Supplementary Materials

Supplementary S1: Specific evaluation indicators for each ecosystem service

（1）WC

WC is closely related to precipitation, evapotranspiration, surface runoff, and vegetation cover type, etc. The water balance method is the difference between precipitation and evapotranspiration and other depletions in terms of water balance.

This method includes six categories of forest ecosystems, four categories of scrub ecosystems, four categories of grassland ecosystems and two categories of wetlands, as shown in Table S1.

Annual average surface runoff (R_i) is obtained by multiplying annual average precipitation (P_i) by the surface runoff coefficient (a) (Equation S1). The surface runoff coefficient reflects the capacity of ecosystems to support water to a certain extent. The surface runoff coefficient data were obtained from the literature [42-43].

$$R_i = P_i \times a \quad \text{(S1)}$$

where R_i represents the annual average surface runoff (mm); P_i represents the annual average precipitation (mm); and a represents the average surface runoff coefficient. The average surface runoff coefficient is shown in Table S1.

Table S1 Average surface runoff coefficient of different ecosystems

	Ecosystem type	Average surface runoff （%）
Forest	Evergreen broadleaf forest	2.67
	Evergreen needle-leaved forest	3.02
	Mixed broadleaf–conifer forest	2.29
	Broadleaved deciduous forest	1.33
	Deciduous coniferous forest	0.88
	Sparse wood	19.20
Shrubland	Evergreen broadleaf scrub	4.26
	Deciduous broadleaf shrub	4.17
	Coniferous brush	4.17

	Open shrublands	19.20
Grassland	Meadow	8.20
	Prairie	4.78
	Grass	9.37
	Sparse grassland	18.27
Wetland	Wetland	0.00
Water	Water	0.00

（2）SC

By sorting and classifying soils of different textures based on their erosion resistance capabilities (Table S2), soil erosion sensitivity is assessed, and the more sensitive the area, the weaker the soil conservation capacity and vice versa [44].

Table S2 Soil erosion sensitivity evaluation

Evaluation index		Classification				Weight
		Insensitive	Mild sensitivity	Medium sensitivity	Highly sensitive	
Raining conditions	Rainfall erosivity	Rainfall erosion is very weak	Rainfall erosion is weak	Rainfall erosion is medium	Rainfall erosion is strong	0.2
Terrain condition	Slope(°)	＜10	10–15	15–25	＞25	0.35
Soil conditions	Soil texture	Built–up areas, reservoirs, others	Clay loam, clay soil	Medium loam, heavy loam, light loam	Sandy loam, sandy soil, loose sand, pebble beach, gravel, bare rock	0.15
Land-cover condition	Vegetation coverage (%)	67–100	51–67	34–51	0–34	0.3
Rank assignment		1	3	5	7	1.0

（3）BC

Ecosystems not only provide habitats for various types of organisms, but more importantly provide the necessary conditions for the generation and formation of biodiversity. This study identifies the core habitats and migration processes of the focal species to reflect the important role of ecosystem services in the conservation of

biodiversity [45].

Determination of "Source"—Habitat Suitability Assessment. The "source" refers to the suitable habitats for each focal species, chosen based on habitat suitability assessments according to the living habits of these species [46-47]. The common crane (*Grus grus*) inhabits open plains, grasslands, swamps, riverbanks, wastelands, lakes, and agricultural areas. It breeds in various wetlands such as marshes and meadows, especially favoring open lakes with abundant aquatic plants and reed marshes [48-49]. During migration and wintering periods, they mainly reside near rivers, lakes, reservoirs, or coasts and frequently forage in open farmlands or fallow fields. The habitat suitability for the hooded crane is influenced by four factors: surface land cover, water distribution, human activities, and topography [50-51]. Scores are determined based on the positive impact of each factor on the habitat, and the weights of these factors are calculated using the analytic hierarchy process (AHP) (Table S3).

