

# Monitoring Spatio-Temporal Dynamics and Causes of Habitat Quality in Yellow River Basin from the Perspective of Major Function-Oriented Zone Planning

Jinfeng Wang<sup>a</sup>, Lingfeng Li<sup>a</sup>, Qing Li<sup>b</sup>, Shixiong Hu<sup>c</sup>, and Sheng Wang<sup>a,\*</sup>

<sup>a</sup> School of Geographical Science, Shanxi Normal University, Taiyuan, 030000 China

<sup>b</sup> Institute of Geographical Sciences, Hebei Academy of Sciences, Hebei Engineering Research Center for Geographic Information Application, Shijiazhuang, 050011 China

<sup>c</sup> Department of History and Geography, East Stroudsburg University of PA, East Stroudsburg, 18301 USA

\*e-mail: wangsheng@sxnu.edu.cn

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**Abstract**—The Major Function Oriented Zone (MFOZ) Planning in the Yellow River Basin shows a positive effect on the orderly development of space planning and the construction of regional ecological security. The land use and habitat quality (HQ) in the Yellow River Basin were analyzed and predicted by using Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model and Cellular Automata (CA)-Markov model, and the main factors affecting HQ were discussed from the perspective of main function-oriented zones and multi-factor landscape pattern. The results showed that: (1) The basin presented fragmentation trend from the perspective of multi-factor landscape pattern. The middle reaches gradually tended to be fragmented. Landscape Shape Index (LSI) in the upper reaches was regular, while landscape richness of the lower reaches was poor and the dominance degree was not obvious. (2) From the perspective of major function oriented zone, a downward trend of HQ under different scenarios in 2030 was the same as that in 1990–2020, with the best HQ in the middle reaches and the worst HQ in the upper reaches. The spatial distribution pattern shows the characteristics of high-high agglomeration and low-low agglomeration. (3) The HQ in upper reaches was affected by complex factors, so the protection of national key ecological function zone should be strengthened. As a key ecological function area, population was the main factor affecting the habitat in the middle reaches. Population density and Normalized Difference Vegetation Index (NDVI) were the main factors affecting the habitat in major grain producing zone of lower reaches.

**Keywords:** major function-oriented zone, multi-factor landscape pattern, habitat quality, InVEST model, The Yellow River Basin

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## INTRODUCTION

Ecosystem is the basis for human survival and development (Fu et al., 2017), which not only provides material resources and living conditions for human life, but also ensures the stability of ecosystem circulation (Wen et al., 2020). Ecosystem services have become a policy tool for biodiversity conservation, aiming to emphasize ecosystem processes and outputs which contribute to human well-being, and could affect regional ecological security and balance the relationship between human and nature (Camino et al., 2016). With the continuous increase of population and rapid social development, three major problems of unbalanced regional development appeared at the same time, i.e. widening regional development gap, blind urbanization, and disorderly spatial development (Fan et al., 2009). These problems have led to the deterioration of ecological environment, increase

in resources pressure, intensified social conflicts, unsatisfactory economic operation and urbanization quality, and questionable healthiness of regional development. As an important evaluation index of ecosystem services, habitat quality (HQ) could reflect the health status of ecosystem and the regional biodiversity level (Zhu et al., 2020).

In order to improve the basic pattern of tense human-land relationship and disorderly spatial development, spatial planning plays an important role and has become an important means to achieve national sustainable development goals (Liu et al., 2014). Major Function-Oriented Zone Planning (MFOZ Planning) was an important attempt in China on spatial planning since the beginning of the new century, and it has also been raised to the national strategic level in the field of land development (Fan et al., 2012). The MFOZ planning established the general

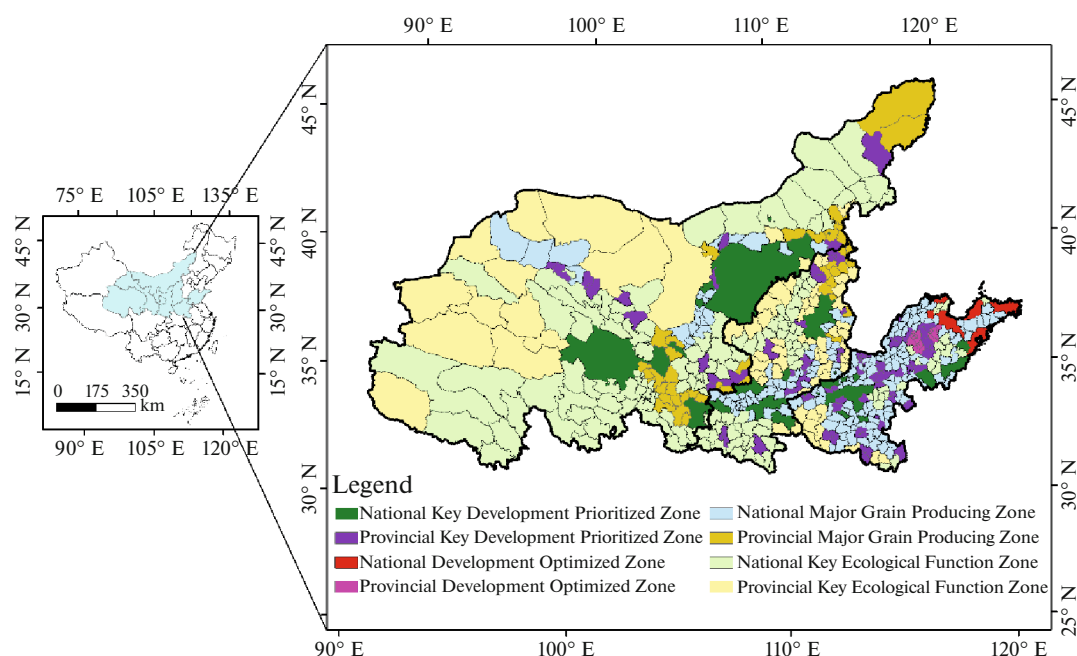


Fig. 1. Location of the study area.

layout of China's land space development pattern. It divided the land space into development-optimized areas, development-prioritized areas, development-restricted areas, and development-prohibited areas according to the carrying capacity of resources and environment, existing development intensity and future development potential (Fan, 2013; Wu et al., 2018; Zhang et al., 2021). The implementation of MFOZ Planning played a positive role in the orderly development of land space and the construction of regional ecological security (Fan et al., 2010, 2012), and also provided a scientific basis for promoting coordinated regional development, among which ecological function quantification was an important method to evaluate coordinated regional ecological development (Liu et al., 2016; Xia et al., 2020).

