its functions, because the purpose of the research is to simulate its evolution trend based on the change characteristics of ecosystem service functions. The steps for evaluating the ecosystem service function value of the evaluation units are as follows:

First of all, determining the equivalent of ecosystem service value per unit area. We constructed the ecosystem types and their ecosystem service function systems according to the equivalent table of ecosystem service value per unit area (equivalent table)[26], and combined with the actual ecosystem types and land use types in Qionglai City. Among them, the ecosystem types were divided into 1 layer and 7 categories, which included farmland, forest, grassland, wetland, desert, water area, and settlements 7 types. The ecosystem service function types were divided into 4 first categories: provisioning service, regulation service, supporting service, and cultural service. The provisioning service included a secondary category: primary product production, which corresponded to the production of food and raw materials in the equivalent table. Regulation service included 4 secondary categories: gas regulation, climate regulation, hydrological regulation, and environmental purification, the hydrological regulation corresponded to the water supply and hydrological regulation in the equivalent table. The supporting service included 2 secondary categories: soil conservation and biodiversity conservation, the soil conservation corresponded to soil conservation and nutrient cycling in the equivalent table. Cultural service included 1 secondary category, which was completely consistent with the equivalent table. We calculated the equivalent of ecosystem service function for per unit area in the equivalent table according to the aforementioned corresponding relationship, and then obtained the equivalent of ecosystem service function for per unit area of each ecosystem in Qionglai City (table 2).
Table 2. Equivalent of ecosystem service function supplied by per unit area.

| Type of ecosystem | Provision service | Regulation service | Support service | Cultural service |
|-------------------|-------------------|--------------------|----------------|-----------------|
|                   | Primary production| Gas regulation    | Climate regulation| Environmental purification | Hydrological regulation | Soil conservation | Biodiversity | Aesthetic landscape |
| Farmland          | 1.35              | 0.89               | 0.47            | 0.14            | 0.19              | 0.68             | 0.17         | 0.08             |
| Forest            | 0.77              | 1.76               | 5.27            | 1.57            | 4.09              | 2.31             | 1.95         | 0.86             |
| Grassland         | 0.58              | 1.21               | 3.19            | 1.05            | 2.53              | 1.58             | 1.34         | 0.59             |
| Wetland           | 1.01              | 1.90               | 3.60            | 3.60            | 26.82             | 2.49             | 7.87         | 4.73             |
| Desert            | 0.00              | 0.02               | 0.00            | 0.10            | 0.03              | 0.02             | 0.02         | 0.01             |
| Water area        | 1.03              | 0.77               | 2.29            | 5.55            | 110.53            | 1.00             | 2.55         | 1.89             |
| Settlement        | 0.00              | 0.00               | 0.00            | 0.00            | 0.00              | 0.00             | 0.00         | 0.00             |

We secondly calculated the ecosystem service function value and comprehensive value of the evaluation unit. Then we counted the area of each types of ecosystem in the evaluation unit by Tabulate Area tool of ESRI ArcGIS and calculated the value of each ecosystem service function such as primary product production and gas regulation according to Eqs. (1) and lastly summarized the comprehensive value of ecosystem service function in the evaluation unit according to Eqs. (2).

\[ V_{kj} = \sum_{i=1}^{m} v_{ij}s_{ki} \]  
\[ V_k = \sum_{j=1}^{n} V_{kj} = \sum_{j=1}^{n} \sum_{i=1}^{m} v_{ij}s_{ki} \]

where \( v_{ij} \) is the equivalent of the j-th ecosystem service function of the i-th type of ecosystem. \( s_{ki} \) is the area of the i-th type of ecosystem in the k-th evaluation unit. \( V_{kj}, V_k \) are the value and comprehensive value of the j-th ecosystem service function of the k-th evaluation unit respectively. \( m, n, K \) are the number of ecosystem types, the number of ecosystem service function types and the number of evaluation units, respectively. \( i, j, k \) are the ecosystem types, ecosystem service function types, and evaluation unit number, respectively, \( i = 1, 2, ..., m; j = 1, 2, ..., n; k = 1, 2, ..., K \).

