Section S1 Quantification of ES

（1）Habitat quality:

Habitat quality (HQ) refers to the ability of ecosystems to provide suitable conditions for the sustainable existence of individuals and populations[35], and is therefore one of the key supporting services. High-quality habitats can provide more resources for population survival, better supporting biodiversity at different levels[38].

This study used the habitat quality module of the InVEST model to quantify the HQ of Honghe Prefecture. The model calculates the habitat quality by combining the pressure intensity of different land use/land cover (LULC) types and their sensitivity to threat factors (Table S1). According to the InVEST user manual, agricultural land, railway, construction land, county roads and bare land were identified as threat factors. The threat source data table is presented in Table S2[39].

The calculation formula of HQ is as follows:

$$Q_{\mathrm{xj}} = H_{\mathrm{j}} \times \left(1 - \frac{D_{\mathrm{xj}^{z}}}{D_{\mathrm{xj}^{z}} + \mathrm{k}^{z}}\right) \quad (1)$$

In Eq. (1), Q_{xj} represents the HQ value of grid x; H_j is the habitat suitability of LULC type j; D_{xj} represents the habitat degradation degree of grid x; z is the scaling parameter, generally set to 2.5; and k is the half-saturation constant, set to 0.05.

Table S1 Sensitivity of different land use types in the Honghe State

Lucode	Name	Habitat	Threat data		
			Crop	Building	Unutilized land
1	crop	0.3	0	0	0
2	Building land	0	0	0	0
3	forest	1	0.65	0.75	0.6
4	grassland	1	0.5	0.6	0.4
5	water	0.9	0.3	0.5	0.3
6	Unutilized land	0.6	0	0	0

Table S2 The weight and the maximum influence distance of the threat source

Threat	Max_dist	Weight	Decay
crop	2	0.5	linear
Main road	1	0.3	linear
Building land	5	1	exponential
county road	0.5	0.2	linear
Unutilized land	1	0.5	exponential

（2）Carbon storage:

Carbon storage (CS) is a key regulatory service in terrestrial ecosystems, which is closely related to the ecosystem's ability to mitigate climate change [35]. The InVEST carbon sink module has been widely used to quantify CS. By combining LULC with the four main carbon pools in the ecosystem (i.e., above-ground biomass, below-ground biomass, soil carbon, and dead organic matter), the CS can be quantified[33]. Table S3 shows the carbon density of each land use/land cover.

The specific calculation formula for CS is as follows:

$$C_{\text{tot}} = C_{\text{above}} + C_{\text{below}} + C_{\text{soil}} + C_{\text{dead}} \quad (2)$$

In Eq. (2), C_{tot} represents total carbon storage, C_{above} represents carbon in

aboveground biomass, C_{below} represents carbon in belowground biomass, C_{soil} represents carbon in soil, and C_{dead} represents carbon in litter layer.

Table S3 The carbon density of each land use/land cover (Mg ha^{-1})

Land use/land cover	C_{above}	C_{below}	C_{soil}	C_{dead}
Cropland	5	3.11	34.3	0.33
Forest	22.31	4.46	124.1	0.432
Grassland	1.79	9.25	60	0.99
water	0	0	0	0
Unutilized land	0.01	0.5	10	0.03
Building land	0	0	0	0

Note: C_{above} is carbon density in aboveground biomass; C_{below} is carbon density in belowground biomass; C_{soil} is carbon density in the soil; C_{dead} is carbon density in dead matter.

（3）Soil conservation:

Soil conservation (SC) is an ecological process that helps maintain the ecosystem by reducing soil erosion caused by rainfall, and is a key element of environmental sustainability and human well-being[33]. The quantification of soil conservation is based on the sediment delivery ratio module of the InVEST model, which is based on the Universal Soil Loss Equation (USLE) [38]. The biophysical attributes of various land use/cover types are presented in Table S4.

The specific calculation formula for SC is as follows:

$$\begin{aligned} RKLS(\mathrm{x}) &= R(\mathrm{x}) \bullet K(\mathrm{x}) \bullet LS(\mathrm{x}) \\ USLE(\mathrm{x}) &= R(\mathrm{x}) \bullet K(\mathrm{x}) \bullet LS(\mathrm{x}) \bullet C(\mathrm{x}) \bullet P(\mathrm{x}) \end{aligned} \qquad (3)$$

In Eq. (3), $RKLS(\mathrm{x})$ and $USLE(\mathrm{x})$ represent the potential erosion and actual erosion of soil in study unit x; $R(x)$ is the rainfall erosion factor in study unit x; $K(x)$is the soil erosion factor in study unit x; $LS(x)$is the slope-length factor; and $P(x)$is the soil conservation practice factor.

