Postprint: Habitat Quality Prediction in the Ili River Valley under Human Activities and Climate Change

Authors: Sui Lu

Date: 2024-01-29T00:00:00+00:00

Abstract

Habitat quality serves as a crucial indicator for measuring ecosystem service functions and their health status, and accurately predicting its evolution is essential for promoting high-quality development of regional ecological environments. This study couples the System Dynamics-Patch-generating Land Use Simulation (SD-PLUS) model with the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model to predict land use/cover pattern changes in the Ili River Valley by 2035 under different climate scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5), and evaluates the spatiotemporal evolution characteristics of habitat quality. The results indicate that: (1) From 1980 to 2020, land use types in the Ili River Valley exhibited a "four increases and two decreases" trend. Under the four climate scenarios in 2035, forest and grassland areas in the Ili River Valley will experience substantial reductions, while construction land expansion will be notably prominent, encroaching upon high-quality cultivated land resources in suburban areas. (2) Habitat quality levels in the Ili River Valley are closely correlated with land use/cover types. Areas with high and relatively high habitat values are primarily distributed in forest and grassland cover regions with rugged terrain, whereas low and relatively low value areas are mainly located in zones of concentrated human activity and unused land cover regions in the northern and southern Tianshan Mountains. (3) From 1980 to 2020, habitat quality in the Ili River Valley demonstrated a declining trend. Habitat quality degradation areas are predominantly distributed in the Ili River-Künes River basin and vicinity of the Tekes River basin. (4) Under the four climate scenarios in 2035, the habitat index in the Ili River Valley continues to decline. The ranking of mean habitat index values is: SSP1-2.6 > SSP2-4.5 > SSP3-7.0 > SSP5-8.5. Regions including Yining City, border ports, and agricultural and pastoral bases face risks of habitat quality degradation. The research findings can provide a reference basis for formulating ecological

restoration policies in the Ili River Valley region and offer new insights for habitat quality prediction in arid and semi-arid zones.

Full Text

Prediction of Habitat Quality in the Ili River Valley Under the Influence of Human Activities and Climate Change

SUI Lu[1], YAN Zhiming[2], LI Kaifang[3], HE Peien[1], MA Yingjie[1], ZHANG Rucui[1]

[1]Faculty of Public Administration (Faculty of Law), Xinjiang Agricultural University, Urumqi 830052, Xinjiang, China
[2]Education Center, Xinjiang Agricultural University, Urumqi 830052, Xinjiang, China
[3]School of Geography and Ocean Science, Nanjing University, Nanjing 210023, Jiangsu, China

Abstract: Habitat quality serves as a crucial indicator for measuring ecosystem service functions and overall health, and accurate prediction of its evolution is essential for promoting high-quality regional ecological development. This study coupled the System Dynamics–Patch-generating Land Use Simulation (SD-PLUS) model with the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model to forecast land use/cover pattern changes and evaluate the spatiotemporal evolution of habitat quality in the Ili River Valley under four climate scenarios (SSP1-2.6, SSP3-7.0, SSP2-4.5, SSP5-8.5) for 2035. The results reveal: (1) From 1980 to 2020, land use in the Ili River Valley exhibited a "four increases, two decreases" pattern. Under all four climate scenarios for 2035, forest and grassland areas show substantial declines, while construction land expansion becomes increasingly prominent, encroaching upon high-quality suburban farmland. (2) Habitat quality levels in the Ili River Valley are closely correlated with land use/cover types. High and relatively high value areas are predominantly distributed in rugged forest and grassland cover regions, whereas low and relatively low value areas are mainly concentrated in human activity agglomerations and unused land cover zones in the northern and southern Tianshan Mountains. (3) From 1980 to 2020, habitat quality in the Ili River Valley demonstrated a declining trend, with degradation zones primarily located near the Ili, Kunes, and Tekes River basins. (4) Under the four climate scenarios for 2035, the habitat index continues to decline, with mean values ranking as: SSP1-2.6 > SSP2-4.5 > SSP3-7.0 > SSP5-8.5. Areas including Yining City, border ports, and agricultural-livestock bases face habitat quality degradation risks. These findings provide reference for ecological restoration policy formulation in the Ili River Valley and offer new perspectives for habitat quality prediction in arid and semi-arid regions.