Table S3 Habitat suitability assessment for common crane (*Grus grus*)

Evaluation factor		Classification	Value	Weight
Land cover	Land-cover types	Waters (rivers, lakes, ponds), beaches, swamps	10	0.2
		Grassland	8	
		Woodland, garden	6	
		Nonirrigated farmland	5	
		Sandy land, Gobi, bare land, bare rock stony land	2	
		Country	1	
		Construction land	0	
Distribution of water	Distance to water (m)	0–50	10	0.2
		50–100	8	
		100–200	6	
		200–300	4	
		>300	0	
Human activity	Distance to settlements (m)	0–500	0	0.15
		500–1000	3	
		1000–2000	6	
		>2000	10	

Table S3 Habitat suitability assessment for common crane (*Grus grus*)

Evaluation factor		Classification	Value	Weight
	Distance to road (m)	0–500	0	0.15
		500–1000	6	
		>1000	10	
	Distance to farmland (m)	0–50	10	0.2
		50–100	8	
		100–200	6	
		200–300	4	
		>300	0	
Terrain	slope	0–10	10	0.1
		10–30	6	
		30–60	2	
		60–90	0	

The habitat of Przewalski's gazelle (*Procapra przewalskii*) is grasslands and sand dunes [52]. Przewalski's gazelle (*Procapra przewalskii*), a typical ungulate of deserts and semi-deserts, inhabits arid environments with vegetation such as ephedra, stipa, moss, sand whisk, sand needle grass, aconite, and artemisia. Within these areas, there are also sand dunes several tens of meters high, gentle slopes, and open plains where the deep parts of the sand dunes often serve as their hiding places. The suitability of Przewalski's gazelle (*Procapra przewalskii*) habitat is influenced by four factors: land cover, water distribution, human activities, and topographical factors [53]. Scores are determined based on the positive impact of each factor on the habitat, and the weights of each factor are calculated using the analytic hierarchy process. Specific factors, scores, and weights related to habitat suitability can be found in Table S4.

Table S4 Habitat suitability assessment for Przewalski's gazelle (*Procapra przewalskii*)

Evaluation factor		Classification	Value	Weight
Land cover	Land-cover types	Meadows, marshes, lakes, sand	10	0.15
		Reservoir, river	8	
		Woodland, garden	6	
		Dry land, bare rock stony land	3	
		Rural, construction land	0	
	Distance to sand (m)	0–100	10	0.2
		100–200	6	
		＞200	4	
Distribution of water	Distance to water (m)	0–50	10	0.2
		50–100	8	
		100–200	6	
		200–300	4	
		>300	0	
Human activity	Distance to settlements (m)	0–1000	0	0.15
		1000–2000	4	
		>2000	10	
	Distance to road (m)	0–400	0	0.15
		400–1200	3	
		>1200	10	
Terrain	slope	0–5	10	0.15
		5–10	6	
		10–25	4	
		>25	0	

Red deer (*Cervus*) prefer open forests and avoid dense, undisturbed forests. They can inhabit coniferous forests, marshes, clearings, poplar broadleaf forests, and mixed coniferous–broadleaf forests [54]. They exist at a wide range of altitudes, typically from sea level up to 3000 meters, and may also appear at even higher altitudes. They generally live in mountainous regions, spending summers in alpine meadows and

winters in valleys. On flatter terrain, they seek densely wooded slopes in the summer and open grasslands in the winter. The suitability of the red deer (*Cervus*) habitat is influenced by four factors: land cover, water distribution, human activities, and topographical factors [55]. Scores are determined based on the positive impact of each factor on the habitat, and the weights of each factor are calculated using the analytic hierarchy process (Table S5).

Table S5 Habitat suitability assessment for red deer (*Cervus*)

Evaluation factor		Classification	Value	Weight
Land cover	Land-cover types	Woodlands, lakes, rivers	10	0.2
		Meadows, marshes, reservoirs	8	
		Woodland, garden	6	
		Dry land, bare rock stony land, sandy land	3	
		Rural, construction land	0	
Distribution of water	Distance to water (m)	0–50	10	0.15
		50–100	8	
		100–200	6	
		200–300	4	
		>300	0	
Human activity	Distance to settlements (m)	0–1000	0	0.1
		1000–2000	4	
		>2000	10	
	Distance to road (m)	0–400	0	0.15
		400–1200	3	
		>1200	10	
Terrain	slope	0—15	10	0.2
		15–36	8	
		＞36	3	
	Elevation(m)	0–1500	10	0.2
		1500–2000	8	
		2000–2500	9	
		＞2500	2	