As an important ecological barrier and economic zone in China, the Yellow River Basin played an important role in China's social economic development and ecological security (Ma and Xu, 2020). The Yellow River Basin is one of the most serious soil erosion areas in China and even the world. Since the 1980s, due to rapid population growth and urban expansion, the environment of the Yellow River Basin has seriously deteriorated (Zhang et al., 2014). At present, the research on land use and ecosystem service function in the natural range of the Yellow River Basin has been carried out, however, the relationship between multi-factor landscape pattern and HQ in the Yellow River Basin was less analyzed from the perspective of county and MFOZ. In order to fully understand HQ variation in the Yellow River Basin since the

implementation of MFOZ Planning, and to meet the requirements of ecological protection and high-quality development of the Yellow River Basin, it was urgent to adopt more scientific methods to quantitatively assess the multi-factor landscape pattern and HQ in the Yellow River Basin under the implementation of MFOZ Planning. Based on land use from 1990 to 2020 in the Yellow River Basin, this paper analyzed land use and HQ by using CA-Markov model and InVEST model, and discussed the main factors affecting the habitat from the perspectives of MFOZ and multi-factor landscape pattern. It is expected to provide scientific basis for the rational planning of land use and landscape pattern, and has reference value for the ecological security of the Yellow River Basin based on MFOZ. The proposal of the main functional area strategy is also a reference for other countries.

## MATERIALS AND METHODS

### *Study Area*

The total area of Yellow River Basin is about 2.546 million km<sup>2</sup>, including 8 provinces, 91 municipal administrative units and 739 districts and counties (Fig. 1), the upper reaches include Qinghai, Gansu, Ningxia and Inner Mongolia, the middle reaches include Shanxi and Shaanxi provinces, and the lower reaches include Henan and Shandong provinces. It can be divided into national key development prioritized zone, provincial key development prioritized zone, national development optimized zone, provincial development optimized zone, national major

grain producing zone, provincial major grain producing zone, national key ecological function zone and provincial key ecological function zone according to function zoning. The key development prioritized zone, development optimized zone, major agricultural production zone and key ecological function zone accounted for 15.08, 1.35, 18.08 and 65.48%, respectively. Grassland was the main land type, followed by unused land (27.19%), cultivated land (18.17%), woodland (8.38%), water area (2.41%) and construction land (3.23%). The Yellow River Basin stretches across three gradient terrain of China and three economic belts (Zhang et al., 2017). It is characterized with uneven precipitation and a gradual increase in temperature from west to east. In addition, the upper reaches are mostly arid and semi-arid areas, with serious desertification problems and fragile ecosystems. Heavy rainfall from July to September in the middle reaches, coupled with unreasonable use of land resources, leads to serious soil and water loss. The land use intensity index in the lower reaches area is 2.94, indicating that human activities have significant effects on landscape development.

#### Data Sources

The land use data were obtained from the Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences (<http://www.resdc.cn/>), including 1990, 1995, 2000, 2005, 2010, 2015 and 2020, with a resolution of 1000m. Digital Elevation Model (DEM) is derived from geospatial data cloud (<http://www.gscloud.cn/>), with a resolution of 90m. The distribution maps of Normalized Difference Vegetation Index (NDVI), Gross Domestic Product (GDP) and population density were obtained from the Data Center of Resources and Environmental Sciences, Chinese Academy of Sciences, with a resolution of 1km, including 2000, 2005, 2010, 2015. The main road and railway data from the national fundamental geographic information system (<http://nfgis.nsd.gov.cn/>). Soil type data were obtained from Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences. Meteorological data from China meteorological data sharing service network (<http://cdc.cma.gov.cn/home.do>), including the temperature and precipitation data of 208 meteorological stations around the Yellow River Basin in 2000, 2005, 2010 and 2015. The data of major function-oriented zone come from the National Major Function-Oriented Zone Planning issued by the State Council and the major function area plans of provincial administrative regions.

#### Multi-Factor Landscape Pattern Indexes

The change of landscape pattern objectively reflects the change of land use, so it could coordinate the contradiction between human and natural environment,

and reflect the impact of landscape pattern on HQ. The land use change affected by topography and soil is closely related to HQ. The landscape pattern index calculated based on land cover alone cannot fully reflect the specific landscape change in the Yellow River Basin. Therefore, this study constructed multi-factor (Land Use and Land Cover(LUCC), slope, soil and NDVI) (Yang, 2019) landscape pattern to explore the impact of landscape pattern on HQ. The slope was divided into five categories:  $0^{\circ}$ – $5^{\circ}$ ,  $5^{\circ}$ – $10^{\circ}$ ,  $10^{\circ}$ – $15^{\circ}$ ,  $15^{\circ}$ – $20^{\circ}$  and  $20^{\circ}$ – $36^{\circ}$ . NDVI was divided into five categories: 0–0.15, 0.15–0.35, 0.35–0.55, 0.55–0.75 and 0.75–0.92. The soil type was classified into 12 classes. Fragstas4.2 software was used and eight representative indicators including Patch Density (PD), Area-Mean (AREA-MN), Landscape Shape Index (LSI), Contagion Index (CONTAG), Splitting Index (SPLIT), Aggregation Index(AI), Shannon's Evenness Index (SHEI) and Shannon's Diversity Index (SHDI) were selected to evaluate the landscape pattern.

#### InVEST Model

HQ in the Yellow River Basin was analyzed by using Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) Model. The HQ model combined LUCC and external threat, and comprehensively considered the influence distance, weight and sensitivity of threat factors to evaluate ecosystem services (Chen et al., 2016). Based on land use data of seven periods, this study explored and predicted the variation of HQ in the Yellow River Basin. The formula is as follows (Bai et al., 2013; Bao et al., 2015; Chen et al., 2020; Rocco and Davide, 2011; Terrado et al., 2016; Wang et al., 2020):

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

Where  $Q_{xj}$  is the HQ of grid  $x$  in land use type  $j$ ,  $D_{xj}$  is the threat level of grid  $x$  in land use type  $j$ ,  $k$  is a half-saturation constant which is half of the maximum value of  $D_{xj}$ ,  $H_j$  is the habitat suitability of land type  $j$ ,  $z$  is the normalized constant, which is 2.5. The formula of  $D_{xj}$  is:

$$D_{xj} = \sum_{r=1}^R \sum_{y=1}^{Y_r} \left( w_r / \sum_{r=1}^R w_r \right) r_y i_{ryx} \beta_x S_{jr}. \quad (2)$$

Where  $R$  is the number of threat factors,  $Y_r$  is the number of grids occupied by the threat factor on the land-use type layer,  $w_r$  is the weight of the threat factor,  $r_y$  is the threat factor value of grid  $y$ ,  $\beta_x$  is the reachability level of grid  $x$ ,  $S_{jr}$  is the sensitivity of land-use type  $j$  to threat factor  $r$ ,  $i_{ryx}$  is the habitat threat level of grid  $x$  from threat factor  $r$  on grid  $y$ . Here,  $i_{ryx}$  can be calculated as follows:

$$i_{ryx} = 1 - \left( \frac{d_{xy}}{d_{r\max}} \right), \quad (3)$$

**Table 1.** Threat factors and weight in the study area

Threat Type	Max distance	Weight	Decay
Construction land	7	1	Exponential
Cultivated land	6	0.7	Linear
Main roads	2	0.6	Linear
Main railways	1.5	0.4	Linear

$$i_{r_{yx}} = \exp\left(\frac{-2.99d_{xy}}{d_{r_{max}}}\right). \tag{4}$$

Where  $d_{xy}$  is the straight line distance between grid  $x$  and grid  $y$  and  $d_{r_{max}}$  is the maximum influence distance of threat factor  $r$ .

