Article

Spatiotemporal Characteristics and Habitat Quality Analysis in the Temperate Desert Sub-Region of Ordos Plateau, China

Min Pei [1,4,5,†], Xiaohuang Liu [2,3,†], Jinjie Wang [1,4,5,*], Jiufeng Liu [2,3], Xiaofeng Zhao [2,3], Hongyu Li [2,3], Ran Wang [2,3], Xinping Luo [2,3], Liyuan Xing [2,3], Chao Wang [2,3] and Honghui Zhao [2,3]

[1] College of Geography and Remote Sensing Sciences, Xingjiang University, Urumqi 830017, Xinjiang, China
[2] Key Laboratory of Natural Resource Coupling Process and Effects, Beijing 100055, China
[3] Command Center of Natural Resource Comprehensive Survey, China Geological Survey, Beijing 100055, China
[4] Xinjiang Key Laboratory of Oasis Ecology, Xinjiang University, Urumqi 830017,Xinjiang, China
[5] Key Laboratory of Smart City and Environment Modelling of Higher Education Institute, Xinjiang University, Urumqi 830017, Xinjiang, China
* Correspondence: skytian552@163.com
† Min Pei and Xiaohuang Liu contributed equally to this work.

Abstract: Habitat quality has great significance for regional ecological conservation and human welfare. In this study, we evaluated the spatial and temporal characteristics of land use and habitat quality in the temperate desert sub-region of Ordos Plateau using patch-generating land use simulation (PLUS) and integrated valuation of ecosystem services and trade-offs (InVEST) models. From 2000 to 2020, the areas of grassland, cropland, and unused land in the study area increased significantly; the areas of water bodies and woodland increased slightly; and the area of wasteland decreased significantly. Moreover, the habitat quality in the temperate desert subzone of the Ordos Plateau showed a trend of increasing and then decreasing from 2000 to 2020. The areas of lower and low habitat quality first decreased and then increased, and the overall area decreased over time. Conversely, the areas of high and higher habitat quality initially increased and then decreased, and the overall area increased over time. The area of medium habitat quality first decreased and then increased, although the overall change was minimal. Based on the PLUS model, the habitat quality of the study area in 2025 predicted under the natural development scenario was compared with that predicted under the ecological conservation scenario, showing higher habitat quality and lower habitat degradation under the ecological conservation development scenario. These results can be used to provide a scientific basis and decision reference for the sustainable use of land resources and high-quality socio-economic development in the temperate desert sub-region of the Ordos Plateau.

Keywords: PLUS model; InVEST model; land use; habitat quality; temperate desert subzone of Ordos Plateau

---

1. Introduction

Land use change is closely related to human activities, and there is an overarching relationship between the evolution of the natural environment and human socio-economic activities. Land use change can visually reflect the conversion process of the surface system by human activities, representing the centerpiece of global environmental change research (Winkler et al 2021). Habitat quality indicates the ability of an ecosystem to provide suitable conditions for the survival and development of individuals and populations, serving as an important measure of biodiversity and regional sustainability (Zhang et al 2019). Land use is closely connected with habitat quality, and different types of land use reflect the intensity of human exploitation of the land. The level of habitat quality is negatively related to the intensity of human use of the land, which is expressed as a decrease in land use intensity and an increase in habitat quality (Lei et al 2022). On the basis that land use status can reflect the level of habitat quality, analysis of the spatial and temporal characteristics of land use can help to further explore the patterns and causes of habitat quality changes (Gomes et al

2021). The research on land use change is becoming increasingly mature in response to increasing demands, and there have been significant advances in dynamic modeling techniques for assessing and predicting land use change in recent years. These mature models enable combining geography, ecology, deep learning, and other theories to predict the future land use change and thus evaluate the future habitat quality (Riedler et al 2018,Wu et al 2021).

At present, futuristic land use prediction models mainly include the meta-automata model and cellular automata (CA)-Markov model (plus references), along with further developments on the basis of the meta-automata model, including the logistic-CA (Gao et al 2022), artificial neural network (ANN)-CA (Zhang et al 2021), Future Land Use Simulation (FLUS) (Liu et al 2017b), and Patch Generation Land Use Simulation (PLUS) models (Wei et al 2022b). Among these, the PLUS model incorporates a land-sprawl optimization strategy and a multi-type stochastic patch seed generation mechanism to improve the model's running speed and simulation accuracy (Huang et al 2022,Wang et al 2022b). The PLUS model, developed by Liang et al. (China University of Geosciences) (Zhu et al 2022), is a proposed patch-generated land use change model based on raster data. The transformation strategy of the PLUS model involves a transformation analysis and a pattern analysis, which can make up for the shortcomings of previous CA models in exploring the causes of land use change and simulating the patch-level changes of multiple land use types at both spatial and temporal scales. For example, Liu et al. (Liu et al 2017a) used a coupled grey multi-objective optimization model and the PLUS model to analyze the spatial and temporal evolution of ecosystem service values in the Sichuan-Yunnan region of China under three scenarios of natural growth, ecological priority, and ecological-economic balance in 2026. Lin et al. (Lin et al) used the PLUS model in conjunction with the "14th Five-Year Plan" for transportation in Guangzhou. Based on the PLUS model and the equivalence factor method, Li et al. (Li et al 2023) predicted the land use changes in Nujiang Prefecture in 2025 under different scenarios and the ecosystem service values in 2025.

Habitat quality is affected by land use changes, mainly because land use causes the flow of material and information between habitat patches (Fu et al 2017). The level of habitat quality can visually reflect the functional status and change trends of ecosystem services in a given area. The study of habitat quality changes in a particular region is of great significance to the sustainable development and ecological protection of the region (Yohannes et al 2021). Currently, the main models used for assessing regional habitat quality include the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model and the Social Values for Ecosystem Services (SolVES) model (Fu et al 2014, Zhao et al 2022b). The SolVES model assesses the value of ecosystem cultural services in terms of a value index (VI), whereas the InVEST model is widely used in the field of habitat quality assessment because it has the advantages of easy operation, strong visualization ability, and a sound existing theoretical foundation (Pan et al 2023). For example, Bai et al. (Bai et al 2020) evaluated the processes of urban expansion and habitat quality evolution in Hohhot, and explored the spatial and temporal mechanisms of habitat quality changes in response to urban land expansion. Liao et al. (Liao et al 2022) used a land use transfer matrix to analyze the transfer of each category and applied the habitat quality module of the InVEST model to assess the habitat quality of the Kunming Dianchi watershed. Qiu et al. (Qiu et al 2022) used the InVEST model to analyze the spatial and temporal pattern evolution characteristics of land use and habitat quality in the ChangZhuTan urban agglomeration in 2000, 2010, and 2020, and further analyzed the evolution mechanism and influencing factors. Yang et al. (Yang et al 2021) assessed the degree of habitat quality degradation in the Yellow River basin based on the InVEST model, analyzed the cold hotspots of habitat quality using a spatial statistical approach combined with the geodetector model, and further explored the main driving forces of the spatial distribution characteristics of habitat quality. Thus, application of the InVEST model to the calculation and assessment of habitat quality at different scales demonstrates the scientific validity and broad applicability of the model.

The Ordos Plateau temperate desert sub-region is located in the hinterland of the loop of the Yellow River with several bends, south to the Mawusu Sands and north to the Kubuqi Desert, and is representative of a typical ecologically fragile area in China (Guo et al 2017). The Ordos Plateau temperate desert sub-region is also a typical transition zone in terms of ecology and geography. With

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 1 June 2023 doi:10.20944/preprints202306.0029.v1

respect to geomorphology, this sub-region is a transition zone from the Gobi Desert to the Plateau (Luo et al 2013). With respect to climate, there is a transition from arid and semi-arid areas to humid areas when moving from west to east. In terms of human activities, the study area is in a transition zone from animal husbandry to agriculture (Qi et al 2020). The complex climate change accompanied by human activities has led to variation in land use change and its driving force role in the region with obvious spatial heterogeneity. In particular, the implementation of desertification prevention and control policies such as enclosed grazing, returning farmland to forest (grass), and the urbanization process and mining in the area have all accelerated in the past 10 years. Therefore, the Ordos Plateau (Zhang et al 2020) offers a typical and representative area for studying desertification dynamics and the driving mechanism.

Based on this background, in this study, we combined the advantages of the accuracy of the PLUS model in predicting land use change and the intuitive accuracy of the InVEST model's habitat quality module in calculating habitat quality, using the temperate desert subzone of the Ordos Plateau as the study area of focus. Specifically, these models were used to analyze the evolution process of land use and habitat quality in the Ordos Plateau from 2000 to 2020. We further predicted land use in 2025 under the scenarios of both natural development and ecological protection to provide a reference for construction of an ecological civilization with regional planning and development in the Ordos Plateau region.