Determining the resistance surface. Based on the spatial movement patterns of the selected indicator species, a resistance surface is established by simulating its movement through the landscape, overcoming resistance. Then, based on the characteristics of this resistance surface, landscape elements outside the core habitats are identified, providing insights into the habitat distribution of different animals. Different land-cover types generate varying resistances as organisms spread outward from their habitats. Therefore, land use is chosen as the resistance factor to determine resistance coefficients. These coefficients and weights are determined based on research by scholars and opinions from experts (Table S6, Table S7, Table S8)

Table S6 Common crane (*Grus grus*) horizontal migration resistance surface assignment

Resistance factor	Classification	Resistance coefficient
Land-cover types	Waters (rivers, lakes, ponds), beaches, swamps	1
	Woodland, shrubland	10
	Woodland, other woodland, dry land, grassland	50
	Permanent glacier, construction land	300
	Sandy land, Gobi, bare land, bare rock stony land	400

Table S7 Przewalski's gazelle (*Procapra przewalskii*) horizontal migration resistance surface assignment

Resistance factor	Classification	Resistance coefficient
Land-cover types	Grassland, sandy land, Gobi, bare land, bare rock stony land, beach, swamp	1
	Water area (rivers, lakes, ponds)	50
	Forest land, shrub land, other forest land, dry land	100
	Permanent glacier, construction land	300

Table S8 Red Deer (*Cervus*) horizontal migration resistance surface assignment

Resistance factor	Classification	Resistance coefficient
Land-cover types	Woodland, shrubbery woodland, other woodland	1
	Meadows, beaches, swamps	10
	Dry land, water area (rivers, lakes, ponds)	50
	Permanent glacier, construction land	300
	Sandy land, Gobi, bare land, bare rock stony land	400

Establish a resistance surface in the GIS model. Utilize ArcGIS's Cost Distance

tool to analyze the minimum cumulative resistance surface between the source habitat and other land-use types in the external environment, determining the migration tendencies of animals. Using the source of the habitat as the core, create multi-level buffer zones around it to form suitable habitat distributions for individual species. Then, overlay the grids of the three species for each year to obtain the BC for that particular year.

（4）CS

NPP directly reflects the productive capacity of the vegetation itself under natural conditions and is a reference for judging carbon storage [56]. Firstly, the biodiversity maintenance service capacity index was calculated and classified into three levels (high, medium, and low) by the natural breakpoint method. Secondly, based on the evaluation results, select high-quality vegetation (forests, grasslands, wetlands) as the “source” for the dispersion of plant genetic resources and assign different resistance values to them using the MCR model [57]. This reflects the carbon storage capacity of vegetation in the region.

Table S9 Classification standard of resistance surface of forest

Evaluation factor		Classification	Value	weight
Terrain	Slope	＜10°	1	0.2
		10°–20°	10	
		20°–30°	50	
		30°–40°	100	
		40°–50°	200	
		＞50°	500	
	Aspect	Flat slope	1	0.2
		Shady slope	50	
		Half shady slope	100	
		Half sunny slope	200	
		Sunny slope	500	
Human interference	Land-cover types	Forest	1	0.3
		Grassland	10	
		Wetland	50	
		Farmland, water	100	
		Sand, bare land	200	
		Construction land, glacier	500	
	Distance from human settlements and traffic arteries (km)	＞5	1	0.1
		4–5	10	
		3–4	50	
		2–3	100	
		1–2	200	
		＜1	500	
Distribution of water	Distance to water (km)	＜1	1	0.2
		1–2	10	
		2–3	50	
		3–4	100	
		4–5	200	

		＞5	500

Table S10 Classification standard of resistance surface of wetland

Evaluation factor		Classification	Value	Weight
Terrain	Slope	＜10°	1	0.2
		10°–20°	10	
		20°–30°	50	
		30°–40°	100	
		40°–50°	200	
		＞50°	500	
Distribution of water	Distance to water (km)	＜1	1	0.3
		1–2	10	
		2–3	50	
		3–4	100	
		4–5	200	
		＞5	500	
Human interference	Land-cover types	Wetland, water	1	0.3
		Grassland	10	
		Forest	50	
		Farmland	100	
		Sand, bare land	200	
		Construction land, glacier	500	
	Distance from human settlements and traffic arteries (km)	＞5	1	0.2
		4–5	10	
		3–4	50	
		2–3	100	
		1–2	200	
		＜1	500	