Due to the great impact of construction land on the ecological environment, construction land was taken as a threat factor according to the actual situation of the Yellow River Basin. In addition, cultivated land, main roads and main railways associated with human activities were also selected as threat factors. Referred to the InVEST model cases and combined with the existing studies of Wu Dan (2020), Zhou Liang (2021), Zhao Xiaojiong (2020) and He Juan (2020), the values of threat factor, sensitivity, influence distance and weight were assigned (Tables 1 and 2).

*CA-Markov Model*

Markov prediction method can explain the quantitative relationship in the process of landscape change. CA model is a discontinuous spatiotemporal dynamic model, which represents the state transfer rules of the interaction between cellular units. CA-Markov model integrates the time series prediction of Markov model and space simulation of CA model (Hu et al., 2013; Mansour et al., 2020; Riao et al., 2020; Wu et al., 2017), and the formula includes:

$$S_{(t+1)} = P_{ij} \times S_{(t)}. \tag{5}$$

Where  $S_{(t)}$  and  $S_{(t+1)}$  are the column vectors of the land-use type status at time  $t$  and  $t + 1$ , respectively,  $P_{ij}$  is the land-use transition probability matrix.  $P_{ij}$  can be calculated as follows:

$$P_{ij} = \begin{bmatrix} P_{11} & P_{12} & \dots & P_{1n} \\ P_{21} & P_{22} & \dots & P_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ P_{n1} & P_{n2} & \dots & P_{nn} \end{bmatrix}, \tag{6}$$

$P_{ij}$  satisfies the following conditions:  $0 \leq P_{ij} \leq 1$ ,  $i, j$  are 0, 1, 2 ...  $n$ , where the sum of the rows is 1.

$$\sum_{i=1}^n P_{ij} = 1, \tag{7}$$

$$S_{(t+1)} = f(S_{(t)}, N), \tag{8}$$

where  $S_{(t)}$  and  $S_{(t+1)}$  are the system state results at time  $t$  and  $t + 1$ ,  $N$  is the cellular neighborhood range, and  $f$  is the state transition rule function of cellular interaction in the neighborhood range.

In IDRISI software, the LUCC in 2000 was taken as the starting year, and 2015 was taken as the ending year. The interval and forecast period are both 15 years and the tolerance was set as 0.15 according to the software instructions, so as to obtain the area transfer matrix and probability matrix. On this basis, taking 2015 as the basis, we set the number of CA cycles to 15, and the filter is  $5 \times 5$  m, to predict the land use change in the Yellow River Basin in 2030. The Kappa coefficient between the referential and predicted LUCC data in 2010 was 0.91, which indicated that the model had high prediction reliability and could provide scientific basis for land planning and rational utilization of resources.

**RESULTS**

*Analysis of Multi-Factor Landscape Pattern*

The Yellow River Basin based on MFOZ spanned three topographic steps in the East, middle and West, including plain, hill, plateau and other terrain. Both temperature and rainfall decreased from southeast to northwest with obvious spatial heterogeneity. So it was necessary to be analyzed from the perspective of upper, middle, lower reaches and the whole region (Table 3). From the perspective of the whole basin, the larger patches in the landscape were divided into smaller patches, which showed fragmentation trend. The decrease of AI reflected the weakening spatial connectivity of land types and the increasing smaller

**Table 2.** The habitat suitability and sensitivity of land use type to each threat factor

Land-use type	Habitat suitability	Construction land	Cultivated land	Main roads	Main railways
Cultivated land	0.9	0.8	0	0.8	0.8
Woodland	1	0.9	0.7	0.9	0.9
Grassland	0.7	0.6	0.6	0.7	0.5
Water	0.9	0.6	0.4	0.3	0.2
Construction land	0	0	0	0.4	0.4
Unused land	0.3	0.4	0.3	0.1	0.1

**Table 3.** Variation of multi-factor landscape index in the Yellow River Basin

		PD	AREA-MN	LSI	CONTAG	SPLIT	AI	SHDI	SHEI
Upper reaches	2000	0.20	488.40	334.22	53.52	223.38	51.54	4.77	0.67
	2005	0.21	473.62	338.76	52.88	234.95	50.89	4.86	0.68
	2010	0.21	472.39	338.42	52.96	206.95	50.93	4.84	0.68
	2015	0.24	420.05	355.36	51.97	234.48	48.42	4.89	0.68
Middle reaches	2000	0.40	250.53	221.36	44.01	6028.14	27.10	4.59	0.71
	2005	0.40	247.59	222.94	44.10	9359.63	26.56	4.56	0.71
	2010	0.41	245.54	223.50	43.99	9540.96	26.36	4.51	0.70
	2015	0.44	229.24	229.54	43.55	14248.07	24.32	4.58	0.70
Lower reaches	2000	0.24	408.76	157.63	53.98	112.40	45.01	3.58	0.59
	2005	0.25	398.09	154.42	54.41	37.58	46.14	3.56	0.59
	2010	0.25	405.74	154.66	54.10	47.38	46.07	3.61	0.60
	2015	0.29	344.19	169.03	52.35	51.14	40.90	3.71	0.60
Whole region	2000	0.24	421.78	424.87	50.57	393.55	47.19	5.09	0.71
	2005	0.24	411.28	427.86	50.10	370.41	46.78	5.14	0.71
	2010	0.24	410.53	428.18	50.17	341.95	46.78	5.13	0.71
	2015	0.27	366.81	450.00	49.22	386.62	44.00	5.17	0.71

LUCC patches. SHDI exhibited an increasing trend, indicating that landscape richness and complexity increased continuously, and land types transformed more frequently. The variation trend of SHEI was the same as SHDI, and all patches tended to be equalized in the landscape pattern. The general trend of PD, AREA-MN and LSI in the upper, middle and lower reaches was the same as that in the whole region, in which PD and LSI increased while AREA-MN was decreased. In the middle reaches, PD was the largest and the average patch area was the smallest, indicating fragmentation trend. SHDI and SHEI showed an overall increasing trend in the lower reaches, but the land use richness was poor and there was no obvious dominant type compared with the upper and middle reaches. By comparing single-factor (LUCC) and multi-factor landscape pattern, PD, AREA-MN, LSI and AI in the whole region, the upper and middle reaches presented the same trend, while in the lower reaches showed different trends. The multi-factor landscape pattern index showed obvious fluctuation state after integrating topographic factors, the evenness index (SHDI and SHEI) illustrated the largest difference, followed by CONTAG and SPLIT. Therefore, multi-factor landscape pattern was more sensitive to spatial heterogeneity and could better reflect the development trend of landscape pattern fragmentation and evenness.