(3) Identifying ecological space. The ecosystem service functions will vary with the time and region, due to the spatiotemporal dynamics and the heterogeneity of ecological space[27-28]. Usually, the ecological space with a small range of changes is less likely to be disturbed by human beings, the structure and function of the ecosystem are more stable, and the protection of regional ecological security is more reliable, so it should be identified as ecological space. Therefore, it is necessary to identify the units whose comprehensive value of ecosystem service function is greater than or equal to the critical value and the average change rate is less than or equal to the critical value as ecological space, based on the analysis of the change range of comprehensive ecosystem service functions in a long time series, and combined with the comprehensive value of ecosystem service function.

2.3.2 Evolution Analysis of the ecological space dominant functions

The processes and steps of the analysis on evolution characteristics are as follows:

(1) Identification of dominant ecosystem service functions in ecological space. Taking the vector grid as the identification unit, the ecosystem service function type with the largest value was taken as the dominant function of the vector grid, and its collection was the dominant functional pattern of ecological space.

(2) Analysis on the evolution of dominant ecosystem service functions in ecological space. We used IDRISI software Markov module to calculate the transition probability matrix of dominant ecosystem
service functions in 2003-2007, 2007-2013 and 2013-2019, based on the grid maps of dominant ecosystem service functions in 2003, 2007, 2013 and 2019, and then analyzed the change characteristics of the quantitative structure of dominant ecosystem service functions in each stage. Meanwhile, we acquired the change types of dominant ecosystem service functions in 2003-2007, 2007-2013 and 2013-2019 with the support of ESRI ArcGIS analysis tool, after that analyzed the spatial change characteristics of dominant ecosystem service functions in each stage.

2.3.3 Evolution simulation of the ecological space dominant functions

Simulating the spatial pattern of dominant ecosystem service functions of ecological space in 2025 by using the Markov-CA composite model. The main processes and steps are as follows:

(1) Defining model parameters. We defined cell as the grid of the distribution of the dominant ecosystem service functions (the size of the grid is 100m), defined cellular space as the spatial pattern of the dominant ecosystem service functions, defined cell state as 8 types of ecosystem service functions, and used a standard $5 \times 5$ proximity filter.

(2) Verifying the model accuracy. Firstly, based on the grid maps of dominant ecosystem service functions in 2007, 2011, 2013, 2015, and 2017 selected by the evolution characteristics of dominant ecosystem service functions in ecological space and the needs of simulation data, we applied the Markov model to calculate the transition probability matrix and conditional probability map of dominant ecosystem service functions in 2015-2017, 2011-2015 and 2007-2013 with the support of IDRISI software, which were respectively used as the cellular number and spatial transformation rules of CA. Then, based on the defined parameter in Step 1 and the cellular number and spatial transformation rules of the three periods aforementioned, we applied the Markov-CA module of IDRISI software to simulate dominant ecosystem service functions in 2019 respectively. Finally, we calculated the Kappa coefficients of three simulated and actual distribution maps of dominant ecosystem service functions in 2019 to evaluate the model accuracy. The model could be used to simulate the spatial changes in case the consistency between the simulated distribution map and the actual distribution map was moderate or above, otherwise, we should adjust the model parameters or simulation data and check the accuracy until it meets the accuracy requirements.

(3) Applying models to simulate. In case the model accuracy is qualified, we could select the grid maps of dominant ecosystem service functions in 2013 and 2019 according to the time-homogeneity and no aftereffect of the Markov chain and the time interval of the accuracy evaluation data, and then set the model parameters by referring to the steps in (2) to construct the cell number and space transformation rules, after that simulated the layout of the dominant ecosystem service functions of the ecological space in 2025 by using the Markov-CA module of IDRISI software.

3 Results and analysis

3.1 Variation characteristics of the comprehensive ecosystem service functions and analysis of the results for delimiting ecological space

3.1.1 Variation characteristics of the comprehensive ecosystem service functions

The comprehensive value of ecosystem service function in Qionglai showed strong spatiotemporal dynamics with the distribution characteristic of high in the west and low in the east and high in the south and low in the north during 2003-2019 (figure 2). In the aspect of the change trend of space area, the space area with a comprehensive value of ecosystem service function greater than 6 decreased year by year, whose change range was from strong to weak and then tended to be stable. However, the space area with a comprehensive value of ecosystem service function less than 6 decreased firstly and then increased, whose change trend was unstable. In terms of spatial distribution changes, the regions whose comprehensive value of ecosystem service function reached 6 were relatively stable during 2003-2019, and it intensively and contiguously distributed in western mountain towns such as Nanbaoshan, Gaohé and central shallow hills towns such as Chayuan, Kongming, as well as some slightly scattered in the
eastern dam area.