Table S11 Classification standard of resistance surface of grassland

Evaluation factor		Classification	Value	Weight
Terrain	Slope	＜10°	1	0.1
		10°–20°	10	
		20°–30°	50	
		30°–40°	100	
		40°–50°	200	
		＞50°	500	
	Elevation (m)	315–500	1	0.3
		500–700	10	
		700–1000	50	
		1000–1400	100	
		1400–1800	200	
		>1800	500	
Distribution of water	Distance to water (km)	＜1	1	0.2
		1–2	10	
		2–3	50	
		3–4	100	
		4–5	200	
		＞5	500	
Human interference	Land-cover types	Wetland, water	1	0.3
		Grassland	10	
		Forest	50	
		Farmland	100	
		Sand, bare land	200	
		Construction land, glacier	500	
	Distance from human settlements and traffic arteries (km)	＞5	1	0.1
		4–5	10	
		3–4	50	
		2–3	100	
		1–2	200	

	＜1	500

Supplementary S2: Driving factor selection

Based on relevant studies and the actual situation and availability of data in the study area, this study considers various types of natural and economic and social factors that may affect ESs in an integrated manner. Through screening and comparison, 17 driving factors (Figure B.1.) were finally identified [64-65]. Natural factors: X_1 (PRE), X_2 (TEM), X_3 (ET), X_4 (NPP), X_5 (NDVI), X_6 (DEM), X_7 (slope), X_8 (surface runoff), X_9 (soil erosion), and X_{10} (soil type); socioeconomic factors: X_{11} (comprehensive index of land-use degree) [66], X_{12} (population density), X_{13} (per cultivated area), X_{14} (livestock density), X_{15} (GDP); location factor: X_{16} (distance to road), X_{17} (distance to river). The intensity of land use directly reflects the extent of the impact of human activities on natural ecosystems, which has become an important driving force of global environmental change and an important indicator of the degree of sustainability of land use [67]. Therefore, in this study, we include some indicators of land use (X_{11}, X_{13}, X_{14}) to explore the relationship between land-use intensity and ESs.

To ascertain the interplay between each ES and these driving factors, a pixel-by-pixel correlation analysis was conducted. The methodology commenced with the utilization of the Fishnet tool in ArcGIS 10.8 to generate a grid of 1 km×1 km sample points. Subsequently, the average ES values for these sample points were extracted via the grid, and the mean ES values were derived from the standardized individual ESs and composite ES (CES) at four distinct temporal points. The driver data for the grid sample points were then extracted, with each driver being rasterized and retrieved accordingly. Each ES dataset and driver dataset underwent a normality test using SPSS 26. Non-normal data were subjected to Spearman's rank correlation analysis, which quantified the strength of relationships based on the absolute value of the correlation coefficients. These relationships were subsequently visualized using Origin 2023 software.