Keywords: habitat quality; climate change scenarios; SD-PLUS model; InVEST model; Ili River Valley

Introduction

Habitat quality refers to the capacity of the natural environment to provide suitable living conditions for species, reflecting regional ecosystem service values and serving as a prerequisite for harmonious human-nature coexistence. With the advancement of new industrialization and urbanization, China's territorial development patterns have undergone dramatic transformations, leading to habitat fragmentation, reduced ecosystem service values, and biodiversity loss in some regions, thereby threatening human well-being. Arid and semi-arid areas constitute vital components of China's ecosystems, yet their harsh natural geographical conditions mean that once degraded, habitats become extremely difficult to restore, demanding heightened attention to ecological evolution in these regions during ecological civilization construction.

Previous habitat quality research has primarily focused on land use type changes. With the emergence and maturation of new models, numerous scholars have investigated future land use change impacts on habitat quality under various development scenarios, establishing a solid foundation for understanding land cover change effects on habitat quality. However, several limitations persist. First, climate factors are often neglected in scenario design. The Intergovernmental Panel on Climate Change (IPCC) reports indicate that human activities have triggered global warming, a trend projected to continue through the mid-21st century, which undoubtedly increases challenges for ecological protection in arid and semi-arid regions. Second, previous predictions frequently exhibit arbitrary and subjective settings for land use quantity demand transfers across scenarios, introducing uncertainty that compromises the practical utility of research findings.

System Dynamics (SD) models can reflect nonlinear dynamic changes in complex system structures and interactions among components, serving as structural models for predicting system dynamic behaviors under various future conditions. Integrating the top-down SD model for land quantity demand prediction with the bottom-up PLUS model for land spatial distribution simulation enables more accurate forecasting of future land change trends. The Ili River Valley, as Xinjiang's western gateway for opening-up, possesses significant advantages and potential in the "Belt and Road" initiative. Its abundant water, soil, light, heat, and mineral resources have established it as a nationally important agricultural, pastoral, and energy base. Since the 1980s, intensified development activities in agriculture, animal husbandry, mineral extraction, and tourism have increasingly disturbed the valley's ecological environment. Balancing ecological security and economic development has become an urgent issue for regional planning.

This study coupled the SD-PLUS and InVEST models to predict land use/cover and habitat quality spatiotemporal evolution under four typical climate scenarios (SSP1-2.6, SSP3-7.0, SSP2-4.5, SSP5-8.5) for the Ili River Valley, providing reference for optimal land resource allocation and ecological protection restoration.

1.1 Study Area Overview

The Ili River Valley (80°09 –84°56 E, 42°14 –44°50 N) is located in northwestern Xinjiang, China, within the Ili Kazakh Autonomous Prefecture. The valley is surrounded by mountains on three sides (north, east, and south), with elevations ranging from 532 to 5741 m. The terrain slopes from high in the east to low in the west, forming a trumpet-shaped opening facing westward. The region experiences a temperate continental climate, yet its unique topography allows it to receive moisture from the Atlantic Ocean year-round, earning it the reputation of a "wet island" with a mild and humid climate. The annual average temperature is 10.4°C, with annual precipitation of 417.6 mm, reaching up to 1000 mm in high-altitude areas.

1.2 Data Sources

Land use data for 1980–2020, population density, annual average temperature, annual precipitation, rivers, and roads were obtained from the Chinese Academy of Sciences Resource and Environmental Data Center (http://www.resdc.cn/). Elevation data were sourced from the Geospatial Data Cloud Platform (http://www.gscloud.cn/). Socioeconomic data were derived from the Xinjiang Statistical Yearbook and Ili Kazakh Autonomous Prefecture Statistical Yearbooks. Future population, GDP, and urbanization rate data were obtained from shared research results in the Shared Socioeconomic Pathways (SSPs) gridded population and economic dataset and China's provincial urbanization rate prediction dataset. Future temperature and precipitation data were sourced from the CMIP6 climate dataset released by the Beijing Climate Center (https://esgf-node.llnl.gov/search/cmip6/).