The regions with an average annual change rate of the comprehensive value of ecosystem service function greater than 5% had obvious characteristics of the spatial distribution, and they were mainly distributed in the eastern dam area with high population density and scattered in the western valley terraces, where the areas are not suitable to be delimited as ecological space because of the concentrated human activities, great human disturbance and unstable functions. However, the areas with an average annual change rate less than 5% were mainly distributed in the western mountainous area and the shallow hilly area in the central part of Qionglai, where the human activities have less disturbance to the ecosystem. Therefore, it is more reliable to identify them as ecological space.

Therefore, the area whose comprehensive value of ecosystem service function is greater than 6 (figure 3-a) and the annual average change rate is less than 5% (figure 3-b) should be delimited as ecological space, comprehensively considering the impact of the ecosystem service function value and the change rate of the ecological space (figure 3-c).

Figure 2. Distribution map of comprehensive value of ecosystem service function in ecological space during 2003-2019.

3.1.2 Analysis of the results for delimiting ecological space

The total area of ecological space in Qionglai is 98,307hm², accounting for 71.39% of the total land area. The ecological space is concentrated and contiguously distributed in the western mountainous areas and slightly scattered in eastern dam areas such as Chayuan, Kongming. The ecological space is concentrated in these areas because the western and southern parts of the city are mainly mountainous and shallow hilly landforms, where the forests are distributed in patches and the ecosystem service function value is high and stable. The eastern part is mostly non-ecological space because it is a dam area with dense populations, well-developed transportation, and great disturbance to the ecosystem.
3.2 Analysis of the dominant function evolution characteristics in ecological space during 2003-2019

3.2.1 Quantity structure variation characteristics of the dominant ecosystem service functions
The dominant function types in ecological space all changed significantly, among which the transfer types of "primary product production → climate regulation", "climate regulation → primary product production", and "hydrological regulation → primary product production" were the most conspicuous in three periods of 2003-2019 (2003-2007, 2007-2013, and 2013-2019) (table 3). In terms of the transfer of dominant functions, the functional areas of primary product production were transferred out of 244hm², 258hm², and 542hm² respectively in the three periods, which were mainly converted to climate regulation, accounting for 79.92%, 75.19%, 83.03% of the transfer area of primary product production, and accounting for 36.11%, 20.74% and 33.86% of the total transfer area of the dominant functions in ecological space. The functional areas of climate regulation were transferred out of 215hm², 603hm², 637hm² respectively, which were mainly converted to primary product production, accounting for 93.02%, 99.17%, 95.13% of the transfer area of climate regulation, and accounting for 37.04%, 63.62% and 33.86% of the total transfer area of the dominant functions in ecological space. The transfer area of "climate regulation → primary product production" was much larger than the total area of primary product production functions transferred out from the second period, that is why the "climate regulation → primary product production" is the dominant factor for the area increase of primary product production functional areas. The area of hydrological regulation transferred was relatively small in the first two periods, and was significant in the third period. The transfer area was 150hm², which was mainly converted into the primary product production, accounting for 84.00% and 9.48% of the transfer area of the hydrological regulation functional area and the dominant functions of ecological space respectively.

Figure 3. The identification results of ecological space in Qionglai.
Table 3. The transfer area matrix of dominant ecosystem service functions of ecological space in Qionglai during 2003-2007, 2007-2013 and 2013-2019.

| Section and Type | 2003-2007 | 2007-2013 | 2013-2019 |
|------------------|-----------|-----------|-----------|
|                  | P(hm²)    | C(hm²)    | H(hm²)    | P(hm²)    | C(hm²)    | H(hm²)    | P(hm²)    | C(hm²)    | H(hm²)    |
| P(hm²)           | 29083     | 200       | 59        | 29084     | 598       | 65        | 29205     | 606       | 126       |
| C(hm²)           | 195       | 55201     | 22        | 194       | 54815     | 14        | 450       | 54386     | 24        |
| H(hm²)           | 49        | 15        | 13483     | 64        | 5         | 13468     | 92        | 31        | 13387     |

Note: P, C, H represent primary product production, climate regulation, and hydrological regulation, respectively.