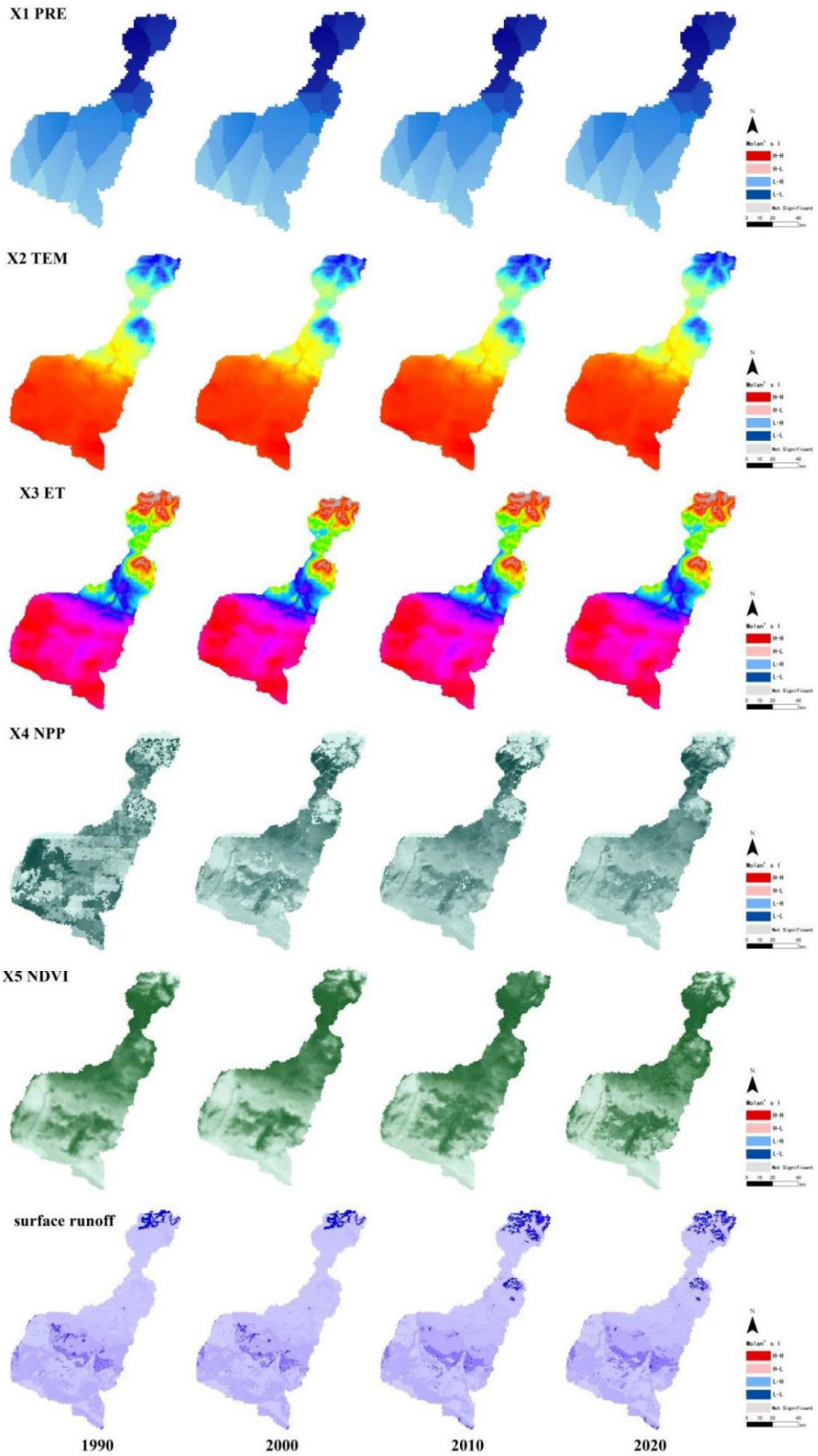


Fig. S1. Spatial and temporal distribution of main ES driving factors

Supplementary S3: Figures and tables of land-use/cover data

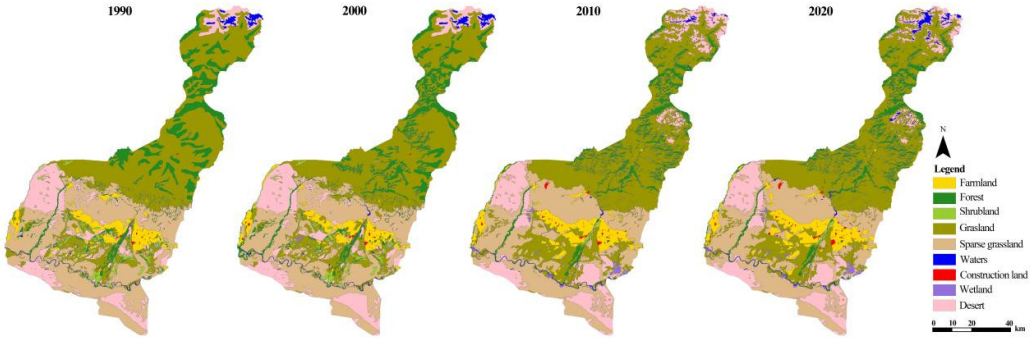


Fig. S2. Spatial pattern of land use/cover in Haba River Basin, 1990–2020 (farmland, forest, shrubland, grassland, sparse grassland, water, wetland, desert, construction land)