1.3.1 System Dynamics (SD) Model

The SD model treats the study area as a relatively independent regional system and achieves system simulation with the assistance of Vensim software. Drawing on previous experience, this study constructed a simulation model suitable for the Ili River Valley. As shown in Figure 2, the simulation model comprises four subsystems: economic, population, climate, and land use. The model establishes causal relationships among subsystems based on internal information feedback mechanisms. Through iterative debugging of relationships between auxiliary and level variables, the system flow diagram and mathematical equations were determined. The simulation process involves two steps: first, using collected historical data from 1980–2020 for model validation; second, predicting land use quantity demand under multiple scenarios from 2020–2035 once accuracy requirements are met.

1.3.2 Patch-Generating Land Use Simulation (PLUS) Model

The PLUS model is a land use change simulation model generated from grid patches that better explores the drivers of various land type changes and simulates changes at the land parcel level within a few meters. The model includes a Land Expansion Analysis Strategy (LEAS) module and a Cellular Automata (CA) module based on multi-class random patch seeds. The LEAS module extracts and analyzes the expansion portion between two periods of land use change, employs random forest algorithms to mine development probabilities for each land type and contribution rates of various driving factors. The CA module combines random seed generation with a threshold decrement mechanism to simulate spontaneous patch generation under development probability constraints. In the model, land expansion from 2010–2020 was analyzed to set neighborhood weights for each land type's transfer rules from 2020–2035.

1.3.3 Climate Scenario Settings

Climate scenarios represent special settings that rationally describe future climate condition spatiotemporal distributions based on scientific assumptions. The Sixth International Coupled Model Intercomparison Project combines Shared Socioeconomic Pathways (SSPs) with the latest anthropogenic emission trends to predict future climate change trends, providing possibilities for forecasting habitat quality evolution under future climate change scenarios.

1.3.4 Habitat Quality Assessment

This study applied the InVEST Habitat Quality module to generate habitat quality maps reflecting the Ili River Valley's habitat conditions. The calculation formula is as follows:

$$Q_{xj} = H_j \left(1 - \frac{D_{xj}^z}{D_{xj}^z + k^z}\right)$$

where Q_{xj} represents the habitat index for land type j in spatial unit x; H_j is the habitat suitability of land type j; z is the model default value; k is the half-saturation parameter; and D_{xj} is the habitat threat level for land type j in spatial unit x, calculated as:

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{w_r}{\sum_{r=1}^{R} w_r}\right) r_y i_{rxy} \beta_x S_{jr}$$

where R represents threat factors; Y_r is the quantity of threat factor r; w_r is the weight of threat factor r; r_y is the quantity of threat factor r in spatial unit y; i_{rxy} is the impact of threat factor r in spatial unit y on spatial unit x; β_x is the protection level of spatial unit x; and S_{jr} is the sensitivity of land type j to threat factor r.

This study selected cultivated land, construction land, unused land, railways, and expressways—areas heavily disturbed by human activities—as threat factors. Based on previous research, threat factor parameters and habitat suitability values for each land type were established (Tables 2 and 3).

2.1 SD-PLUS Integrated Model Accuracy Validation

The SD model simulation results show that from 1980–2020, the relative error between simulated and actual values for all variables remained within 5%, indicating high simulation accuracy and effective prediction of land use structure changes in the study area. The Kappa simulation achieved an overall accuracy of 85.7%. The raster quantities of various land types derived from the simulation were input into the PLUS model to obtain the 2020 land use spatial distribution simulation results for the Ili River Valley (Figure 3). The simulated distribution patterns closely matched actual distributions across the valley, with high consistency observed in the spatial distribution of land use types across six selected local areas. These results demonstrate that the system flow diagram, mathematical equations, development probabilities, and driving factors constructed by the SD-PLUS integrated model align with actual conditions in the Ili River Valley, effectively representing regional land use dynamics and proving suitable for modeling future land use/cover changes.