#### *Temporal and Spatial Change in Habitat Quality*

The habitat quality Index (HQI) was used to characterize HQ, which ranges from 0 to 1. The closer to 1, the better the HQ. According to the existing research

and the HQ status of the Yellow River Basin, the HQ was divided into five grades: low (0–0.20), relatively low (0.21–0.40), medium (0.41–0.60), relatively high (0.61–0.80) and high (0.81–1) (Fig. 2). In general, the habitat quality is the best in the middle reaches, followed by the lower reaches with an average value of 0.662, and the upper reaches with the worst HQ (Fig. 3). The HQ in the upper reaches reached the peak in 1995, and the lowest was 0.549 in 2015. After that, the HQ improved but not reached the average level of the basin, which was caused by the special topography of the upper reaches, large unused land, large area with relatively low HQ and poor ecological environment. The HQ trend in the middle reaches is almost the same as that in the lower reaches. This was mainly due to the rapid economic construction in the middle and lower reaches, especially the construction land in the lower reaches occupied a large amount of woodland and grassland, and increased by 7361 km<sup>2</sup> from 2015 to 2020, which resulted in the maximum degradation rate of HQ.

The strategy of MFOZ planning is of great significance to guide the sustainable development of ecosystem. Based on the major function oriented zoning, the relationship between each functional area and habitat can be judged. From the perspective of zoning, the HQ in the provincial major grain producing zone was the best, while the provincial key ecological function zone was the worst, with an average value of 0.478 (Table 4). Global spatial autocorrelation analysis showed that all the 7 periods LUCC passed 1% significance test, indicating that there was spatial autocorrelation of HQ under 99.9% confidence. Moran's I values were 0.1497, 0.1488, 0.1512, 0.1512, 0.1519, 0.1532, 0.1552, respectively, indicating that HQ in the

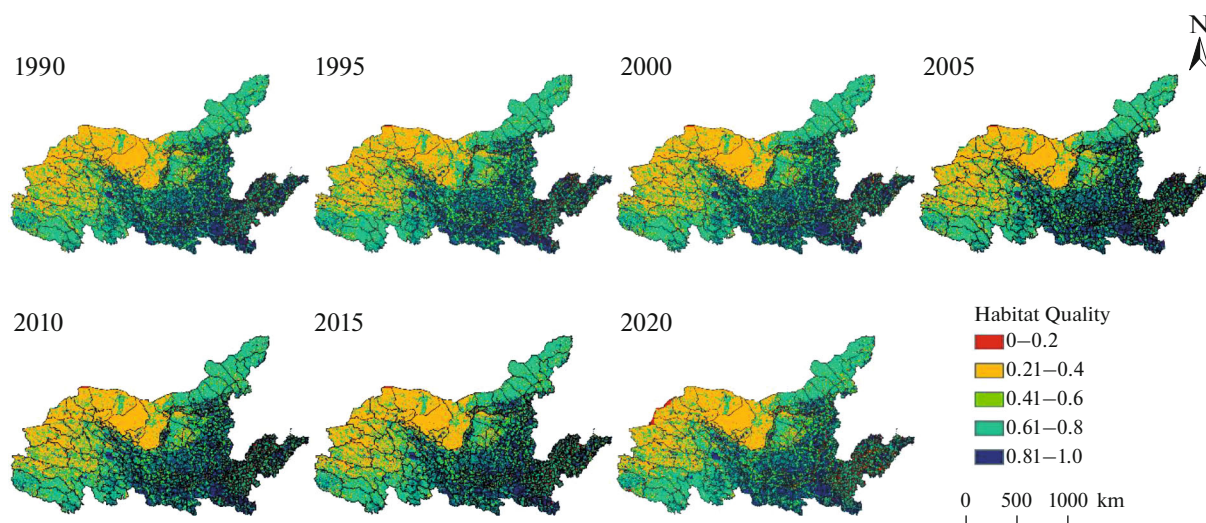


Fig. 2. Spatial distribution of HQ in the Yellow River Basin during 1990–2020.