Table S12 Land-use transfer matrix from 1990 to 2020

Unit: hectare

1990-2020	Grassland	Farmland	Shrubland	Desert	Construction land	Wetland	Water	Sparse grassland	Forest	Transfer-out area
Grassland	230422.2	5673.3	896.2	20253.1	228.9	2879.5	3432	15417.5	31410.2	80190.7
Farmland	2789.3	33773.8	28.9		1127.5	54.7	33.7	3297.4	192	7523.6
Shrubland	12813.2	1387	377.7	448.1		1119.5	128.9	1080.6	459.4	17436.8
Desert	10266.5	4040.9	136.1	67865.6	530.7	126.4	2408.6	21101.9	475.6	39086.6
Construction land	167.3	268.3			661.8			2.9		438.5
Wetland	17.3	22.9					14.2	2.1		56.5
Water	1646.2	36.2	107.5	2519.1		202.4	3865.8	257.9	115.1	4884.5
Sparse grassland	20115.5	11089	568.2	25746.3	691	1621.7	819.7	172939.2	1536.5	172939.2
Forest	55685	1281.5	1995.2	2499.7	33.3	333.9	695.4	2474.9	31378.2	64998.8
Transfer-in area	103500.4	23799.2	3732	51466.4	2611.5	6338.2	7532.6	43635.1	34188.9	387555.2