3.2.2 Spatial layout variation characteristics of the dominant ecosystem service functions

The spatial distribution of the "primary product production → climate regulation" showed consistency and continuity, mainly distributed in western mountainous areas during 2003-2019. It was concentrated in the southwest of Wolong with the highest degree of agglomeration during 2007-2013 and was scattered in the western mountainous area during 2013-2019. The transfer type of “primary product production → climate regulation” was promoted because of the rugged terrain, dense forest, low traffic accessibility and low population density in the western mountainous areas, the increase of farmland abandoned by farmers, and the government's ecological protection policies such as returning farmland to forest (figure 4).

The change type of "climate regulation → primary product production" distributed in the western mountainous area sporadically, with the smallest distribution range and the highest dispersion degree during 2003-2007. The spatial distribution showed obvious agglomeration, which mainly concentrated in Pingle, Linji, Jiaguan, the southwest of Guyi and Huilong, as well as the agglomeration degree in the southwest region was higher than that in the southeast region during 2007-2013. It mainly distributed in the southwest and northwest of the city with vast distribution range during 2013-2019. This is because southwest and northwest regions develop tourism industry vigorously with the rich tourism, and the human interference may affect the stability of the forest ecosystem functions. In addition, the need of food security and farmland protection have led to the transfer of climate regulation function to the primary product production (figure 4).

The change type of "hydrological regulation → primary product production" concentrated in the central and southern part of Wolong and Guyi as well as the northwest of Datong county during 2013-2019. According to the Control Plan of Urban Modern Agricultural Industry in Qionglai City, Qionglai continued to optimize and adjust the agricultural industrial structure and implemented moderate scale management in recent years. As a result, some ponds with small storage capacity and low development and utilization value in the area were planned to be adjusted to the corresponding agricultural industrial areas, which generated the transfer of hydrological regulation function to the primary product production (figure 4).
3.3 Analysis of the spatial variation simulation results for the ecological space dominant functions in 2025

3.3.1 Accuracy of the spatial variation simulation results

We adopted the Kappa coefficient classification standard put forward by Feinstein[29-30] to evaluate the simulation effect of the model (When 0.81< Kappa< 1.00, it indicates that the consistency of the two images is the best). The Kappa coefficient of time gradient of 2, 4, 6 years were 0.9737, 0.9730, 0.9689 respectively (table 4), which indicated that the consistency between the simulation results and the actual distribution decreased slowly with the increase of the gradient, but both of them reached the optimal level. So the results showed that the model is reliable and can be used to simulate the spatial changes of ecosystem service functions.

| Basic data | Time gradient | Simulation/test data | Kappa coefficient |
|------------|---------------|----------------------|-------------------|
| Distribution map of dominant ecosystem service functions in 2015 and 2017 | 2 | Distribution map of dominant ecosystem service functions in 2019 | 0.9737 |
| Distribution map of dominant ecosystem service functions in 2011 and 2015 | 4 | Distribution map of dominant ecosystem service functions in 2019 | 0.9730 |
| Distribution map of dominant ecosystem service functions in 2007 and 2013 | 6 | Distribution map of dominant ecosystem service functions in 2019 | 0.9689 |

3.3.2 Analysis of the spatial simulation results

The ecological space will still maintain three dominant functions including primary product production, climate regulation and hydrology regulation in 2025, whose area is 32793hm², 52490hm² and 13024hm² respectively, accounting for 33.36%, 53.39% and 13.25% of the total ecological space. The functional
areas of primary product production are concentrated in the southwest, northwest and central south, and else is scattered in the western valley area (figure 5-a). The region is to be delimited as the functional areas of primary product production because that it is located in mountain valley and central plain with good irrigation conditions, fertile soil and high primary product production capacity. The functional areas of climate regulation are concentrated in the western mountainous areas, and others are rarely scattered in the southwest of Mouli and southeast of Huilong. It is practical to delineate this area as a climate regulation functional area, because the area is a concentrated forest distribution area, and green plants can regulate atmospheric oxygen and carbon dioxide, and they can also regulate the regional microclimate. The functional areas of hydrological regulation are mainly distributed in the Xiejiang River, Nanhe River and Xihe River basins, and others are rarely scattered in the pits and large ditches in the eastern dam area. It is reasonable to delimit the River systems, reservoirs, and weir ponds as hydrological regulation areas because of the strong ability of regulating the spatiotemporal distribution of water resources they have.