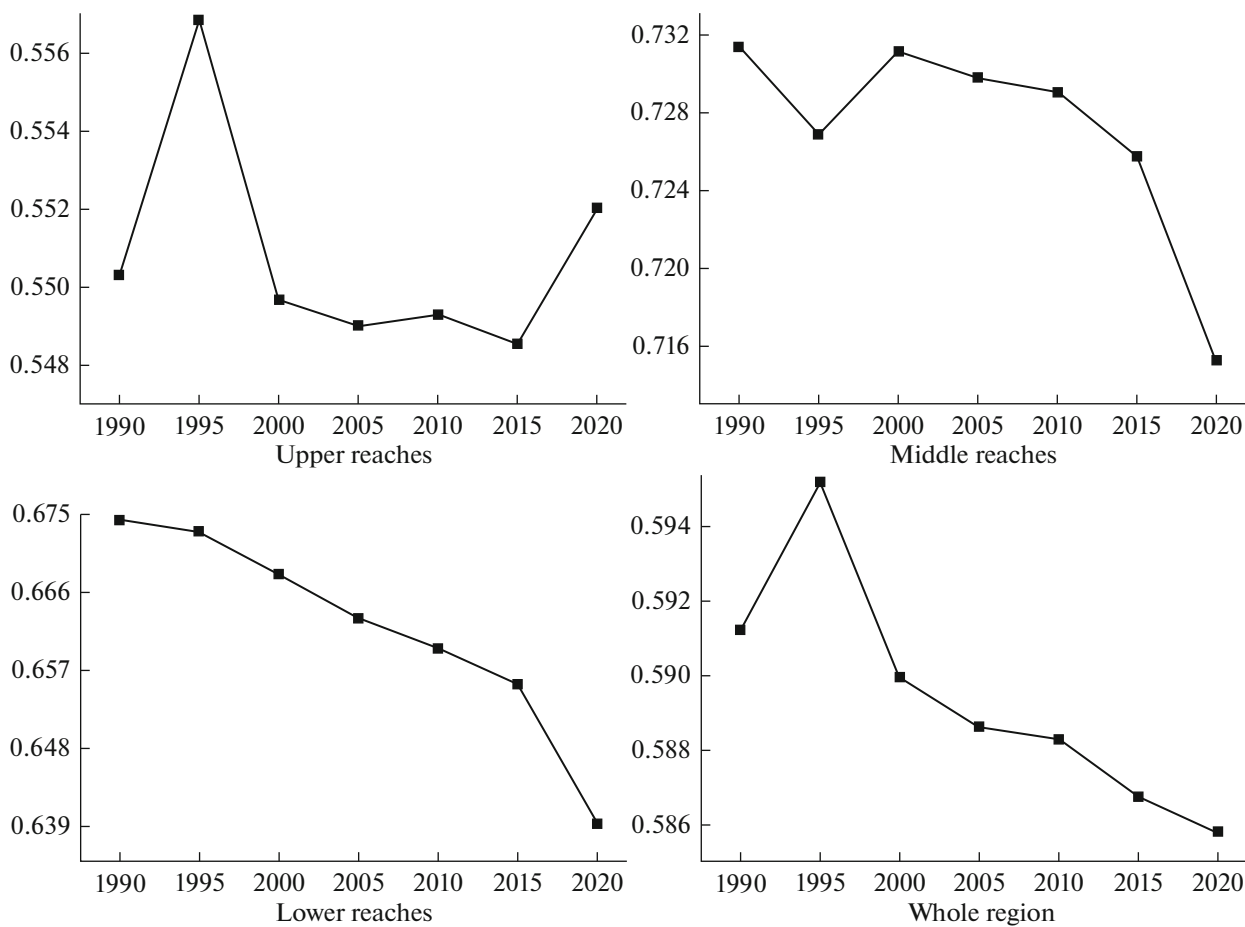


Fig. 3. Temporal trend of HQ in the upper, middle and lower reaches of the Yellow River Basin from 1990 to 2020.

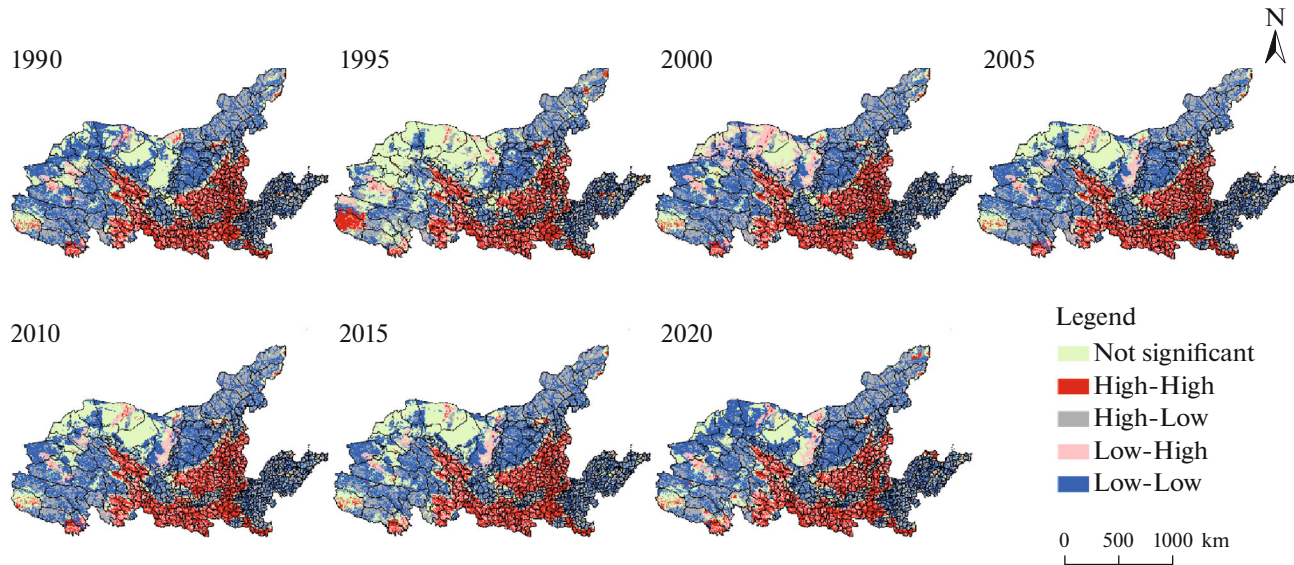


Fig. 4. Spatial Lisa clustering map of HQ in the Yellow River Basin from 1990 to 2020.

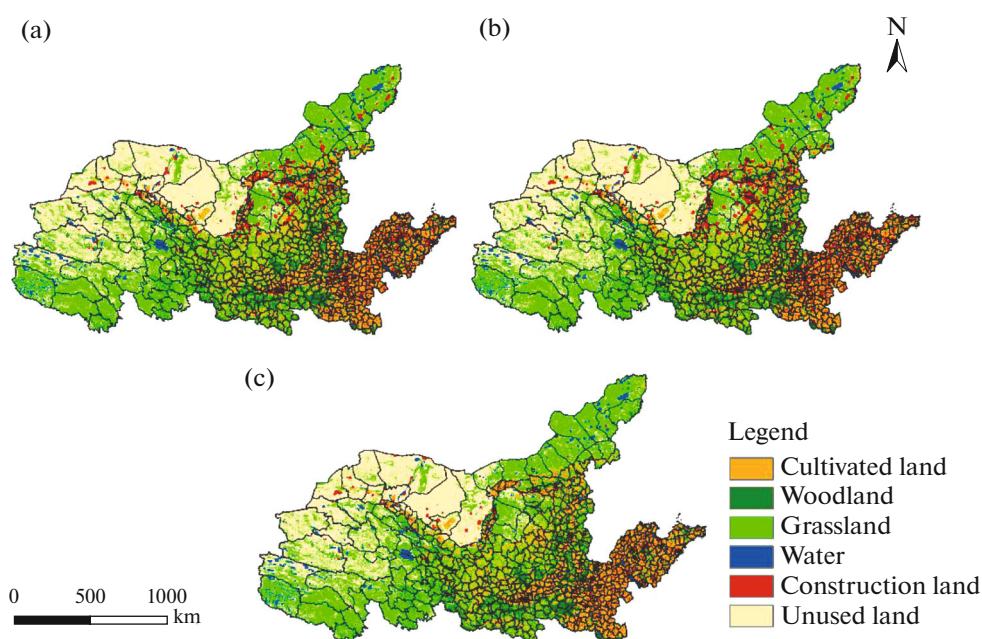
Yellow River Basin presented a spatial clustering pattern, the regions with high HQ agglomerated (high-high agglomeration), and the regions with low HQ also agglomerated (low-low agglomeration). The spatial agglomeration characteristics of HQ were similar during 1990–2020. The area with high HQ were mainly located in the national key ecological function zones, part of the national major grain producing zones and east of the provincial key ecological function zones. The area with low HQ were distributed in the national key development prioritized zones in the northwest part of the Loess Plateau and western part of the national and provincial key ecological function zones. From 1990 to 2020, the area with high-value HQ decreased from 15.90 to 15.67%, while the low-value area increased from 31.19 to 33.41%, which indicated that the HQ in the Yellow River Basin presented an obvious downward trend (Fig. 4).