2.2 Land Use/Cover Evolution in the Ili River Valley

From 1980 to 2020, the Ili River Valley's land use/cover types were dominated by grassland, cultivated land, and forest, collectively accounting for approximately 95% of the total study area. During this period, the area of cultivated land, construction land, unused land, and water bodies increased by 2793.30 km^2, 83.70 km^2, 71.42 km^2, and 35.57 km^2 respectively, while grassland and forest areas decreased by 3324.82 km^2 and 295.14 km^2 respectively. The total land transfer area reached 6002.29 km^2, with grassland transfer accounting for the largest proportion at 71.42%. Grassland transferred 3516.12 km^2 to cultivated land, 255.03 km^2 to unused land, 202.37 km^2 to construction land, and 153.43 km^2 to water bodies, indicating that grassland served as the primary contributor to increased area of other land types (Table 5). Notably, due to the unique "three mountains embracing two valleys" topography, the area suitable for human development and construction is limited. Consequently, construction land expansion during 1980–2020 encroached upon 295.04 km^2 of high-quality suburban farmland.

The SD-PLUS integrated model predictions reveal that from 2020–2035, cultivated land, forest, and grassland areas will primarily show declining trends, while water bodies, construction land, and unused land areas will increase (Figure 4). Under the SSP1-2.6 scenario, ecological land areas (forest, grassland, water) account for a larger proportion than in other scenarios, with unused land effectively developed and construction land growth most gradual. Under SSP5-8.5, ecological land areas decline most dramatically, construction land surges, and uncontrolled human expansion activities such as rampant mining and unrestrained fossil fuel combustion cause permanent glacier melting and snow line elevation in the north and south Tianshan Mountains, substantially increasing water and unused land areas. The SSP2-4.5 and SSP3-7.0 scenarios, which resemble current development patterns and prioritize regional development respectively, show moderate fluctuations in various land type areas between these two extreme climate scenarios.

2.3 Habitat Quality Assessment in the Ili River Valley

Overall, the Ili River Valley exhibits relatively good habitat quality, with higher-value areas dominating and comprising 65.2% of the total study area. Temporally, the mean habitat index values were 0.715 in 1980, 0.711 in 2000, 0.703 in 2020, and are projected to be 0.699 (SSP1-2.6), 0.698 (SSP2-4.5), 0.696 (SSP3-7.0), and 0.694 (SSP5-8.5) in 2035, showing a continuous declining trend. Spatially, habitat quality exhibits a zonal nested distribution pattern (Figure 5). Habitat quality levels are closely linked to land use/cover types: high- and higher-value areas are mainly distributed in forest and grassland regions with high vegetation coverage, typically featuring rugged terrain with minimal human disturbance; low- and lower-value areas are primarily located in valley urban agglomerations, glacier-snow cover zones in the north and south Tianshan Mountains, and alluvial plain cultivation areas, which experience significant human impacts and relatively fragile resource environments.

The InVEST model projections for future habitat quality (Figure 5) indicate that under all four climate scenarios in 2035, the mean habitat index shows a downward trend, ranking as SSP1-2.6 > SSP2-4.5 > SSP3-7.0 > SSP5-8.5. Compared with 2020, SSP1-2.6 shows the smallest decline of 0.004, with high-value habitat area increasing by 0.89% and low-value area lower than other scenarios. SSP2-4.5 shows a decline of 0.005, with high-value habitat proportions similar to 2020 levels and low-value proportions only higher than SSP1-2.6. SSP3-7.0 exhibits a more significant decline of 0.007, with high-value area proportion decreasing by 0.89% and lower-value area proportion second only to SSP5-8.5. SSP5-8.5 shows the most severe decline of 0.009, with the lowest proportion of high-value habitat and the highest proportion of low-value habitat among all scenarios.