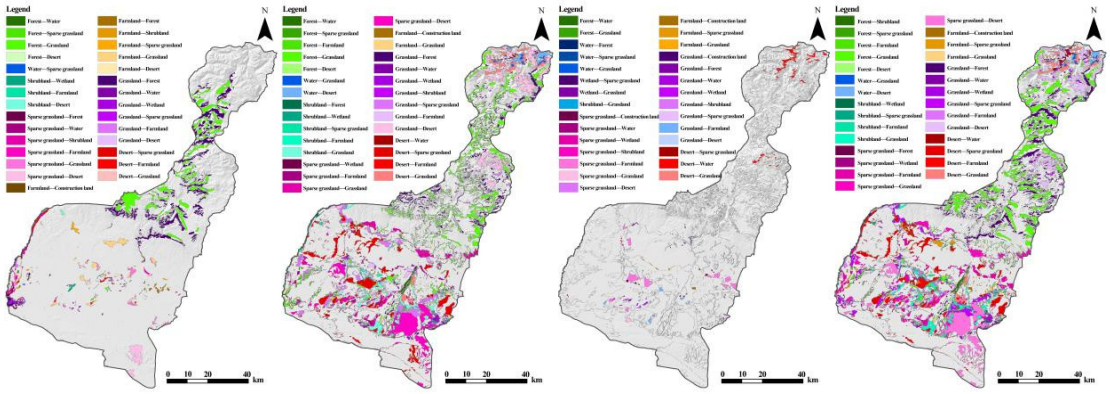


Fig. S3. Spatial transfer of land use/cover from 1990 to 2020

Supplementary S4: Spatial and temporal distribution characteristics of ES

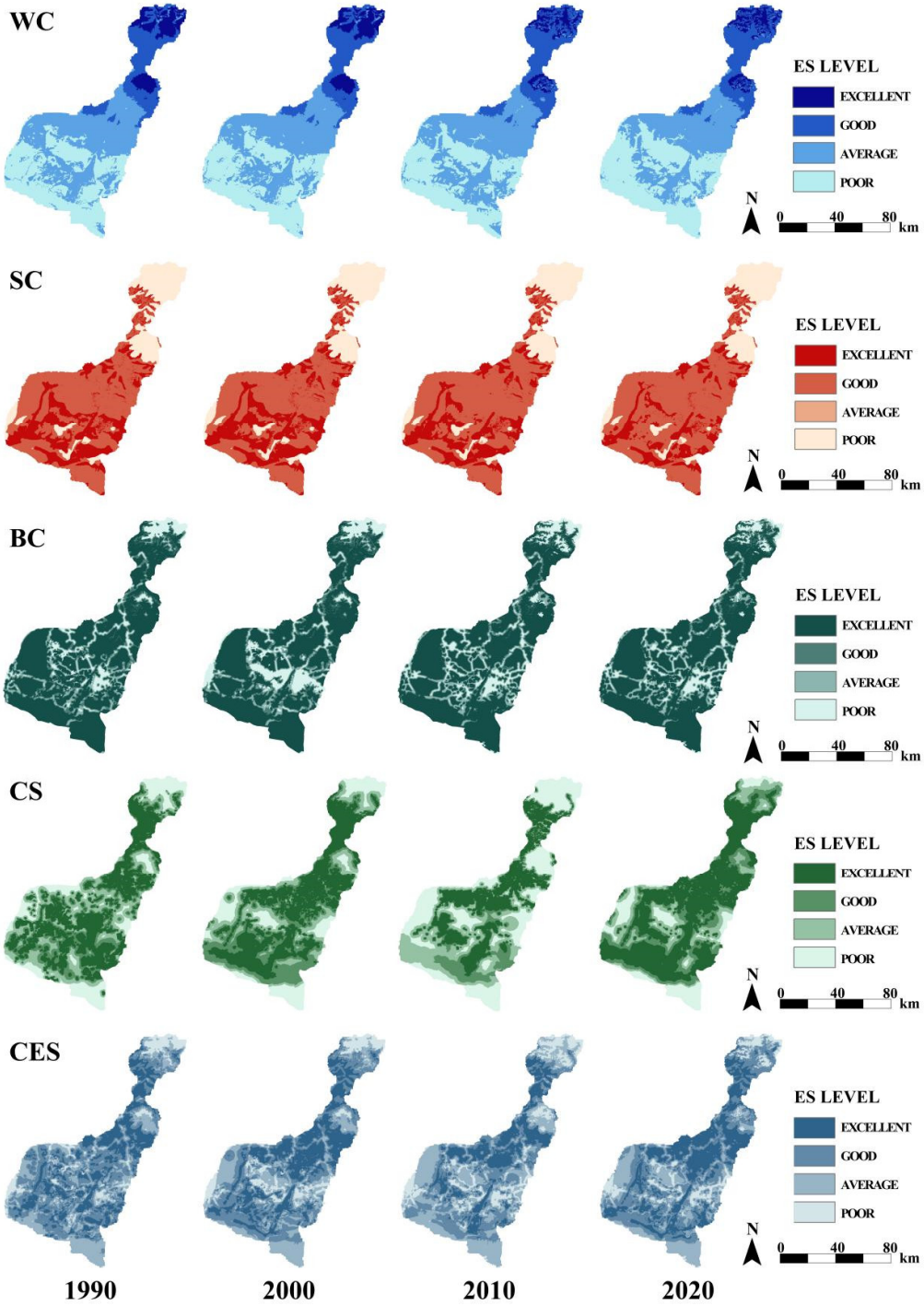


Fig. S4 Spatial and temporal distribution of ES (WC, SC, BC, CS, CES)