#### *Future Prediction of Land Use Pattern and Habitat Quality*

Understanding the future variation of LUCC and its impact on HQ under different scenarios was a key indicator of ecosystem service. According to the development planning in the Yellow River Basin, three scenarios of natural development, urban expansion and ecological protection were simulated by using CA-Markov model. The natural scenario was based on natural development rules, without setting restrictions and without any change on the conversion probability obtained by Markov model. Compared with the forestland in 2020, it increased by 5816 km<sup>2</sup>, which was consistent with the growth trend of forestland in 1990–2020, indicating the profound impact of the Grain for Green Project (GGP) on the future development of land use (Table 5). The urban expansion scenario was based on the current development trend

Table 4. Variation of HQ in MFOZ from 1990 to 2020

	1990	1995	2000	2005	2010	2015	2020
National key development prioritized zone	0.639	0.637	0.635	0.631	0.630	0.625	0.616
Provincial key development prioritized zone	0.643	0.640	0.636	0.633	0.631	0.626	0.612
National development optimized zone	0.615	0.605	0.604	0.591	0.583	0.580	0.585
Provincial development optimized zone	0.616	0.611	0.607	0.593	0.578	0.571	0.508
National major grain producing zone	0.620	0.617	0.619	0.616	0.615	0.612	0.604
Provincial major grain producing zone	0.679	0.676	0.681	0.678	0.678	0.676	0.673
National key ecological function zone	0.638	0.641	0.638	0.637	0.638	0.637	0.645
Provincial key ecological function zone	0.477	0.491	0.476	0.476	0.476	0.475	0.473
Average habitat quality	0.591	0.595	0.590	0.589	0.588	0.587	0.586



**Fig. 5.** Spatial distribution of land use in the Yellow River Basin under natural development scenario (a), urban expansion scenario (b) and ecological protection scenario (c).

of construction land from 1990 to 2020. Construction land was 1.96 times of that in 2020, and extended outward in an elliptical shape, which occupied a large amount of ecological land, leading to cultivated land and grassland decrease by 15616 and 95619 km<sup>2</sup>, respectively. Considering the ecological protection and high-quality development of the Yellow River Basin, water was taken as a constraint condition to prohibit the transformation from water to any land type, and the probability of converting cultivated land, forestland and grassland to construction land was adjusted in the ecological protection scenario. The construction land is controlled to some extent, resulting in the increase of cultivated land and forest land. Therefore, under the influence of a series of policies such as ecological protection and high-quality development in the Yellow River Basin, ecological land area increased and the ecological environment tended to be better. In general, the change of land use pattern in

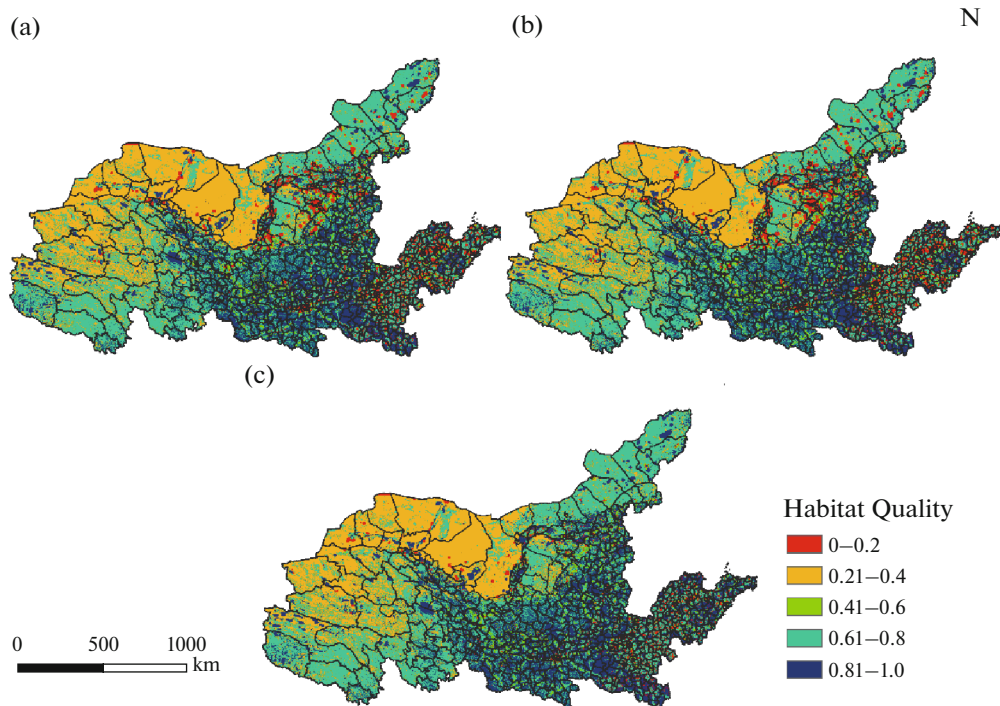
natural development scenario and urban expansion scenario was small. The cultivated land, forest land and grassland under urban expansion scenario all decreased. The changes of the ecological protection scenario were reflected in the construction land, especially in Inner Mongolia and Shandong Peninsula (Fig. 5).

Distribution pattern of HQ under three scenarios only changed slightly in some areas. Compared with the natural development scenario, the area with low HQ in the urban expansion scenario showed an increasing trend in the northeast of the Yellow River Basin, and the area with low HQ in the ecological protection scenario was significantly smaller than that in the other two scenarios (Fig. 6). The area above medium level decreased by 2.17% in natural development scenario and 3.01% in urban expansion scenario compared with 2020, respectively, while the area below medium level increased, indicating that the

**Table 5.** Land use change in the Yellow River Basin from 1990 to 2030

	Cultivated land	Woodland	Grassland	Water	Construction land	Unused land
1990	479085	207567	1030457	51273	51482	725680
2000	481749	207569	1022903	51641	55558	726124
2010	474641	210596	1020939	52862	61151	725355
2020	461453	212833	1031970	61242	82039	696007
Natural development scenarios	456112	218649	943596	98766	161028	667393
Urban expansion scenarios	445837	217749	936351	98766	180273	666568
Ecological protection scenario	484897	225804	976206	98766	89178	670693





**Fig. 6.** Spatial distribution of HQ in the Yellow River Basin under natural development scenario (a), urban expansion scenario (b) and ecological protection scenario (c).

habitat quality has decreased. Under the ecological protection scenario, the area above medium level increased by 0.97%, indicating that the habitat quality was improved. The effect of forestland and grassland restoration was remarkable due to the implementation of the Grain for Green Project (GGP).