2. Materials and Methods

2.1. Study area

The Ordos Plateau temperate desert sub-region (Ma et al 2019) belongs to the second level of the first-level Inner Mongolia Plateau Grassland Resource Region, which is located in the southeast of the first level, at 37°20′–40°50′N, 106°24′–111°28′E (Figure 1). This sub-region includes Ordos City in Inner Mongolia and Yulin City in Shaanxi Province. The topography is slightly inclined from northwest to southeast, with gentle undulations (Zhao et al 2019). The majority of the land is 862–1627 m above sea level, and the main land use type is grassland, which accounts for approximately 70% of the total area of the region. The study area can be divided into five sections: sandy uplands in the central and western regions, lakes and sand dunes in the southeast, the Kubuchi Desert of the Yellow River terrace in the north, and the Table Mountain in the west, whose soil type is dominated by brown calcium soils (Liu et al 2023). The climate of the study area is arid and semi-arid continental monsoon, with an average annual temperature of approximately 5°C and an average annual precipitation of approximately 400 mm, which is low and concentrated in summer (Fang et al 2016).

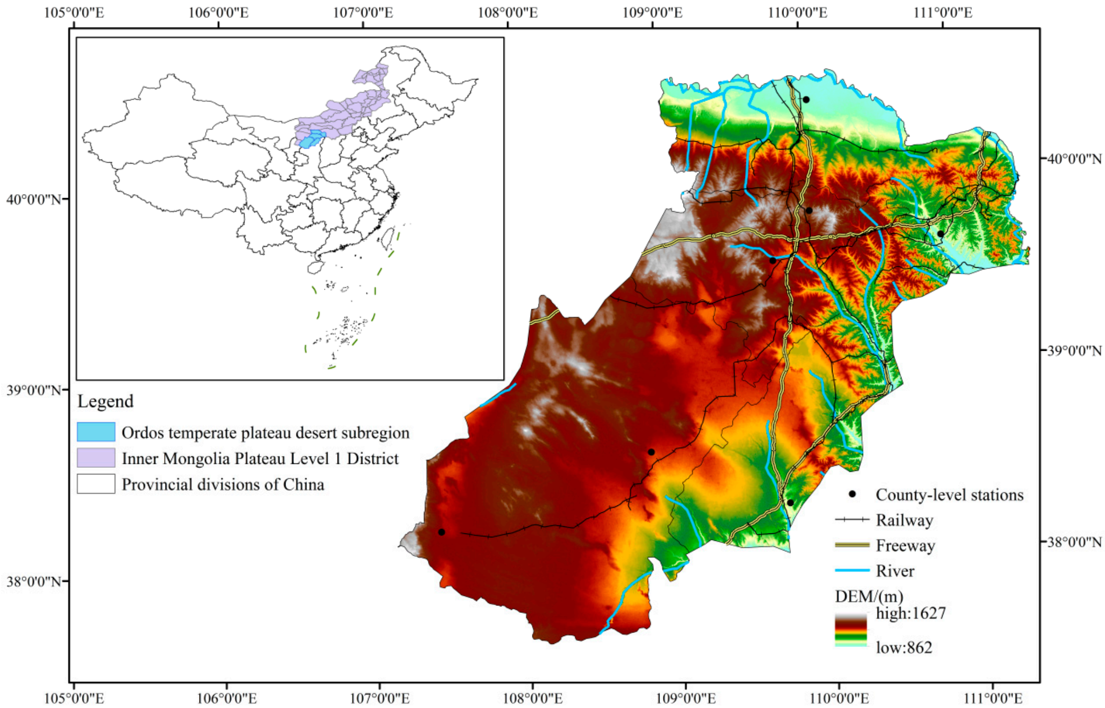

Figure 1. Location map of the Ordos Plateau.

2.2. Research data

The primary data used for this study included land use data, soil data, topographic data, climate data, road accessibility data, and socio-economic data. Referring to previous studies related to land use prediction and habitat quality evaluation, based on the basic situation of the study area, accessibility, timeliness, and significance of the data according to the accuracy and practicality of the PLUS model, 14 candidate driving factors affecting land use change from natural and human perspectives were selected for a land use simulation study of the study area, which are detailed in Table 1.

Table 1. Data sources.

Data type	Secondary data type	Data source
Land Use Data	Land use data for 2000, 2005, 2010, 2015, 2020	https://essd.copernicus.org/
Soil Data	Soil texture data	https://www.fao.org/
Terrain Data	DEM Slope	https://www.gscloud.cn/
Climate Data	Annual average rainfall data Annual average temperature data	National Earth System Science Data Center, National Science & Technology Infrastructure of China (http://www.geodata.cn)
Road accessibility data	Distance from river Distance from county seat Distance from highway Distance from railroad Distance from primary roads	CAS Resource and Environmental Science and Data Center(https://www.resdc.cn/)
Socio-economic data	Luminous data GDP	
	Population	Worldpop (https://hub.worldpop.org/)

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 1 June 2023 doi:10.20944/preprints202306.0029.v1

2.3. Research methodology

2.3.1. PLUS model

The selection of driving factors was based on the current situation of Ordos Plateau, the availability of data, and with reference to existing relevant studies. A total of 14 influencing factors were selected, including slope, elevation, soil texture, average annual rainfall, average annual temperature, distance from rivers, distance from county-level stations, distance from highways, distance from railroads, distance from primary roads, night light data, per capita gross domestic product, and population data (Lu et al 2022).

The land use expansion analysis strategy (LEAS) was selected as a random sampling mechanism to reduce the computational effort of the model with the random forest algorithm, which can handle high-dimensional data and solve the covariance of the driving factors, to mine the excessive land use transfer pattern (Biau 2012) and obtain the development probability of each land use type, calculated as follows:

$$P_{i,k(X)}^{d} = \frac{\sum_{n=1}^{M} I[h_n(X)=d]}{M} \quad (1)$$

In this equation, $P_{i,k(X)}^{d}$ is the probability of growth of land use type k at spatial unit i; X is a vector consisting of driving factors; M is the number of decision trees; d takes the value of 0 or 1, with 0 indicating that other land classes are not convertible to land class k and 1 indicating the opposite; and is the type of land use prediction calculated when the decision tree is n. $[h_n(X) = d]$ is the exponential function of the decision tree.

The multi-class random forest patch seed-based CA model (CARS) was used to determine the land use distribution obtained from the simulation by obtaining the development probability that each type of land use belongs to the scenario-driven land use simulation model. CARS is based on meta-cellular automata simulation of multi-class land use change in Dongguan City from random forest CA, and the calculation formula of the transfer probability of land use types is as follows:

$$OP_{i,k}^{d=1,t} = P_{i,k}^{d} \times \Omega_{i,k}^{t} \times D_{k}^{t} \quad (2)$$

In this equation, $OP_{i,k}^{d=1,t}$ is the integrated probability of the transition to ground class k at moment t at spatial unit i, $P_{i,k}^{d}$ is the probability of suitability for the development of the land type at spatial unit i to land class k, $\Omega_{i,k}^{t}$ is the domain effect of cell i, z is the proportion of land use components of land class k that are covered in the next domain, and D_{k}^{t} provides the impact of future demand on land class k (Shiferaw et al 2019).

The prediction of 2010 land use data based on the PLUS model using 2000 and 2005 land use data of the temperate desert sub-region of the Ordos Plateau was compared and analyzed with the Kappa coefficient and according to the overall accuracy with respect to the actual land use data in 2010. The results showed that the overall accuracy was 0.91 and the Kappa coefficient was 0.77. Therefore, the PLUS model has high prediction accuracy and can accurately reflect the land use change with strong general applicability in the study area.

2.3.2. InVEST model

The InVEST model (version 3.12.0) was released by Sharp et al. at Stanford University (Wang et al 2023). Its habitat quality module is designed to evaluate the impact of human activities on the ecological environment. The InVEST model considers habitat quality as a continuous variable while taking into account the influence distance and spatial weights of stressors, and fully considers the impact of and changes in land cover patterns on habitat quality when conducting the assessment (Li et al 2021b). The model is calculated as follows:

$$D_{xj} = \sum_{r=1}^{R}\sum_{y=1}^{Y_r}\left({W_r}/{\sum_{r=1}^{R} W_r}\right) r_y i_{rxy} \beta_x S_{jr} \quad (3)$$

In this equation, D_{xj} is the degree of habitat degradation for raster x in habitat type j, R is the number of threat sources, W_R is the weight of the threat source r, Y_r is the number of grids of threat sources, r_y is the stress value of grid y, β_x is the accessibility of the threat source to the raster x, S_{jr} is the sensitivity of habitat type j to the threat source, and i_{rxy} is the stress value r_y of grid y to the stress level of grid x. There are two types of decay considered: linear decay and exponential decay.

$$\text{Linear attenuation: } i_{rxy} = 1 - \left(\frac{d_{xy}}{d_{rmax}}\right) \quad (4)$$

$$\text{Exponential decay: } i_{rxy} = exp\left(\frac{-2.99 d_{xy}}{d_{rmax}}\right) \quad (5)$$

In the above equation, d_{xy} is the linear distance between raster x and raster y, and d_{rmax} is the maximum stress distance of the threat source r. The habitat quality index is calculated by the following formula:

$$Q_{xj} = H_j \left|1 - \left(\frac{D_{xj}^z}{D_{xj}^z + k^z}\right)\right| \quad (6)$$

In this equation, Q_{xj} is the habitat quality index of raster x in habitat type j, H_j is the habitat suitability of habitat type j, k is the half-saturation constant, and z is the normalization constant. Based on the above equations, the weights of the stressors and the maximum stress distance, along with other parameters, were calculated for the study area (Table 2).