Table S4 P value and C value of different land use types

Lucode	Description	usle_c	usle_p
1	Cropland	0.4	1
2	Forest	0.03	1
3	Grassland	0.12	1
4	Water	1	0
5	Building land	0	0.5
6	Unutilized land	0.8	1

（4）Food supply

As one of the key supply services for human survival and development, FP refers to the food produced by terrestrial ecosystems. Consistent with previous research[36], we quantified FP by combining LULC data with agricultural statistical data in statistical yearbooks. We calculated the grain yield provided by cultivated land, including rice, wheat, barley, corn, sorghum and millet, as well as potatoes and beans. The food production data came from the Honghe statistical yearbooks (HSBS, 2001; HSBS, 2011, HSBS, 2021).

$$G_i = \frac{NDVI_i}{NDVI_{sum}} \times G_{sum} \qquad (4)$$

In Eq. (4), G_i is the grain production, meat, egg, and milk production(ton) assigned to the ith raster; G_{sum} is the total grain production, meat, egg, and milk production(ton); $NDVI_i$ denotes the NDVI value of the ith raster; and $NDVI_{sum}$ is the sum of NDVI of the cropland/grassland in the Honghe Prefecture.

（5）Water yield:

Human beings depend on water to maintain their daily life and production. The water production services provided by ecosystems affect human production and living

conditions in various ways[37]. Water resources play a crucial role in the sustainable development of the socio-economic system in Honghe Prefecture. This study used the annual water production module of InVEST to estimate the water production services of ecosystems. This module is based on the principle of water balance, and uses the difference between rainfall and evapotranspiration in the region to determine the water yield of the river basin. The biophysical tables required by the module can be found in Table S5 [38]. Through multiple experiments and validations, the Z parameter was determined to be 3.7662. The specific calculation formula is as follows:

$$WY_i = \left(1 - \frac{AET_i}{P_i}\right) \times P_i \quad (5)$$

In Eq. (5), WY_i is the water yield of grid cell i ; AET_i is the actual annual evapotranspiration of grid cell i ; P_i is the annual precipitation of grid cell i .

Table S5 Biophysical parameters in water yield module

lucode	Description	root_depth	Kc	LULC_veg
1	Cropland	2000	0.7	1
2	Forest	5000	1	1
3	Grassland	2300	0.8	1
4	Water	100	1	0
5	Building land	100	0.3	0
6	Unutilized land	300	0.2	1

Section S2 Quantification of ES

（1）land-use intensity （LUI）

The changes of land use and pattern caused by human being are affected by the preferences and demands of human beings, which lead to different investment and utilization of land resources. The most direct manifestation is the change of LUI [34]. This form not only affects the structure and function of regional ecosystems, but also is

an important driving force to stimulate the change of ecosystem function. In this paper, the impact of human activities is characterized by the temporal and spatial changes of LUI. The formula is as follows[41]:

$$LUI = \sum_{i=1}^{n} Ai \times \frac{S_i}{S} \quad (6)$$

In Eq. (6),the LUI is the land use intensity value of an area, and the A_i is the land use intensity coefficient of land use type i, which represents the intensity of human activities per unit land area. The larger the value, the stronger the impact of human activities. The land use intensity coefficients of different land use types are shown in Table S6. The S_i is the area of land use type i in the study area, and S is the total land area of the study area.

Table S6 The classification of land-use intensity

Land-use type	Building land	Cropland	Grassland	Forest	Water	Unutilized land
Land-use intensity	4	3	2	2	2	1

（2）The index of landscape disturbance

The Landscape Disturbance Index (LDI) indicates the resistance of i-type land landscape to external disturbances and its self-restoring capacity. The greater the intensity of artificial and natural disturbances on the landscape pattern, the stronger the sensitivity of the entire land landscape ecosystem, and the greater the ecological risk. Landscape Fragmentation Index (Pi), Landscape Separation Index (Di), and Landscape Fractal Dimension Index (Fi) are selected to construct the Landscape Disturbance Index. The calculation formula is [40]:

$$LDI_i = W_1 \times P_i + W_2 \times D_i + W_3 \times F_i \quad (7)$$

In Eq. (7), W1, W2, W3 represent the weight values of three landscape indices including landscape fragmentation, landscape isolation, and landscape dimensionality. These weight values are assigned based on relevant research findings as 0.5, 0.3, and 0.2 respectively. i represents a specific land cover type.