2.4 Habitat Degradation in the Ili River Valley

Habitat degradation refers to the phenomenon of habitat quality decline and reduced capacity to support biological communities caused by human activities and natural factors. Using the raster calculator tool in ArcGIS 10.8, two-period habitat quality raster layers were overlaid and analyzed to generate a habitat quality degradation map for the Ili River Valley. From 1980–2020, most areas maintained relatively stable habitat quality. Regions such as the southern slopes of the Keguqin-Boluokenu Mountains and northern slopes of the Haerketu-Nalati Mountains benefit from abundant rainfall and lush vegetation growth due to topographic conditions, experiencing minimal human impact and insignificant habitat degradation. Significant degradation zones are mainly distributed in agricultural cultivation belts along the Ili, Kunes, and Tekes River valleys, where the "Yining-Horgos" urban agglomeration shows high habitat degradation clustering. The extensive construction of the Kokdala Industrial Park has caused the most severe degradation, while agricultural and pastoral development in northeastern Gongliu County and northwestern Xinyuan County has exceeded natural resource carrying capacity, resulting in noticeable quality decline. Additionally, the development of horse breeding and tourism in Zhaosu County has created pressure on local ecological protection.

To enhance reference value, this study visualizes degradation levels using natural breaks classification into five categories: cold spot, sub-cold spot, non-significant, sub-hot spot, and hot spot zones. Under SSP1-2.6, cold spot areas dominate, indicating minimal habitat degradation. Under SSP2-4.5, SSP3-7.0, and SSP5-8.5 scenarios, hot spot, sub-hot spot, and sub-cold spot areas increase. The ranking of counties with ecological degradation hot spots is SSP5-8.5 > SSP3-7.0 > SSP2-4.5 > SSP1-2.6. Bayandai Town in Yining City represents a hot spot across all scenarios, while border ports at Horgos and Dulata, agricultural-livestock bases such as Xinyuan County's Breeding Sheep Farm and Public Security Farm, and Gongliu County's Cattle Farm and Comprehensive Farm all face habitat quality degradation risks. At the county level, Yining County, Qapqal Xibe Autonomous County, Gongliu County, Xinyuan County, and Huocheng County exhibit significant degradation, while Nileke County and Zhaosu County maintain relatively stable habitat quality.

Regarding habitat quality centroid shifts (Figure 7), low-value and higher-value area centroids show noticeable southeastward movement under all four climate scenarios, while high-value and lower-value centroids exhibit smaller shifts. Under SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5, low-value centroids shift southeastward by 32.24 km, 35.57 km, 43.83 km, and 67.65 km respectively, while higher-value centroids shift southeastward by 25.24 km, 60.73 km, 42.21 km, and 66.28 km respectively. These results indicate that the Ili River Valley must strengthen protection of grassland ecosystems in southeastern areas to prevent grassland degradation and ecological patch fragmentation caused by human activities and climate change.

3.1 Habitat Quality Prediction Study in the Ili River Valley

Constructing habitat quality evaluation models to predict future ecological evolution and degradation under different development scenarios provides valuable reference for local ecological protection measures. This study comprehensively considers impacts from both human activities and climate factors, addressing the current research gap of insufficient climate change consideration in habitat quality prediction. Additionally, the SD-PLUS integrated model incorporates multi-source data including SSP-based population, urbanization rate, GDP, and CMIP6 temperature and precipitation data to construct land use feedback mechanisms based on historical data, enabling prediction of land use quantity demand under multiple climate scenarios and simulation of spatial distribution patterns through the PLUS model.

This integrated approach reduces the arbitrariness and uncertainty in land type transfer quantity settings, yielding more accurate simulations. Results indicate that from 1980–2020, habitat quality in the Ili River Valley continuously declined, and under all four climate scenarios for 2035, the habitat index maintains a downward trend, suggesting serious ecological challenges. These findings align with research by Zhu Zengyun et al. [?].

3.2 Response of Habitat Quality to Land Use/Cover Change

Habitat quality levels in the Ili River Valley are intimately linked to land use types. Spatially, high and relatively high habitat value areas are distributed in rugged forest and grassland cover regions, while low and relatively low value areas are concentrated in human activity agglomerations and unused land cover zones in the north and south Tianshan Mountains. From a degradation perspective, degradation zones during 1980–2020 were primarily located in the Ili, Kunes, and Tekes River basins, where industrial and agricultural production activities caused land type conversions, reducing ecosystem service values and habitat quality along river corridors.