The InVEST model, which has the advantages of easily accessible data and high visualization ability, was utilized to assess the habitat quality in 2000, 2005, 2010, 2015, and 2020 in the desert sub-region of Ordos Plateau. According to the characteristics of the InVEST model, previous studies conducted in the agricultural-pastoral interlacing zone of arid and semi-arid regions, and the specific situation of the study area, the threat sources were set as the ecological environment vulnerable to human activities, including cultivated land, wasteland, and unused land (Moreira et al 2018,Sharp et al 2016). After checking the existing research results and conducting a comprehensive analysis, the weights of threat sources, the maximum impact distance, and the type of degradation were determined (Berta Aneseyee et al 2020). Based on the above, the sensitivity of different site types in the study area to different habitat threat sources was calculated (Table 3).

Table 2. Threat feed parameters.

Threat feeds	Maximum coercive distance(km)	weight	Spatial attenuation type
cultivated land	4	0.6	Linear
wasteland	8	0.4	Exponential
Unused land	6	0.5	Linear

Table 3. Sensitivity of different site types to habitat threat sources.

Type of land use	Habitat suitability	cultivated land	wasteland	Unused land
cultivated land	0.3	0	0.8	0.4
woodland	1	0.6	0.4	0.2
grassland	0.9	0.8	0.6	0.6
water	0.7	0.5	0.4	0.3
wasteland	0	0	0	0.1
Unused land	0.5	0.6	0.4	0

2.3.3. Multi-scene simulation

Two development situations were established for comparison: a natural development scenario and an ecological protection scenario (Berta Aneseyee et al 2020, Chu et al 2018). The Markov chain module in the land use PLUS model for 2025 under the natural development scenario had no restrictions on the conversion of woodland, grassland, and water bodies, and no restricted area for development based on the future land use change trends predicted by the 2015–2020 land use change trends. The ecological protection scenario represents the area of high-quality protected habitat in the future, which needs to strictly restrict the conversion of waters, woodland, and grassland to cropland, construction land, and unused land; control the overgrowth of construction land and cropland; and improve the development potential of woodland and grassland. The multi-scenario transfer matrix settings are shown in Table 4, where 1 indicates that the conversion of land types can occur and 0 indicates that the conversion of land types cannot occur.

Table 4. Land use transfer matrix settings for two scenarios: natural development scenarios (NDS) and ecological conservation scenarios (ECS).

Now / **Future**	**cultivated land**		**woodland**		**grassland**		**water**		**wasteland**		**Unused land**	
scenery	NDS	ECS	NDS	ECS	NDS	ECS	NDS	ECS	NDS	ECS	NDS	ECS
cultivated land	1	1	1	1	1	1	0	0	1	1	1	1
woodland	1	0	1	1	1	1	0	0	1	0	1	0
grassland	1	0	1	1	1	1	0	0	1	0	1	0
water	1	0	1	0	1	1	1	1	0	0	0	0
wasteland	0	0	0	0	1	0	0	0	1	1	1	1
Unused land	1	1	1	1	1	1	0	0	1	1	1	1

3. Results

3.1. Land use change from 2000 to 2020

We first calculated the area of each type of land in the temperate grassland sub-region of the Ordos Plateau using geographic information spatial analysis (Figure 2). The areas of grassland, unused land, and arable land increased significantly, while the area of wasteland decreased significantly. From 2000 to 2020, the area of unused land increased to a greater extent, and the change rate of unused land area was 43.09%, 57.55%, 24.23%, and 21.98% in 2005, 2010, 2015, and 2020, respectively. The change rate of unused land area for these same four years was 43.09%, 57.55%, 24.23%, and 21.98%, respectively, showing a trend of first decreasing and then increasing. The rate of change of the water body area in 2005, 2010, 2015, and 2020 was 0.62%, –1.17%, 4.15%, and 12.06%, respectively, showing a gradual increasing trend, with an overall increase in the water body of 40.58 km^2. From 2000 to 2020, the area of grassland first increased and then decreased, with a significant increase in 2020 compared with 2000, and the rates of variation of grassland area in 2005, 2010, 2015, and 2020 were 5.07%, 4.47%, 2.55%, and –1.30%, respectively. The arable land area first increased and then decreased, and the rate of change of arable land area was –7.69%, –1.72%, 10.55%, and 9.57% in 2005, 2010, 2015, and 2020, respectively.

The rate of change in the woodland area in 2005, 2010, 2015, and 2020 was 14.78%, 121.53%, 986.38%, and 189.98%, respectively, showing an overall increase over time. The rate of change of the water body area was 0.62%, –1.17%, 4.15%, and 12.06% in 2005, 2010, 2015, and 2020, respectively, showing a gradual increasing trend, and the area of water body in 2020 increased by 40.58 km^2 compared with that in 2000. The trend is increasing, and the woodland area in 2020 increased by 30.83 km^2 compared with that in 2000, representing an obvious increase over time.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 1 June 2023 doi:10.20944/preprints202306.0029.v1

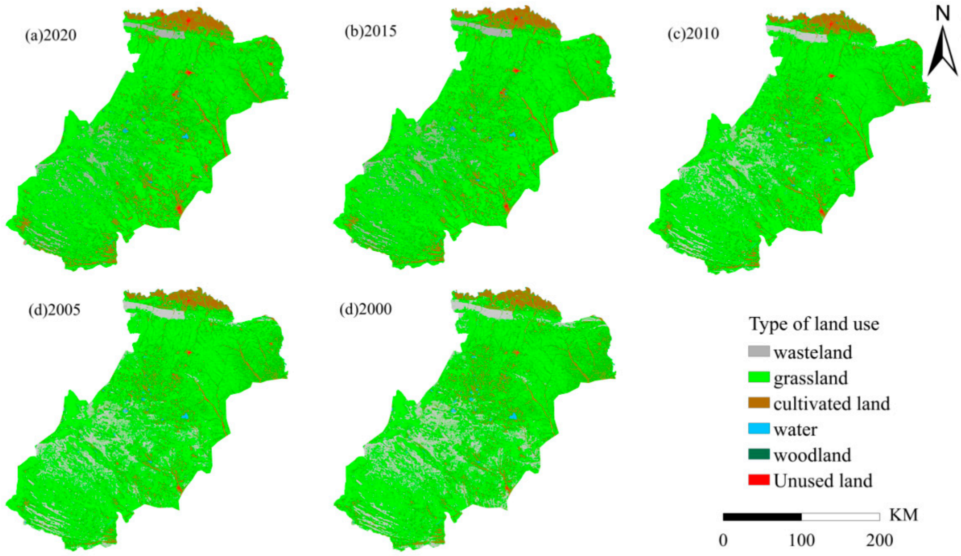

Figure 2. Land use change. (**a**) Land use in 2000. (**b**) Land use in 2005. (**c**) Land use in 2010. (**d**) Land use in 2015. (**e**) Land use in 2020.

The spatial changes of each category in the study area from 2000 to 2020 were obtained from the standard deviation ellipse calculation (Figure 3) (Zhao et al 2022c). From 2000 to 2020, the most obvious change was detected in the woodland, and the gravity center shifted from the central part of the study area to the northeast. The center of gravity of the wasteland shifted from the central part to the north over time, and the distribution of the wasteland was more concentrated in 2020 than in 2000. From 2000 to 2020, the center of gravity of grassland was concentrated in the central part of the study area and the area of grassland showed a trend of expansion, with obvious expansion to the northeast of the study area in 2020 compared with that in 2000. The center of gravity of cropland slowly moved southward between 2000 and 2020, and the area of cropland expanded to the southwest. Between 2000 and 2020, the center of gravity of unused land and water bodies moved slowly, with water bodies concentrated in the west of the central part of the study area and unused land concentrated in the southeast part of the study area.