Section S3: The analysis of natural-social driving forces of ES

Using the random forest algorithm, the explanatory power of "natural-social" driving factors of spatial heterogeneity of five ESs was calculated to determine the leading driving factors and the changes of these leading driving factors over time and scale (Fig.S1 and Fig.S2). The research results indicated that:

(1)The human activity factor was always the most important driving force of FP. Among them, the spatial differentiation of FP at the grid scale was always driven by LUI and LDI, and the explanatory power of DEM for spatial differentiation of FP gradually increased. At the township scale, the spatial differentiation of FP was mainly driven by LDI, and the explanatory power of natural factors (NDVI, Slope) gradually increased.

(2) Topographic factors (Slope) and meteorological factors (Rain, AI) were always the main driving factors of SC spatial differentiation, and at the township scale, the explanatory power of Vegetation factors (NDVI) on SC differentiation gradually increased over time.

(3)On the grid scale, WY was mainly driven by human activity factors (LUI, LDI), and the explanatory power of meteorological factors (AI) gradually increased. On the township scale, it was mainly affected by climate factors (AI, Rain).

(4)The spatial differentiation of CS was always affected by human activity factors (LUI, LDI) and DEM at the grid scale. However, at the township scale, CS was mainly driven by LDI, followed by topographic factors (Slope) and vegetation factors (NDVI).

(5) At the grid scale, HQ was mainly affected by human activity variables (LUI, LDI), followed by DEM and NDVI. It is worth noting that at the township scale, LDI and NDVI were the main influencing factors, and the explanatory power of NDVI gradually increased over time.

In summary, the main driving forces of the same ESs are different at two scales, and these main driving factors will also vary over time.