The trend of HQ was consistent with that in 1990–2020 in the upper, middle and lower reaches, with the highest HQ in the middle reaches and the lowest in the upper reaches. Compared with 2020, the habitat in the upper and lower reaches of the natural development scenario was worse, and the middle reaches slightly got better. Under the urban expansion scenario, the lower reaches deteriorated the most due to the expansion of construction land, with the HQ index decreased by 0.065. Under the ecological protection scenario, the HQ in the middle reaches presented maximum variation as the increase of cultivated land and woodland. The variation trend and distribution of HQ under simulation scenarios were also the same as 1990–2020 from the perspective of MFOZ, and the HQ in the provincial major grain producing zone and provincial key ecological function zone were respectively corresponded to the high and low value HQ areas (Table 6). HQ was the highest under ecological protection, followed by natural development, and the worst in urban expansion scenario. Under the ecological protection scenario, the HQ was higher than that of 2020 among all zones except the national development optimized zone.

## DISCUSSIONS

### *Impact Factors of Habitat Quality*

The habitat quality of the Yellow River Basin based on MFOZ showed different temporal and spatial changes. The area with low habitat quality was increasing year by year, increasing by 37 588 km<sup>2</sup> from 1990 to 2020. The change was most obvious in Shandong Peninsula, which was located in the coastal area, and the rapid economic development was accompanied by the emergence of ecological problems. The lower level area decreased first, then increased and finally decreased again, which mainly distributed in the northwest of the Yellow River Basin. The change of medium area has increased steadily after 2005 and reached the maximum value of 92 034 km<sup>2</sup> by 2020. The relatively high habitat quality was the largest in each year, showing an increasing trend from 1990 to 2020. The southwest of the basin and the middle of Shandong Peninsula were the areas with remarkable changes. At the end of the 20th century, the state promulgated relevant policies for the emergence of ecological problems and advocated strengthening the protection of grassland in the southwest of the Yellow River Basin. In 2003, Shandong put forward the outline of Shandong ecological province construction plan, which aimed to promote the construction of ecological civilization. High habitat quality in the basin generally decreased, indicating that the land with high habitat quality was being destroyed and gradually transformed to other grades. The Yellow

**Table 6.** HQ of MFOZ in the Yellow River Basin

	Natural development scenarios	Urban expansion scenarios	Ecological protection scenario
National key development prioritized zone	0.570	0.557	0.629
Provincial key development prioritized zone	0.569	0.552	0.626
National development optimized zone	0.470	0.445	0.567
Provincial development optimized zone	0.420	0.395	0.519
National major grain producing zone	0.580	0.565	0.622
Provincial major grain producing zone	0.674	0.668	0.696
National key ecological function zone	0.639	0.637	0.648
Provincial key ecological function zone	0.476	0.475	0.483
Average HQ	0.574	0.568	0.596

**Table 7.** Correlation between HQ and impact factors in the Yellow River Basin

		Climate factor		Topographic factor		Vegetation factor	Social factor
		temperature	precipitation	elevation	slope	NDVI	population density
Upper reaches	2000	-0.087	0.451**	-0.373**	0.193**	0.370**	-0.261**
	2005	-0.164*	0.323**	-0.456**	0.282**	0.420**	-0.280**
	2010	-0.180**	0.313**	-0.416**	0.229**	0.485**	-0.133**
	2015	-0.086	0.262**	-0.252**	0.261**	0.420**	-0.296**
Middle reaches	2000	0.213**	-0.118*	0.217**	-0.001	0.193**	-0.794**
	2005	0.204**	-0.145**	0.127**	0.009	0.226**	-0.804**
	2010	0.139**	-0.142**	0.266**	0.029	0.323**	-0.612**
	2015	0.125*	-0.126**	0.267**	0.081	0.247**	-0.644**
Lower reaches	2000	0.069*	-0.003	0.067	0.234**	0.288**	-0.636**
	2005	0.079**	0.045	0.134*	0.144*	0.282**	-0.623**
	2010	-0.087*	0.076*	-0.038	0.345**	0.529**	-0.377**
	2015	0.009	0.001	-0.045	0.314**	0.568**	-0.347**
Whole region	2000	-0.043	-0.031	-0.173**	0.313**	0.381**	-0.660**
	2005	0.036	-0.111**	-0.116*	0.257**	0.455**	-0.671**
	2010	-0.230**	-0.176**	-0.322**	0.402**	0.611**	-0.403**
	2015	-0.151**	-0.127**	-0.165**	0.296**	0.514**	-0.506**

\*\* Means significant correlation at 0.01 level, \* means significant correlation at 0.05 level.

River Basin included 739 counties and districts based on the MFOZ planning. The variation of HQ was caused by natural factors and human activities. According to land use and HQ of the Yellow River Basin, six factors, including climate (temperature and precipitation), topography (elevation and slope), vegetation (NDVI) and social factor (population density), were selected to quantitatively analyze the spatio-temporal evolution characteristics of HQ by using regression analysis (Table 7).

Owing to the large east-west span of the Yellow River Basin and the rugged terrain, the regional climate was obviously different, leading to the non-significant correlation between HQ and climate factors.

Population density presented the greatest impact on habitat in 2000 and 2005, followed by NDVI, while NDVI had the greatest impact on habitat in 2010 and 2015. The climate was dry in most upper reaches, with the increase of precipitation and NDVI index, the HQ tended to be better. At the same time, the greater the slope, the less affected by human activities and the HQ also became better. Generally, the influencing factors in the upper reaches were complex. National key development prioritized zone, provincial and national key ecological function zone were mainly distributed in the upper reaches, and the HQ of provincial key ecological function zone was the worst. Therefore, the protection of national key ecological function zones

**Table 8.** Correlation between HQ and multi factor landscape pattern index

	PD	AREA-MEAN	LSI	CONTAG	SPLIT	AI	SHDI	SHEI
Upper reaches	-0.903	0.913	-0.914	0.974*	-0.567	0.912	-0.964*	-0.910
Middle reaches	-0.982*	0.984*	-0.990**	0.907	-0.986*	0.991**	0.045	0.924
Lower reaches	-0.785	0.787	-0.619	0.695	0.710	0.620	-0.824	-0.680
Whole region	-0.925	0.934	-0.902	0.969*	0.132	0.903	-0.958*	-0.778

\*\* Means significant correlation at 0.01 level, \*means significant correlation at 0.05 level.

should be strengthened in the upper reaches. The correlation coefficients of population density were -0.794, -0.804, -0.612 and -0.644 in the middle reaches, respectively, indicating that population was the main factor on HQ. Water and soil erosion is serious due to loess soil, heavy rainfall in summer and low vegetation coverage. The HQ deteriorated with the increase of precipitation. Middle reaches as the key ecological function areas, population factors have become the main factors affecting HQ, human activities (land use change, the reservoir construction, irrigation water, soil and water conservation, urbanization, etc.), broke the balance of the original natural water cycle system, changed the precipitation, evaporation, infiltration, runoff, sediment yield pattern. The adverse effects of human activities on the environment should be controlled in future. The lower reaches are important grain production areas, and the optimized development zones are only distributed in the lower reaches of the basin. Population density and NDVI were the main factors affecting habitat quality. At the same time of economic development, we should not only change the current mode of economic development, but also strengthen the protection of national major grain producing zone.