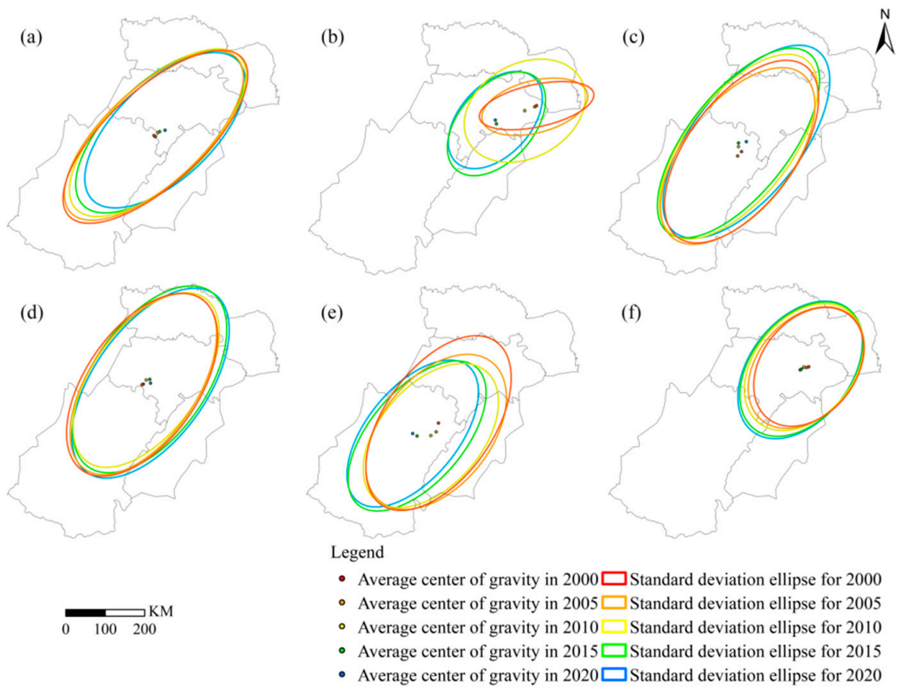

Figure 3. Direction of change of different land types. (**a**) Cultivated land. (**b**) woodlands. (**c**) Grasslands. (**d**) Water bodies. (**e**) Wasteland. (**f**) Unused land.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 1 June 2023 doi:10.20944/preprints202306.0029.v1

3.2. Habitat Quality Changes from 2000 to 2020

The habitat quality of the study area was analyzed using the habitat quality module of the InVEST model, demonstrating that the habitat quality of the temperate desert subregion of the Ordos Plateau ranged from 0 to 1. The spatial and temporal variations of habitat quality are presented in Figure 4. From 2000 to 2020, the low values of habitat quality were concentrated in the northern and central areas of the study area, whereas the high values of habitat quality were mainly concentrated in the southeastern areas. Grassland was the main land use type in areas with high habitat quality values, with relatively low land use intensity and dense vegetation cover. Habitat quality in the northern part of the study area was concentrated on the lower values, and the main land use type in the northern part was arable land, which is more intensive and influenced by human activities. The habitat quality of the temperate desert sub-region of the Ordos Plateau showed an overall trend of increasing first by time lapse.

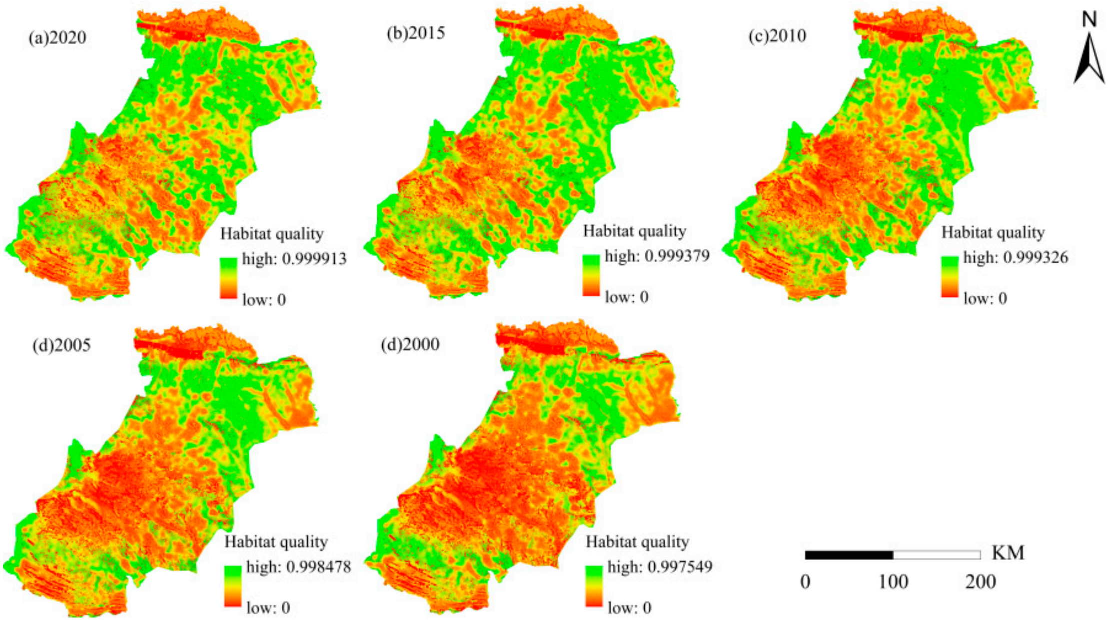

Figure 4. Changes in habitat quality over time. (**a**) Habitat quality in 2000. (**b**) Habitat quality in 2005. (**c**) Habitat quality in 2010. (**d**) Habitat quality in 2015. (**e**) Habitat quality in 2020.

The degree of habitat quality degradation in the study area was calculated according to the habitat quality module of the InVEST model (Figure 5). The high values of habitat degradation degree in the Ordos Plateau from 2000 to 2020 were concentrated in the northern and southwestern areas. The land use types in this area are mainly arable land, grassland, and wasteland. The habitat quality largely deteriorated owing to human farming and construction planning. Lower habitat degradation values occurred in the grassland cover area in the central part of the study area, which was mainly due to the fact that the grassland cover area is not eagerly exploited on a large scale and has low disturbance by human activities. The degree of habitat degradation was highly variable from 2000 to 2020. From 2000 to 2010, the degree of habitat degradation in the study area increased by 0.28%; from 2010 to 2015, the degree of habitat degradation in the study area decreased by 0.01%; and from 2015 to 2020, the degree of habitat quality degradation in the study area increased by 0.02%.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 1 June 2023 doi:10.20944/preprints202306.0029.v1

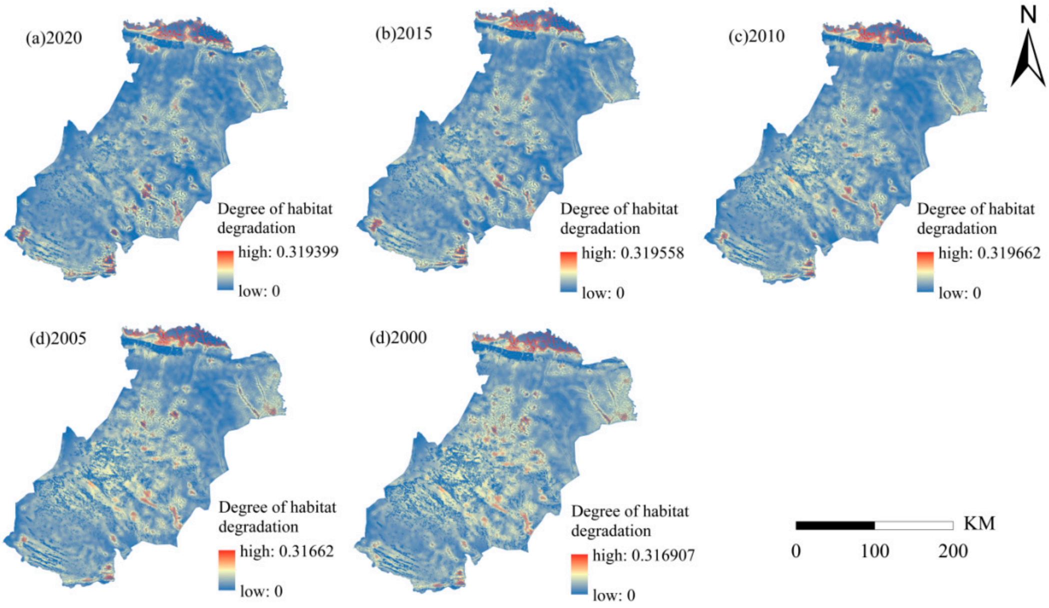

Figure 5. Change in habitat degradation over time: (**a**) 2000, (**b**) 2005, (**c**) 2010, (**d**) 2015, (**e**) 2020.