Supplementary S5: Spatiotemporal variation of ES cold and hotspots

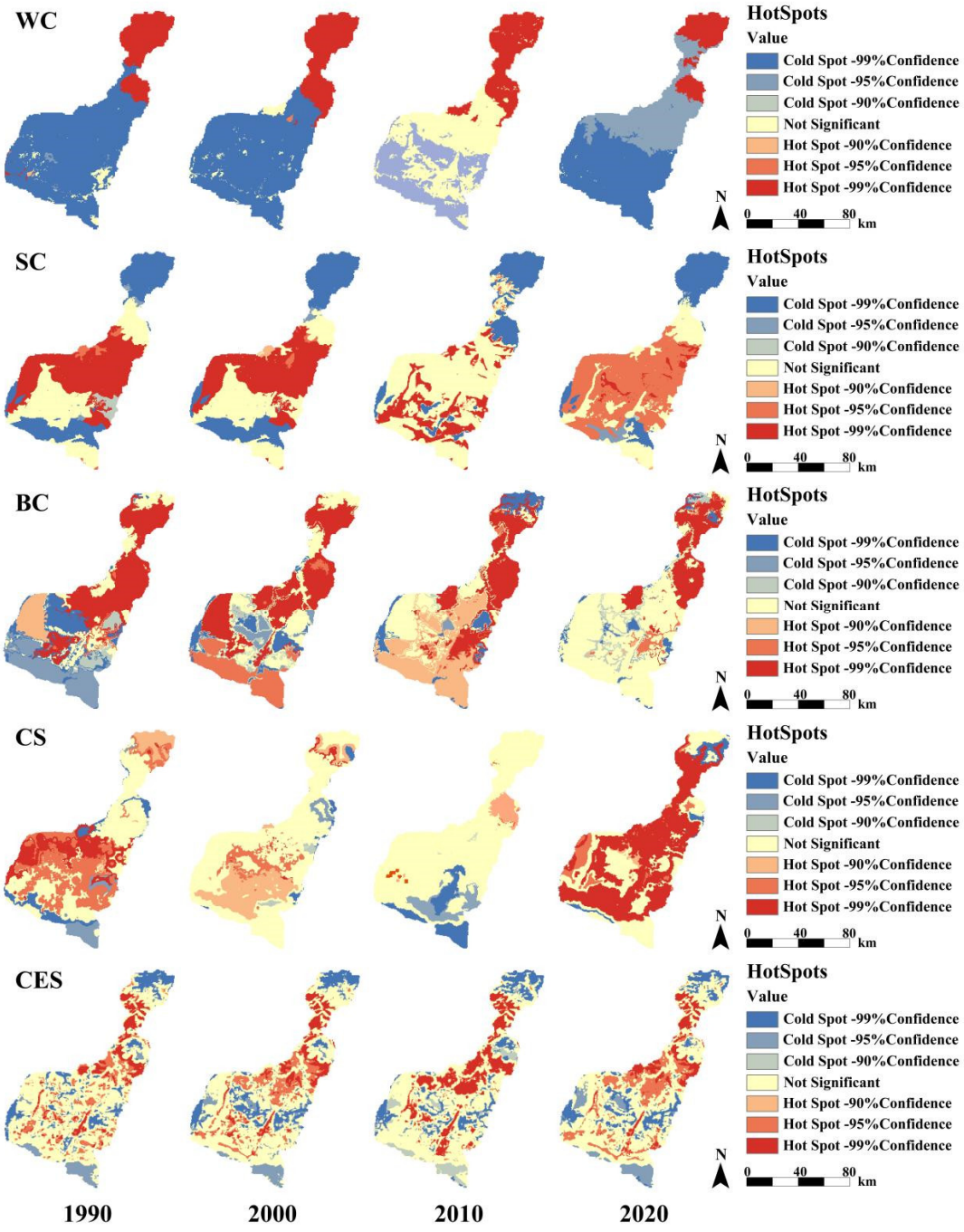


Fig. S5 1990–2020 ES spatial changes in cold and hotspots

Supplementary S6: ES Trade-off/synergy

Table S13 ES Trade-off/synergy at grid scale

		High-High	Low-Low	Not Significant	High-Low	Low-High	Trade-off	Synergy
WC–SC	1990	7%	2%	61%	17%	14%	30%	9%
	2000	6%	3%	62%	16%	13%	30%	9%
	2010	7%	3%	62%	12%	16%	28%	10%
	2020	5%	3%	65%	16%	11%	27%	8%
BC–WC	1990	14%	7%	50%	21%	8%	30%	21%
	2000	14%	7%	49%	22%	8%	30%	21%
	2010	13%	8%	52%	19%	8%	27%	21%
	2020	13%	7%	50%	22%	8%	30%	20%
CS–WC	1990	12%	10%	49%	18%	10%	28%	23%
	2000	12%	15%	49%	14%	11%	25%	26%
	2010	8%	20%	53%	6%	13%	19%	28%
	2020	11%	18%	52%	9%	10%	19%	29%
BC–SC	1990	12%	9%	61%	10%	8%	18%	20%
	2000	14%	9%	62%	10%	5%	15%	23%
	2010	13%	9%	62%	10%	6%	16%	22%
	2020	11%	9%	66%	10%	4%	15%	20%
SC–CS	1990	21%	8%	53%	4%	14%	18%	29%
	2000	26%	8%	46%	14%	5%	20%	34%
	201	22%	11%	47%	18%	3%	21%	33%

	0							
	2020	0%	5%	72%	17%	6%	23%	5%
	1990	16%	8%	52%	11%	14%	25%	23%
	2000	23%	8%	46%	14%	9%	23%	31%
BC–CS	2010	15%	9%	46%	19%	10%	29%	24%
	2020	0%	6%	68%	15%	11%	25%	6%