Land development intensity ranking follows SSP5-8.5 > SSP3-7.0 > SSP2-4.5 > SSP1-2.6, with research showing that development intensity negatively correlates with habitat quality, consistent with findings by Yang Zhipeng et al. [?]. Regarding centroid shifts, the most significant movements occur in low-value and higher-value areas, associated with large-scale grassland degradation to unused land in southern and eastern regions and ecological patch fragmentation in southeastern areas, aligning with research by Yan Junjie et al. [?]. These conclusions comprehensively demonstrate land use change impacts on habitat quality, highlighting that rational territorial spatial planning represents an effective pathway for improving habitat quality in the Ili River Valley.

3.3 Recommendations and Prospects for Ecosystem Management in the Ili River Valley

As a strategic node in China's western development and a region surrounded by extremely arid deserts and Gobi in the hinterland of the Eurasian continent, strengthening ecological protection and restoration in the Ili River Valley is crucial for building a northwestern ecological security barrier. Despite existing regulations such as the Ili River Valley Ecological Environmental Protection

Regulations and the Million-Mu Ecological Economic Forest Construction and Ecological Restoration Engineering Plan, predictions show continuous habitat quality decline across all climate scenarios, indicating that ecological restoration policies alone are insufficient. Habitat quality evolution is closely related to land use/cover change, making rational land resource optimization an effective approach for improving habitat quality and preventing degradation.

To address three major ecological issues—continuous grassland area decline, "sprawl-style" construction land expansion, and suburban farmland encroachment—the Ili River Valley must strictly follow the Ili Prefecture Territorial Spatial Master Plan (2021–2035) by constructing valley and border urban development axes, strengthening regional center functions in Yining City, Horgos City, and Xinyuan County, promoting intensive development, and guiding relatively concentrated population and industry layout. Simultaneously, the region should consolidate its agricultural foundation, strengthen cultivated land protection, ensure food security, strictly implement cultivated land and permanent basic farmland protection tasks to prevent "non-agriculturalization" and "non-grainization," and advance supplementary cultivated land reserve improvement. For grassland ecosystem protection, the region should continue implementing subsidy and reward mechanisms for grassland-livestock balance, grazing bans, and herder production support, while enhancing dynamic monitoring of grassland degradation to improve coverage and productivity.

This study coupled the SD-PLUS and InVEST models to predict spatiotemporal patterns of land use/cover and habitat quality under typical climate scenarios, providing basis and reference for ecological environmental protection and sustainable development in the Ili River Valley. However, limitations exist. First, the SD model uses multi-source data for climate scenario prediction, including global or national-scale future population, urbanization rate, GDP, temperature, and precipitation data, whose precision and inter-data matching require further consideration. Second, the Ili River Valley features complex topography with significant relief. Research by Jia Lei et al. [?] demonstrates that topographic gradient effects have absolute influence on habitat quality in mountainous cities. Future research could explore topographic gradient effects on habitat quality in the Ili River Valley to provide scientific references for regional biodiversity conservation and ecological security pattern construction.

4 Conclusions

1. This study employed the SD-PLUS integrated model to simulate future land use type quantity and spatial evolution. The SD model controlled errors within 5% when determining land use demand, with Kappa simulation achieving 85.7% overall accuracy, demonstrating the model's suitability for future land use/cover evolution and habitat quality prediction research in the Ili River Valley.

2. From 1980–2020, the Ili River Valley exhibited a "four increases, two de-

creases" trend in land type areas. SD-PLUS model predictions indicate that under four climate scenarios for 2035, cultivated land, forest, and grassland areas will primarily decline, while water bodies, construction land, and unused land areas will increase.