3.2.1. Change in habitat quality class

According to the results of habitat quality classification, the area share of each habitat quality in the study area was determined to be approximately 20%, and the area share of each habitat quality class was relatively uniform. From 2000 to 2020, the lower habitat quality area changed most obviously, showing a trend of rapid decline followed by a slow rise (Figure 6).

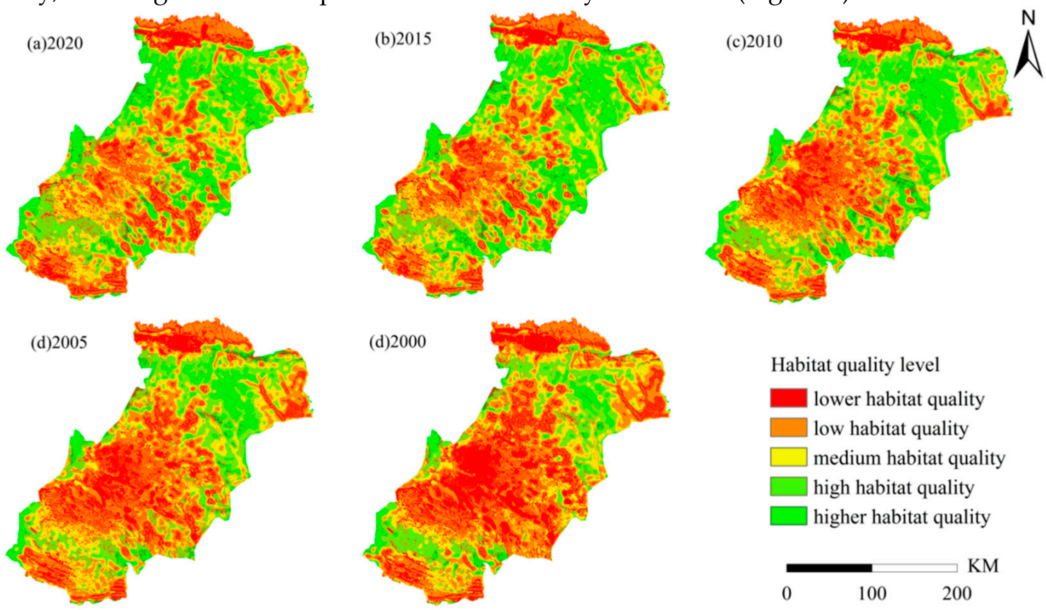

Figure 6. Habitat quality level over time. (**a**) Habitat quality rating for 2000. (**b**) Habitat quality rating for 2005. (**c**) Habitat quality rating for 2010. (**d**) Habitat quality rating for 2015. (**e**) Habitat quality rating for 2020.

From 2000 to 2015, the area of lower habitat quality decreased by 10,045.27 km^2 and the area share decreased by 16.59%, whereas from 2015 to 2020, the area of lower habitat quality increased by 575.46 km^2 and the area share increased by 0.95%. From 2000 to 2020, the area of lower habitat quality showed a trend of first decreasing and then increasing; the area decreased from 18,146.86 km^2 to 15,413.47 km^2 from 2000 to 2015, and the area share decreased by 4.52%. In the period of 2015–2020,

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 1 June 2023 doi:10.20944/preprints202306.0029.v1

the area share increased by 1.17% with an increase of 708.80 km². From 2000 to 2020, the area of medium habitat quality increased by 1394.12 km² and the area share increased by 2.30%. Between 2000 and 2010, the area of medium habitat quality showed a decreasing trend. The area of medium habitat quality showed an increasing trend from 2010 to 2020. The area of high habitat quality in the study area increased and then decreased during the study period. The area share of high habitat quality within the period 2000–2015 increased by 7.45%. From 2015 to 2020, the area share decreased by 0.7%. In 2020, the area of high habitat quality in the region increased by 60.36 km² compared to that of 2000, and the overall area increased by 4088.04 km² with an area share increase of 6.75%. The area of higher habitat quality increased by 6011.94 km². From 2000 to 2015, the area of higher habitat quality increased significantly, and the area share increased by 12.34%. From 2015 to 2020, the area decreased by 1457.35 km² and the area share decreased by 2.41%.

On the basis of the standard deviation ellipse and mean center of gravity calculations (Li et al 2021a), during the period of 2000–2020, changes in higher habitat quality were evident, with the center of gravity of higher habitat quality shifting from the east to the center and its distribution moving closer to the center as time progressed. From 2000 to 2010, the center of gravity of medium habitat quality shifted significantly, moving from the center to the north, and its area shrunk from east to south. From 2010 to 2020, the center of gravity of medium habitat quality shifted insignificantly, with little change in the area. During the study period, the center of gravity of lower habitat quality shifted to the northeast and the area occupied was concentrated toward the north over time. The center of gravity of lower habitat quality shifted to the south, and the area occupied by lower habitat quality showed a decreasing trend over time, with obvious changes from 2000 to 2015 (Figure 7).

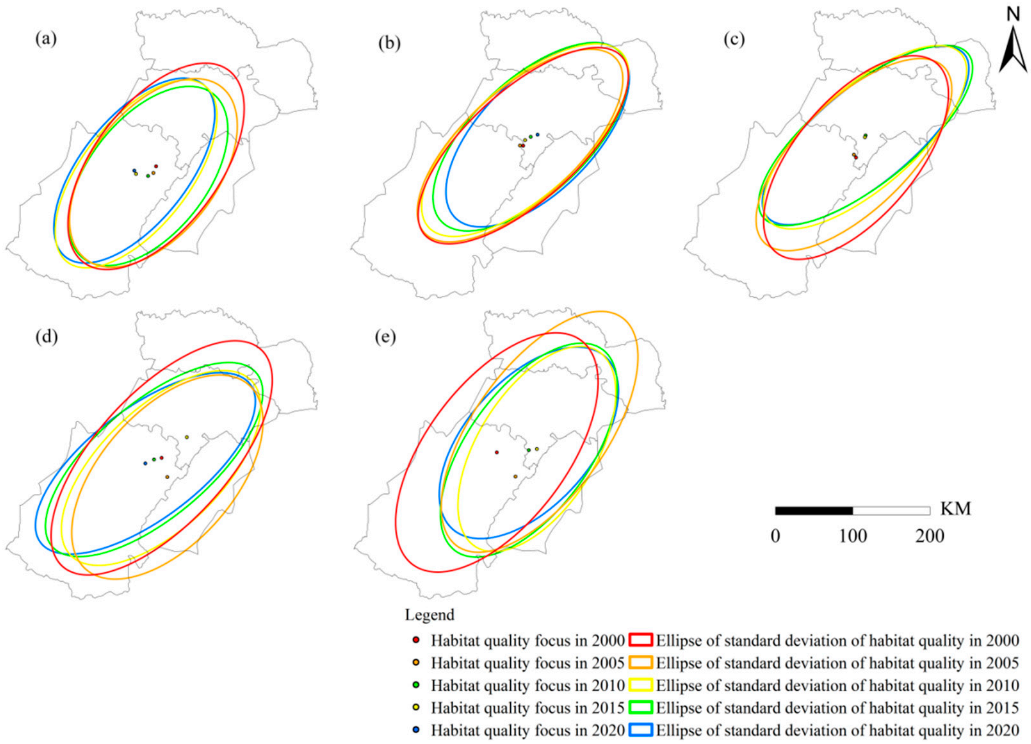

Figure 7. Different landscape species change directions: (**a**) higher habitat quality, (**b**) high habitat quality, (**c**) medium habitat quality, (**d**) low habitat quality, (**e**) lower habitat quality.

3.3. Habitat quality in relation to land use

The areas of habitat quality classes corresponding to different land use types were statistically analyzed and the results are presented in Figure 8. From 2000 to 2020, wasteland, including urban and rural residential construction land and industrial and mining land, represented an area belonging to high human development, and its habitat quality class was the lowest in all five years.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 1 June 2023 doi:10.20944/preprints202306.0029.v1

The habitat quality class of cropland was lower in all five years, and the area of the lowest habitat quality class decreased year by year. The habitat quality of unused land was classified as lower and medium; the area of medium habitat quality showed a trend of increasing and then decreasing, while the area of lower habitat quality did not change significantly. All habitat quality classes were represented for woodlands and grasslands. The higher habitat quality of grassland from 2000 to 2015 showed an upward trend, and the area decreased slightly from 2015 to 2020. The high habitat quality class of grassland increased year by year, and the area of medium habitat quality class fluctuated year by year. The area of the lower habitat quality of grassland in 2020 decreased compared to that in 2000. The area of higher habitat quality in the woodland increased and then decreased; the area of high habitat quality tended to increase and then decrease, followed by another increase; and the area of lower habitat quality and low habitat quality both tended to decrease and then increase. In water bodies, the habitat quality included the lower habitat quality class, lower habitat quality class, and medium habitat quality class. Among them, the area of medium habitat quality class increased first and then decreased. The area of lower habitat quality class decreased continuously from 2000 to 2010 and the percentage of area increased from 2010 to 2020. The area of lower habitat quality decreased from 2000 to 2005 and from 2010 to 2015, and then increased from 2015 to 2020.