Here are two obvious transfer types of dominant functions including "climate regulation → primary product production" and "hydrological regulation → primary product production" during 2019-2025 (table 5). In the aspect of the transfer of dominant functions, the climate regulation functional area continues the transfer trend during 2003-2019 and transfers out of 2370hm², which is mainly converted to primary product production, accounting for 80.02% of the total transfer area of dominant functions in ecological space. The hydrological regulation functional area shows a transfer trend of increasing year by year on the basis of 2003-2019 and transfers out of 533hm², which is mainly converted to primary production function, accounting for 18.36% of the total transfer area of dominant functions in ecological space.

Table 5. The characteristics of quantitative structural of dominant ecosystem service functions of ecological space in Qionglai in 2019-2025.

| TYPE | P(hm²) | C(hm²) | H(hm²) | The area in 2025(hm²) |
|------|--------|--------|--------|---------------------|
| P(hm²) | 29937  | 2323   | 533    | 32793               |
| C(hm²) | 0      | 52490  | 0      | 52490               |
| H(hm²) | 0      | 47     | 12977  | 13024               |
| The area in 2019 (hm²) | 29937  | 54860  | 13510  | 98307               |

Note: P, C and H have the meanings stated above.

In the future, there will still be different degrees of conversion between the dominant ecosystem service functions of ecological space in Qionglai City (figure 5-b). Among them "climate regulation → primary product production" is mainly distributed in Tiantaishan, Huojing, etc., and partly distributed in the central and southern part of the regions with the widest distribution range and the largest change area. The change type of "hydrological regulation → primary product production" is concentrated in Wolong, Baolin and Guyi in the central south, and others is rarely scattered in Shuikou and Datong in the northwest with narrow distribution range and small change area. It is quite possible and in line with the actual regional development plan for some hydrological regulation functional areas to be transformed into primary product production functional areas in the future, because the central and southern part of Qionglai City will be planned as an agricultural park to implement the construction of high-standard farmland vigorously, according to the Guidelines for the Application of Construction Projects of Qionglai City's Municipal Finance Modern Agricultural Industrial Functional Zone (Park) in 2019.
4. Conclusions
To resolve the problems in the current theoretical and practical research, this study tried to delimit ecological space and simulate its spatial change at the county scale from the perspective of dynamic changes in ecosystem service functions. The main conclusions are as follows:

(1) From 2003 to 2019, the comprehensive value of ecosystem service function showed a distribution characteristic of high in the west and low in the east in Qionglai City, which showed strong spatiotemporal heterogeneity, and the critical value of its comprehensive function value and annual average change rate was 6% and 5%, respectively. The ecological space area of Qionglai City was 98,307hm², accounting for 71.39% of the total land space area, which was mainly concentrated in the west and central south.

(2) From 2003 to 2019, the dominant ecosystem service functions of ecological space in Qionglai City had shifted to varying degrees, and showed strong dynamics. During 2003-2007, 2007-2013, 2013-2019, the transfer types of dominant ecosystem service functions mainly included "primary product production → climate regulation", "climate regulation → primary product production", and "hydrological regulation → primary product production".

(3) The ecological space will still maintain the three dominant functions including primary product production, climate regulation and hydrological regulation in 2025. The area of these function space is 32793hm², 52490hm² and 13024hm², and accounts for 33.36%, 53.39% and 13.25% of the total ecological space, respectively. The dominant ecosystem service functions will still undergo varying degrees of transfer, showing obvious non-stationarity. The main transfer types of dominant ecosystem service functions are "climate regulation → primary product production" and "hydrological regulation → primary product production".

In conclusion, this study had made three beneficial achievements: Firstly, we established a method for delimiting ecological space on the basis of the dynamics of ecosystem service functions, which enhanced the rationality and reliability of ecological space delineation. Secondly, we further confirmed the non-stationary nature of the dominant ecosystem service functions, and proposed a suggestion for reasonably simulating the dominant ecosystem service functions according to its dynamics during the process of conducting ecological function zoning and other related planning. Thirdly, we successfully realized the objective of simulating the spatial change of the dominant ecosystem service functions with the Markov-CA model, and provided a useful method and a valuable results reference for simulating the spatial change of dominant ecosystem service functions in the ecological space. However, this study still had some flaws in data. The time interval of the first period was 2 years less than that of the second and third periods during the process of analyzing the evolution characteristics of the dominant ecosystem.
service functions, because the land use data in 2002 and 2003 couldn’t be obtained by interpreting with the poor quality of remote sensing images. In the future, we can conduct the study at equal intervals by using other methods to obtain land use data with a larger time span.

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