3. Habitat quality levels in the Ili River Valley are closely correlated with land use/cover types. High-value habitat areas are mainly distributed in forest and grassland cover regions, while low-value areas are concentrated in human activity agglomerations and unused land cover zones in the north and south Tianshan Mountains.
4. From 1980–2020, the habitat index in the Ili River Valley showed a declining trend. Under four climate scenarios for 2035, the habitat index continues to decline, with mean values of 0.699, 0.698, 0.696, and 0.694 respectively. Habitat degradation zones from 1980–2020 were mainly concentrated in the Ili, Kunes, and Tekes River basins. Under the four climate scenarios, habitat degradation ranks as SSP5-8.5 > SSP3-7.0 > SSP2-4.5 > SSP1-2.6. Areas including Bayandai Town in Yining City, Horgos and Dulata border ports, Xinyuan County's Breeding Sheep Farm and Public Security Farm, and Gongliu County's Cattle Farm and Comprehensive Farm face habitat quality degradation risks. Future development in the Ili River Valley must prevent grassland degradation and ecological patch fragmentation caused by human activities and climate change, and avoid southeastward shifts of low-value and higher-value habitat areas.

References

[1] Ji Yongfan, Jia Lujing, Yang Lian'an, et al. Spatiotemporal evolution and prediction analysis of habitat quality in Yulin City coupled with InVEST-PLUS model[J]. Journal of Soil and Water Conservation, 2023, 37(1): 123-132.

[2] Feng Wenbin, Lin Meizhen, Gong Jianzhou, et al. Spatiotemporal differentiation of habitat quality in Zhongshan City based on InVEST model[J]. Ecological Science, 2022, 41(3): 16-23.

[3] Hu Feng, Zhang Yan, Guo Yu, et al. Spatial and temporal changes in land use and habitat quality in the Weihe River Basin based on the PLUS and InVEST models and predictions[J]. Arid Land Geography, 2022, 45(4): 1125-1136.

[4] Tang Jiaojiao, Yu Cheng, Zhang Weiwei, et al. Habitat quality assessment and prediction in Suzhou based on CLUE and InVEST models[J]. Journal of Environmental Engineering Technology, 2023, 13(1): 377-385.

[5] Wan Xinru, Cheng Chaoyuan, Bai Defeng, et al. Ecological impacts of climate change and adaptation strategies[J]. Bulletin of Chinese Academy of Sciences, 2023, 38(3): 518-527.

[6] Chen Yan, Wu Rui, Ma Yuewei, et al. Spatial and temporal differentiation and simulation of habitat quality in typical karst areas[J]. Journal of Ecology

and Rural Environment, 2022, 38(12): 1593-1603.

[7] Sui Lu, Pu Chunling, Liu Zhiyou, et al. Trade-off synergy of ecosystem service value in Urumqi City based on PLUS model[J]. Arid Land Geography, 2023, 46(1): 159-168.

[8] Yu Zhonglei, Zhang Wenxin, Liang Jinshe, et al. Progress in evaluating suitability of spatial development and construction land[J]. Progress in Geography, 2015, 34(9): 1107-1122.

[9] Wang Z Y, Li X, Mao Y T, et al. Dynamic simulation of land use change and assessment of carbon storage based on climate change scenarios at the city level: A case study of Bortala, China[J]. Ecological Indicators, 2022, 134: 108499, doi: 10.1016/j.ecolind.2021.108499.

[10] Wang Chao, Chang Yong, Hou Xiyong, et al. Temporal and spatial evolution characteristics of habitat quality in Jiaodong Peninsula based on changes of land use pattern[J]. Journal of Geo-information Science, 2021, 23(10): 1809-1822.

[11] Hu Yeting, Li Tianhong. Forecasting spatial pattern of land use change in rapidly urbanized regions based on SD model[J]. Acta Scientiarum Naturalium Universitatis Pekinensis, 2022, 58(2): 372-382.

[12] Wu J, Luo J, Zhang H, et al. Projections of land use change and habitat quality assessment by coupling climate change and development patterns[J]. Science of the Total Environment, 2022, 847: 157491, doi: 10.1016/j.scitotenv.2022.157491.

[13] Cui Wenbing, Hou Guobo, Chen Wanji, et al. Landscape pattern analysis of land use in Yili River Valley based on multi-scenario simulation[J]. Water Resources and Hydropower Engineering, 2023, 54(9): 1-12.

[14] Chen Zhu'an, Liu Ziqiang, Zhang Liting, et al. Multi-scenario simulation of LUCC and spatiotemporal evolution and prediction of habitat quality in Nanchang[J]. Transactions of the Chinese Society for Agricultural Machinery, 2023, 54(5): 170-180.