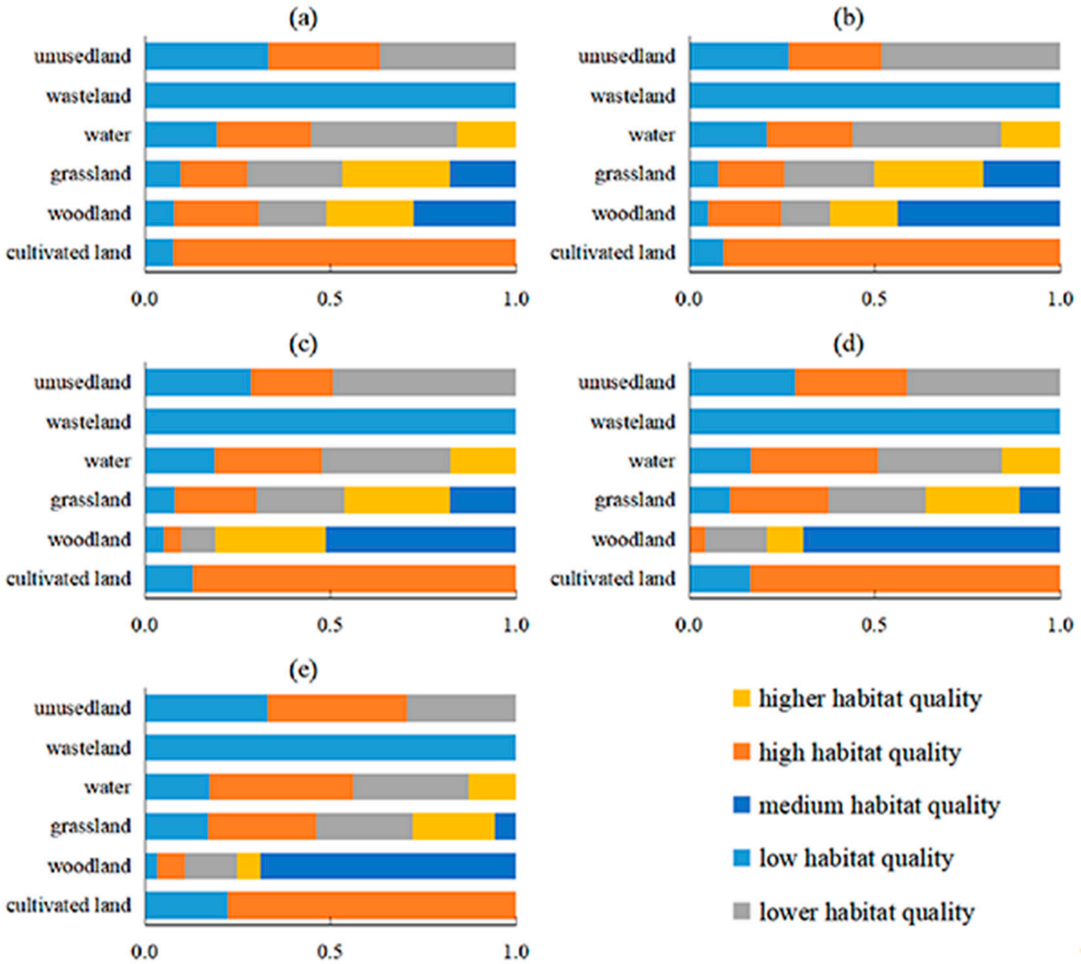

Figure 8. Map of habitat quality and land use 2000–2020. (**a**) 2020. (**b**) 2015. (**c**) 2010. (**d**) 2005. (**f**) 2000.

 doi:10.20944/preprints202306.0029.v1

3.4. Land use projections to 2025

The PLUS model was used to project land use data for 2025 based on 2020 land use data. Under the nature development scenario, no adjustment was made to the original parameters of the model.

Under the ecological conservation development scenario, the area with lower habitat quality in 2020 was set as the key protected area in the PLUS model (i.e., the restricted conversion area). The land use distribution pattern of the temperate desert sub-region of the Ordos Plateau in 2025 under the ecological conservation scenario was obtained by running the PLUS model. Based on the arithmetic results, the improvement of habitat quality in the study area under the ecological protection scenario was more obvious. Under the natural development scenario, the higher ranked habitat quality accounted for 20.76% of the total area of the study area and the highest ranked habitat quality accounted for 12.76% of the total area of the study area, which was generally lower than the area predicted under the ecological protection scenario. The area of the lowest habitat quality under both scenarios accounted for approximately 17% of the total area. The habitat quality in the study area was higher under ecological conservation development conditions (Figures 9 and 10).

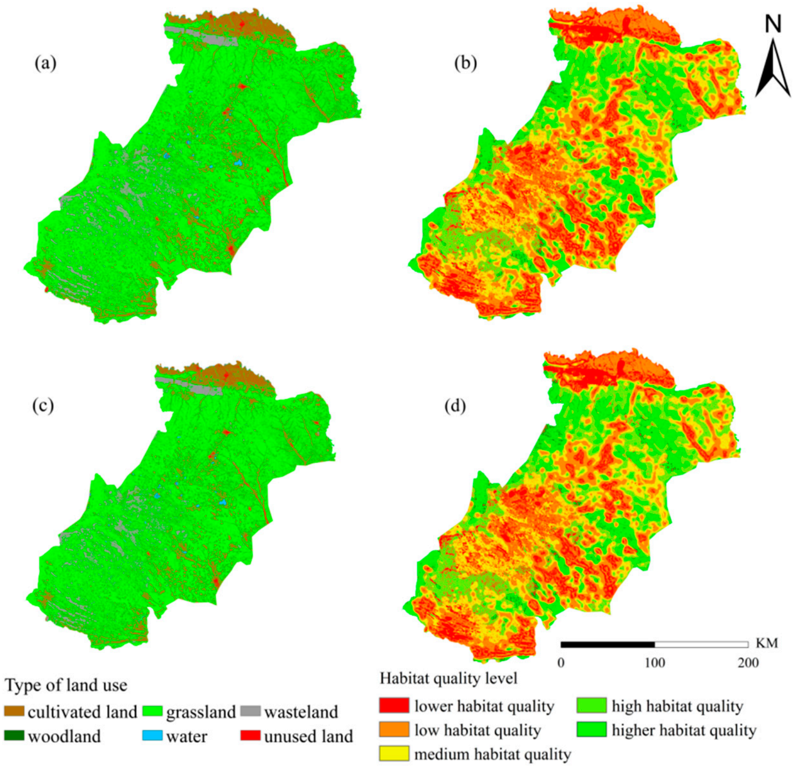

Figure 9. Land use and habitat quality grades under different conditions. (**a**) Land use under ecological protection in 2025. (**b**) Habitat quality level in 2025 under ecological conservation scenarios. (**c**) Land use in the context of natural development in 2025. (**d**) Habitat quality in 2025 under natural development scenarios.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 1 June 2023 doi:10.20944/preprints202306.0029.v1

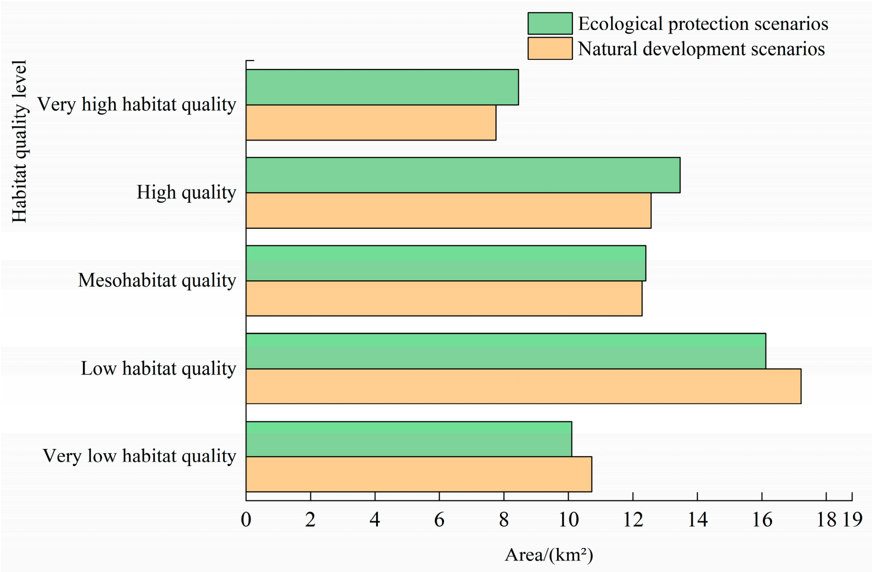

Figure 10. The corresponding areas of individual habitat quality levels under different development conditions.