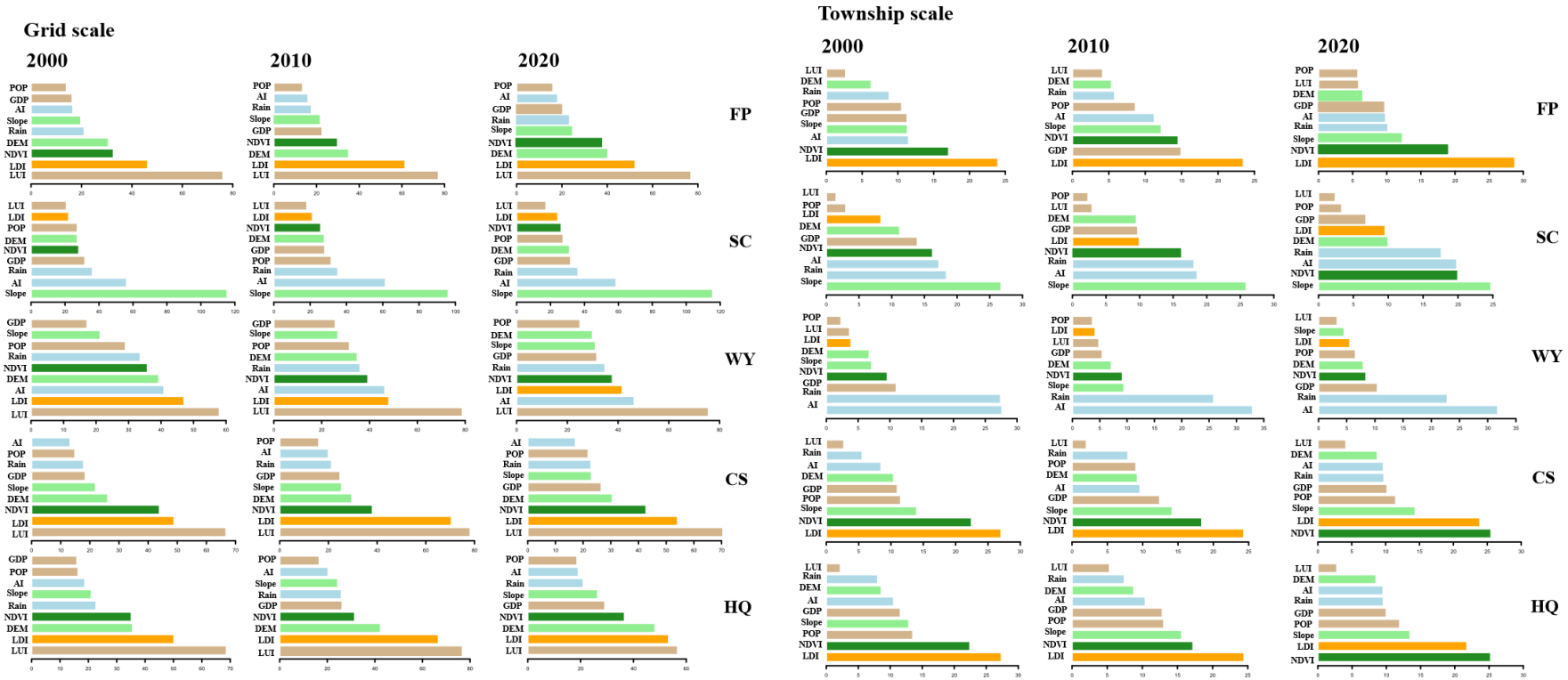


Figure S1 The explanatory ability of socio-ecological driving forces for five ESs at the grid and township scale (the definitions of acronyms are shown in Table2 and Table 3).

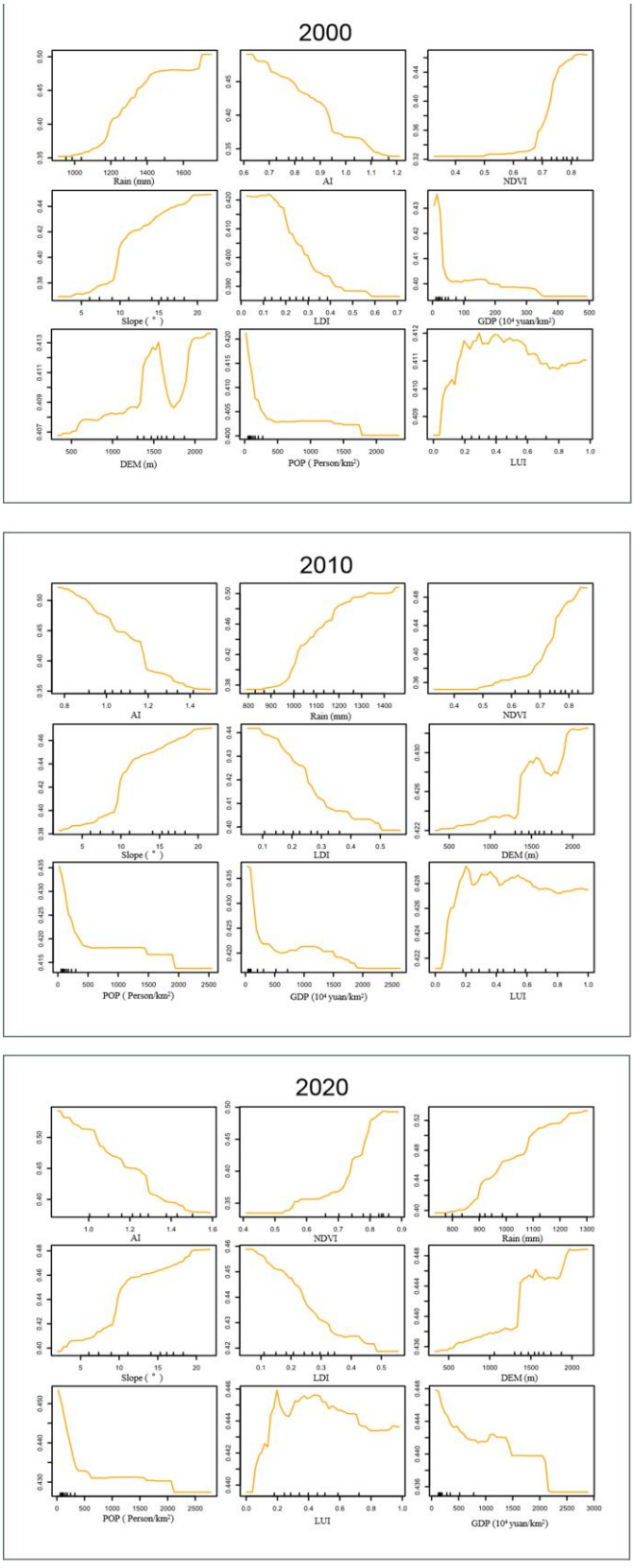


Figure S2 Dependence of potential natural-social factors on grid scale for ESI from 2000 to 2020 (the definitions of acronyms are shown in Table 3).