[15] Jiang Tong, Su Buda, Wang Yanjun, et al. Gridded datasets for population and economy under shared socioeconomic pathways for 2020—2100[J]. Climate Change Research, 2022, 18(3): 381-383.

[16] Wang K C, Wang C, Cai W J, et al. Projected provincial urbanization rate for China[J]. Scientific Data, 2020, 83(7): 421, doi: 10.1038/s41597-020-0421-y.

[17] Tian He, Liang Xun, Li Xia, et al. Simulating multiple land use scenarios in China during 2010—2050 based on system dynamic model[J]. Tropical Geography, 2017, 37(3): 547-561.

[18] Zhang P, Liu L, Yang L W, et al. Exploring the response of ecosystem service value to land use changes under multiple scenarios coupling a mixed-cell cellular automata model and system dynamics model in Xi'an, China[J]. Ecological Indicators, 2023, 147: 110009, doi: 10.1016/j.ecolind.2023.110009.

[19] Liang X, Guan Q, Clarke K C, et al. Understanding the drivers of sustainable land expansion using a patch-generating land use simulation (PLUS) model: A case study in Wuhan, China[J]. Computers, Environment and Urban Systems, 2021, 85: 101569, doi: 10.1016/j.compenvurbsys.2020.101569.

[20] Li C, Wu Y, Gao B, et al. Multi-scenario simulation of ecosystem service value for optimization of land use in the Sichuan-Yunnan ecological barrier, China[J]. Ecological Indicators, 2021, 132: 108328, doi: 10.1016/j.ecolind.2021.0108328.

[21] Meng Yali, Duan Keqin, Shang Wei, et al. Analysis on spatiotemporal variations of near-surface air temperature over the Tibetan Plateau from 1961 to 2100 based on CMIP6 models' data[J]. Journal of Glaciology and Geocryology, 2022, 44(1): 24-33.

[22] Lei Jinrui, Chen Yiqing, Chen Zongzhu, et al. Spatiotemporal evolution of habitat quality in three basins of Hainan Island based on InVEST model[J]. Chinese Journal of Applied Ecology, 2022, 33(9): 2511-2520.

[23] Zhu Zengyun, Kasimu Alimujiang. Spatial-temporal evolution of habitat quality in Yili Valley based on geographical detector and its influencing factors[J]. Chinese Journal of Ecology, 2020, 39(10): 3408-3420.

[24] Cheng Jing, Wang Peng, Chen Hongxiang, et al. Spatiotemporal evolution of habitat quality in the Weihe River Basin and its topographic gradient effects and influencing factors[J]. Arid Land Geography, 2023, 46(3): 481-491.

[25] Yang Zhipeng, Wang Shijun, Tian Junfeng, et al. Spatial relationship between county development intensity and habitat quality in the three provinces of northeast China[J]. Geography and Geo-information Science, 2022, 38(3): 83-90.

[26] Yan Junjie, Liu Haijun, Cui Dong, et al. Spatiotemporal dynamics of grassland degradation in Yili Valley of Xinjiang over the last 15 years[J]. Pratacultural Science, 2018, 35(3): 508-520.

[27] Jia Lei, Yao Shunbo, Deng Yuanjie, et al. Temporal and spatial evolution of habitat quality and its topographic gradient effect in Qinling-Daba Mountain area, Shaanxi Province, 2000—2020[J]. Resources and Environment in the Yangtze Basin, 2022, 31(2): 398-413.

[28] Liu Changyu, Yang Jie, Xie Baopeng, et al. Temporal and spatial characteristics of habitat quality and its topographic gradient effect in the Gansu-Qinghai section of the Yellow River Basin[J]. Journal of Agricultural Resources and Environment, 2023, 40(2): 372-383.

[29] Zhou Jiayue, Lu Hui, Yang Kun, et al. Projection of China's future runoff based on the CMIP6 mid-high warming scenarios[J]. Science China Earth Sciences, 2023, 53(3): 505-524.

Note: Figure translations are in progress. See original paper for figures.