4. Discussion

4.1. Reasons for land use change

The transformation of land use patterns in the temperate desert sub-region of the Ordos Plateau is the result of the combination of many factors (Luo et al 2023, Wei et al 2022a). Factors that threaten habitat quality include wasteland, unused land, and cropland (Long et al 2022,Ma et al 2022). Changes in the areas of these three land use types directly affect the changes in habitat quality. The Ordos Plateau temperate desert sub-region land use pattern change is therefore the result of many elements acting together. Analyzed from the perspective of land use transformation, the area of cultivated land decreased before increasing from 2000 to 2020, and the area of woodland continued to increase. The area of woodland in 2020 increased by 30 km^2 compared to that in 2000 and the area of grassland in 2020 increased by 4661.66 km^2 compared to that in 2000. Among all land use types, woodland appears to have the most obvious impact on habitat quality. Therefore, we can predict the best balance among ecological restoration, habitat quality conservation, and socio-economic development in arid areas with an inherently fragile ecological environment (Fu et al 2020). In this study, we compared the habitat quality of the study area under two scenarios with the actual situation of the temperate desert sub-region of the Ordos Plateau, and conclude that ecological conservation significantly contributes to the improvement of habitat quality. The results of this study are similar to those of the habitat quality study in Jilin performed by Zhao et al (Zhao et al 2022a).

4.2. Reasons for changes in habitat quality

In the temperate desert sub-region of the Ordos Plateau, habitat quality is closely related to the status of land use. As a result, the level of habitat quality rose and then fell over time. The continued improvement in habitat quality is due to the high cover of grasslands and the active ecological and management measures carried out in recent years. In the southeastern part of the study area, there are large areas of grassland with high and stable habitat quality and low habitat degradation. In the northwestern part of the study area, there are large areas of cultivated land with low habitat quality and high degradation.

4.3. Suggestions and outlook

The temperate desert sub-region of the Ordos Plateau straddles Ordos City in Inner Mongolia Autonomous Region and Yulin City in Shaanxi Province, located in the Yellow River basin in China, with a fragile ecosystem. The ecological environment of the study area is of great practical significance for promoting socio-economic development and ecological environment construction (Sun et al 2021, Wang et al 2022a), among other activities. The results of this study show that there are still some problems that need attention according to the analysis of land use and habitat quality changes. In the period of 2000–2020, the arable land area increased, the expansion of arable land area and the imbalance of regional economic development are prominent, and further rational planning of regional land use is needed. In particular, there is a need to further rationalize the planning of regional land development, protect high-quality arable land and limit the arbitrary expansion of urban land, clarify urban positioning and functions, and scientifically lead the coordinated development of regional and urban expansion. In terms of habitat quality, areas with a concentrated population and better economic development are characterized by lower habitat quality and a higher degree of degradation. Therefore, we need to focus on these corresponding areas to improve habitat quality by constructing ecological landscape corridors, occupying high-quality arable land for urban expansion, and returning farmland to woodland.

The predicted results in comparing the two scenarios of natural development and ecological protection show that the trend of land use change in 2025 under the ecological protection scenario is stable and the habitat quality is high. This can be used as a basis to confirm the rationality and necessity of implementing ecological management and protection in the study area in recent years. The government can establish nature reserves, return farmland to grassland for reforestation, and guide the development of the ecological economy. This will enhance the regional ecological barrier, improve the quality of the regional ecological environment, and reduce the degradation of the quality of human habitat.

5. Conclusion

In this study, the habitat quality module of the InVEST model was used to appraise the habitat quality of the Ordos Plateau in five periods of 2000, 2005, 2010, 2015, and 2020, and to characterize the changes. In addition, the PLUS model was used to predict the natural development scenario and ecological conservation. The main conclusions are as follows.

First, the grassland area, arable land area, and woodland area in the temperate desert sub-region of the Ordos Plateau increased significantly from 2000 to 2020; the area of water bodies and unused land increased slightly; and the area of wasteland continued to decrease. Grassland develops rapidly, and the area increased by 4661.66 km^2 in 20 years. The area of arable land showed a trend of first decreasing and then increasing, but the overall trend was in the upward direction. The area of woodland continued to increase, with the area increasing by 300 times in 2020 compared with that in 2000. The area of wasteland continued to decrease, and the decreasing part has mainly transformed into grassland.

Second, the low-value areas of habitat quality in the Ordos Plateau region from 2000 to 2020 are distributed in the northern and central areas of the study area, while the high-value areas of habitat quality are mainly distributed in the southeastern areas. The main land use type in the high-value area is grassland, with relatively low land use intensity and dense forest and grass cover. The low-value area is dominated by arable land, and the land use intensity in this area is higher and more influenced by human activities.

Finally, the following patterns can be seen from the time-lapse analysis. The habitat quality in the temperate desert subzone of the Ordos Plateau shows a trend of increasing and then decreasing; the degradation of habitat quality in the study area shows a trend of increasing, decreasing, and then increasing; and the areas with high degradation of habitat quality are mainly cultivated land types. Analysis of the PLUS model prediction results using the InVEST model showed that the habitat quality in the study area was higher under the ecological conservation scenario in 2025. The ecological conservation scenario shows a decrease in the area of higher habitat quality, an increase in the area of medium and high habitat quality, little change in the area of low habitat quality, a decrease in the area of lower habitat quality, and an overall increase of approximately 5% in the area above the medium habitat quality level compared to the natural development scenario. Thus, habitat quality is higher in the ecological conservation scenario.

References

1. Bai L M, Feng X H, Sun R F and Gao H 2020 Spatial and temporal responses of habitat quality to urbanization: A case study of Changchun City, Jilin Province, China **31** 1267-1277
2. Aneseyee A B, Noszczyk T, Soromessa T and Elias E 2020 The InVEST habitat quality model associated with land use/cover changes: A qualitative case study of the Winike Watershed in the Omo-Gibe Basin, Southwest Ethiopia **12** 1103
3. Biau 2012 Analysis of a random forests model **13** 1063-1095
4. Chu L, Sun T C, Wang T W, Li Z X and Cai C F 2018 Evolution and prediction of landscape pattern and habitat quality based on CA-Markov and InVEST model in Hubei section of Three Gorges Reservoir Area (TGRA) **10** 3854
5. Fang Q, Wu H C, Hinnov L A, Wang X L, Yang T S, Li H Y and Zhang S H 2016 A record of astronomically forced climate change in a late Ordovician (Sandbian) deep marine sequence, Ordos Basin, North China **341** 163-174
6. Fu and Zhang 2014 Land-use change and ecosystem services: Concepts, methods and progress **33** 441-446
7. Fu B J, Yu D D and Nv N 2017 Biodiversity and ecosystem services assessment index system in China Acta Ecologica Sinica **37** 341-348
8. Fu Y J, Shi X Y, He J, Yuan Y and Qu L L 2020 Identification and optimization strategy of county ecological security pattern: A case study in the Loess Plateau, China **112** 106030
9. Gao L N, Tao F, Liu R R, Wang Z L, Leng H J and Zhou T 2022 Multi-scenario simulation and ecological risk analysis of land use based on the PLUS model: A case study of Nanjing **85** 104055
10. Gomes E, Inácio M, Bogdzevič K, Kalinauskas M, Karnauskaitė D and Pereira P 2021 Future scenarios impact on land use change and habitat quality in Lithuania *Environ. Res* **197** 111101
11. Guo Q, Fu B H, Shi P L, Cudahy T, Zhang J and Xu H 2017 Satellite monitoring the spatial-temporal dynamics of desertification in response to climate change and human activities across the Ordos Plateau, China *Remote Sens*. **9** 525
12. Huang C, Zhao D Y and Deng L 2022 Landscape pattern simulation for ecosystem service value regulation of Three Gorges Reservoir Area, China *Environ. Impact Assessment Review* **95** 106798
13. Lei J R, Chen Y Q, Li L M, Chen Z Z, Chen X H, Wu T T and Li Y L 2022 Spatiotemporal change of habitat quality in Hainan Island of China based on changes in land use *Ecol. Indic.* **145** 109707
14. Li L, Wang J J, Yang C X and Wei C F 2021 Implementation Process of General Land-Use Planning and Its Adjustment—A Case Study of Rongchang District in Chongqing, China *Environ. Res. and Pubilic Health* **18** 5639
15. Li A L, Zhou Y, Tang L Y, Niu L D and Pan M 2023 Land use simulation and ecosystem service value assessment in Nujiang Prefecture - a multi-scenario analysis based on PLUS model *China's Agricultural Resources and Zoning* **44** 140-149
16. Li M Y, Zhou Y, Xiao P N, Tian Y, Huang H and Xiao L 2021 Evolution of Habitat Quality and Its Topographic Gradient Effect in Northwest Hubei Province from 2000 to 2020 Based on the InVEST Model *Land* **10** 857
17. Liao Z M and Wang Y 2022 Habitat quality assessment of Dianchi watershed based on InVEST model *Three Gorges ecological Environment Monitoring* **7** 42-52
18. Lin S L and Wang F 2022 Simulation and analysis of land use scenarios in Guangzhou based on PLUS model and taking into account traffic planning *Journal of Agricultural Resources and Environment* 1-15
19. Liu C Y, Zhu K W and Liu J P 2017 Evolution and prediction of land cover and biodiversity function in Chongqing section of Three Gorges Reservoir Area *Transactions of the Chinese Society of Agricultural Engineering* **33** 258-267