#### *Effects of Multi-factor Landscape Pattern on Habitat Quality*

The results of correlation analysis between HQ and multi factor landscape pattern indicators were shown in Table 8. The correlation between HQ and spread index and Shannon diversity index passed the 5% significance test, and the correlation coefficient was above 0.9, indicating that HQ was significantly positive correlated with CONTAG, while negative correlated with SHDI. There was a negative correlation between HQ and SHDI in the upper reaches, indicating that the lower the degree of diversity in the upper reaches, the better the HQ. However, due to the fact that the upper reaches are national and provincial key ecological function zones with unused land as the main land type, the habitat quality is poor. Considering the impact of landscape pattern on habitat, we could optimize the landscape area with good HQ and focus on protecting the landscape patches with good ecological effect. The middle reaches include three functional types: development optimized zone, major

grain producing zone, and key ecological function zone, with various landscape types, obvious fragmentation and serious soil and water loss. According to the correlation analysis, there is a positive correlation between HQ and AI, indicating that the higher the degree of landscape aggregation, the less the possibility of soil erosion. Therefore, it is necessary to focus on the landscape aggregation of each functional area to reduce the loss caused by soil erosion, and give full play to the role of functional areas. Since the unused land only accounted for 0.52% of the lower reaches, the land utilization rate was extremely high, the correlation between HQ and each index was not significant affected by human activities. There is no obvious dominant landscape type in the lower reaches. More attention should be paid to the fragmented development trend of landscape as the major grain producing zone, so as not to affect the sustainable development of agricultural ecology.

#### *Application of the MFOZ Planning*

The spatial planning system of the major developed countries abroad is perfect, with distinct levels, clear rights and responsibilities. The basic differences in systems and resource endowments of various countries determine that the corresponding spatial planning model continues to maintain diversified characteristics. The regional development planning system of Japan is divided into four levels: city, town, village and district (Tominaga, 2011). It defines five types of areas, including urban area, agricultural area, forest area, natural park area and nature protection area, and proposes the development goals, spatial layout and corresponding land control requirements of different areas. The land space planning of Germany is divided into federal, state, regional and local levels according to the administrative level, and the land space is divided into dense area, rural area, residential area and transportation corridor, and central area system (Zhou and Tan, 2020). It aims at reducing spatial differences, maintaining urban functions, increasing survival opportunities in rural areas, planning management and regional coordination. The fifth spatial plan divides the Netherlands into foundation layer, network layer and application layer (Chen, 2012). The foundation layer mainly adheres to the principle of taking rivers as the center to solve various problems

concerning water resources, while the network layer solves the environmental problems caused by infrastructure network and transportation network. The application layer solves the problem of spatial difference between developed and underdeveloped regions. Britain has formed a new two-level spatial planning system of “national and local”. Put forward programmatic and strategic macro guidance from 13 aspects of economic development, urban vitality and rural construction (Wang and Chen, 2019). The land development policy of France divides the whole land into four types: urban area, urban-rural mixed area, rural area, mountainous area and coastal area (Liu, 2011). Its policy objectives are to narrow the gap of municipal development, strengthen coordination of urban-rural mixed area, improve natural environment, and achieve the balanced development of mountainous area and coastal area respectively. To sum up, the land spatial planning proposed by various countries is mainly aimed at regional differences and environmental problems. Countries such as France, the Netherlands, England and Germany started their land space planning and management earlier, focusing on refining spatial functions and optimizing the quality of development, while Japan pays attention to its national development model and level (Zhang, 2011; Zhang et al., 2020). MFOZ emphasizes multi-spatial division, which can balance protection and development, and solve inter-regional development problems in a more targeted way. Research in the field of system mainly focuses on the interpretation of theoretical basis, remote sensing monitoring evaluation and statistical analysis, but comprehensive quantitative evaluation is still lacking.

Therefore, this paper studied land use and habitat quality in the Yellow River Basin based on MFOZ. On the one hand, it can provide reference for the national land use planning. On the other hand, it put forward reasonable suggestions for the different problems faced by the upper, middle and lower reaches. The upper reaches faced complex factors, so it was necessary to strengthen the protection of national key ecological function zone. Human activities should be reduced in the ecological function zones of the middle reaches to avoid more serious water and soil erosion, while the protection of major grain producing zone should be emphasized in the lower reaches. MFOZ refines the major functions of each region and clearly reflects the current ecological problems and future development direction. Moreover, it determines the development mode and resource allocation efficiency to some extent, reverses the trend of ecological environment deterioration from the source.

As an important factor to measure the status and level of regional ecosystem services, habitat quality could reflect whether regional ecological security was guaranteed. Rational construction of ecological security pattern could maintain the integrity of regional ecological structure and guarantee the effective allo-

cation of resources. It is one of the important spatial ways to alleviate the contradiction between ecological protection and economic development in each region. In the future, key ecological functional zone and major grain producing zone will be taken as the construction focus, and the construction of ecological security pattern will be carried out on this basis. The MFOZ planning has achieved remarkable results in the past ten years (Huang et al., 2020), and has played an important role in promoting the formation of an efficient, coordinated and sustainable land and space development pattern. In a more complex international background, it is expected to be applied in the international environment, and scientific and exploratory research can be carried out based on this planning.

## CONCLUSIONS

This study took the Yellow River Basin based on the MFOZ as the research object to analyze the characteristics and impact factors for LUCC and HQ variation from the perspective of MFOZ and multi-factor landscape pattern.

(1) The multi-factor landscape pattern was more sensitive to spatial heterogeneity, and the Yellow River Basin based on the MFOZ presented a fragmentation trend. The middle reaches tended to be fragmented. The LSI in the upper reaches was regular, while the landscape richness of the lower reaches region was poor and the dominance degree was not obvious.

(2) The trend of HQ in the future was the same as that in the present. The area with high HQ were mainly located in the national key ecological function zones, part of the national major grain producing zones and east of the provincial key ecological function zones. The area with low HQ were distributed in the national key development prioritized zones in the northwest part of the Loess Plateau and western part of the national and provincial key ecological function zones.

(3) The HQ in the upper reaches was affected by complex factors, so the protection of national key ecological function zone should be strengthened. As a key ecological function area, population was the main factor affecting the habitat in the middle reaches. The lower reaches were the major grain producing zone, in which population density and NDVI were the main factors affecting the habitat, and it was necessary to pay attention to the protection on the major grain producing zone.

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## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

## ETHICAL APPROVAL

This article does not contain any studies with human participants or animals performed by any of the authors.

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