20. Liu X P, Liang X, Li X, Xu X C, Ou J P, Chen Y M, L S Yi, Wang S J and Pei F S 2017 A future land use simulation model (FLUS) for simulating multiple land use scenarios by coupling human and natural effects *Landscape and Urban Planning* **168** 94-116
21. Liu Z M, Zhou Q L, Ma Q, Kuang W N, Daryanto S, Wang L X, Wu J, Liu B, Zhu J L and Cao C Y 2023 Scale effect of climate factors on soil organic carbon stock in natural grasslands of northern China *Ecol. Indi.* **146** 109757
22. Long Y, Luo S Q, Liu X, Luo T Y and Liu X J 2022 Research on the Dynamic Evolution of the Landscape Pattern in the Urban Fringe Area of Wuhan from 2000 to 2020 *Geo-Inf*. **11** 483
23. Lu C, Qi X, Zheng Z S and Jia K 2022 PLUS-model based multi-scenario land space simulation of the Lower Yellow River Region and its ecological effects *Sustainability* **14** 6942
24. Luo J, Xu D Y and Ren H Y 2013 Identification of desertification dynamics and the impact of climate change and human activities in Ordos from 2000 to 2010 *Glacial permafrost* **35** 48-56
25. Luo Z W, Hu X J, Wang Y Z and Chen C Y 2023 Simulation and Prediction of Territorial Spatial Layout at the Lake-Type Basin Scale: A Case Study of the Dongting Lake Basin in China from 2000 to 2050 *Sustainability* **15** 5074
26. Ma Q M, Long Y P, Jia X P, Wang H B and Li Y S 2019 Vegetation response to climatic variation and human activities on the Ordos Plateau from 2000 to 2016 *Environ. Earth Sci.* **78** 1-15
27. Ma, Lü, Fu, Lü, Wu, Sun and Zhang 2022 A modified habitat quality model to incorporate the effects of ecological restoration *Environ. Res. Letters* **17** 104029
28. Moreira M, Fonseca C, Vergílio M, Calado H and Gil A 2018 Spatial assessment of habitat conservation status in a Macaronesian island based on the InVEST model: a case study of Pico Island (Azores, Portugal) *Land Use Policy* **78** 637-649
29. Pan Z J, Ma Y W, Cai S Q, Chen Y and Chen Y M 2023 Application of SolVES model in social value assessment of ecosystem service functions %J World Forestry Research *World Forestry Research* **36** 20-25
30. Lu Q, Lei J Q, Li X S, Yang Y L and Wang F Sciences 2020 Great Power Desertification Control: China's Approach and the Global Paradigm *Bulletin of the Chinese Academy of Sciences* **35** 656-664
31. Qiu T Q and Wang X R 2022 Spatial-temporal evolution analysis of habitat quality in Changzhutan urban agglomeration based on InVEST model *Forestry Resource Management* **5** 99-106
32. Riedler B and Lang S 2018 A spatially explicit patch model of habitat quality, integrating spatio-structural indicators *Ecol. Indic* **94** 128-141
33. Sharp R, Tallis H T, Ricketts T, Guerry A D, Wood S A, Chaplin-Kramer R, Nelson E, Ennaanay D, Wolny S and Olwero N 2016 The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund *InVEST+ VERSION+ User's Guide*
34. Shiferaw H, Bewket W, Alamirew T, Zeleke G, Teketay D, Bekele K, Schaffner U and Eckert S 2019 Implications of land use/land cover dynamics and Prosopis invasion on ecosystem service values in Afar Region, Ethiopia *Sci. of the Total Environ.* **675** 354-366
35. Sun X Q, Yu Y H, Wang J J and Liu W D 2021 Analysis of the spatiotemporal variation in habitat quality based on the invest model-a case study of Shangri-la city, northwest Yunnan, China *Journal of Physics: Conference Series. IOP Publishing.* **1961** 012016.
36. Wang B X and Cheng W M 2022 Effects of land use/cover on regional habitat quality under different geomorphic types based on InVEST model *Remote Sens*. **14** 1279
37. Wang Z Y, Li X, Mao Y T, Li L, Wang X R and Lin Q 2021 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 *Ecol. Indic*. **134** 108499
38. Wang X J, Liu G X, Xiang A C, Xiao S M, Lin D R, Lin Y B and Lu Y 2023 Terrain gradient response of landscape ecological environment to land use and land cover change in the hilly watershed in South China *Ecol. Indic.* **146** 109797
39. Wei L, Zhou L, Sun D Q, Yuan B and Hu F M 2022 Evaluating the impact of urban expansion on the habitat quality and constructing ecological security patterns: A case study of Jiziwan in the Yellow River Basin, China *Ecol. Indic.* **145** 109544

 doi:10.20944/preprints202306.0029.v1

40. Wei Q Q, Abudureheman M, Halike A, Yao K X, Yao L, Tang H and Tuheti B 2022 Temporal and spatial variation analysis of habitat quality on the PLUS-InVEST model for Ebinur Lake Basin, China *Ecol.Indic.* **145** 109632
41. Winkler K, Fuchs R, Rounsevell M and Herold M 2021 Global land use changes are four times greater than previously estimated Nature Communications *Nature Communications***12** 2501
42. Wu L L, Sun C G and Fan F L 2021 Estimating the characteristic spatiotemporal variation in habitat quality using the invest model—A case study from Guangdong–Hong Kong–Macao Greater Bay Area *Remote Sens.* **13** 1008
43. Yang J, Xie B and Zhang D 2021 Spatial-temporal evolution of habitat quality in the Yellow River Basin and its influencing factors *Journal of Desert Research* **41** 12-22
44. Yohannes H, Soromessa T, Argaw M and Dewan A 2021 Spatio-temporal changes in habitat quality and linkage with landscape characteristics in the Beressa watershed, Blue Nile basin of Ethiopian highlands *Journal of Environmental Managemen*t **281** 111885
45. Zhang H B, Wu F E, Zhang Y N, Han S and Liu Y Q 2019 Spatial and temporal changes of habitat quality in Jiangsu Yancheng Wetland National Nature Reserve-Rare birds of China *Appl. Ecol. Environ*. Res **17** 4807-4821
46. Zhang C C, Wang P, Xiong P S, Li C H and Quan B 2021 Spatial Pattern Simulation of Land Use Based on FLUS Model under Ecological Protection: A Case Study of Hengyang City *Sustainability* **13** 10458
47. Zhang H Y, Fan J W, Huang L, Tang Y L, Yue Y, Yang Y and Liu X H 2020 Theoretical research and technical scheme of comprehensive zoning of natural resources in China *Resource Science* **42** 1870-1882
48. Zhao B X, Li S J and Liu Z S 2022 Multi-Scenario Simulation and Prediction of Regional Habitat Quality Based on a System Dynamic and Patch-Generating Land-Use Simulation Coupling Model—A Case Study of Jilin Province *Sustainability* **14** 5303
49. Zhao Y L, Liu H X, Zhang A B, Cui X M and Zhao A Z 2019 Spatiotemporal variations and its influencing factors of grassland net primary productivity in Inner Mongolia, China during the period 2000–2014 *Journal of Arid Environments* **165** 106-118
50. Zhao L S, Yu W Y, Meng P, Zhang J S and Zhang J X 2022 InVEST model analysis of the impacts of land use change on landscape pattern and habitat quality in the Xiaolangdi Reservoir area of the Yellow River basin, China *Land Degradation & Development* **33** 2870-2884
51. Zhao Y F, Wu Q R, Wei P P, Zhao H, Zhang X W and Pang C K 2022 Explore the mitigation mechanism of urban thermal environment by integrating geographic detector and standard deviation ellipse (SDE) *Remote Sens.* **14** 3411
52. Zhu and Huang 2022 Multi-Scenario Simulation of Ecosystem Service Value in Wuhan Metropolitan Area Based on PLUS-GMOP Model **14** 13604