Spatiotemporal Evolution of Ecosystem Service Value in Caohai National Nature Reserve

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Abstract Wetland ecosystems are important regulators of global climate change. Studying the spatiotemporal changes and driving mechanisms of their ecosystem service values (ESV) is beneficial for the sustainable development of wetlands. This paper uses the equivalent factor method, based on land use changes, to reveal the spatiotemporal evolution of the ecosystem service value in the Caohai National Nature Reserve (CNNR). The results show the following: ① from 2000 to 2020, there was a significant decrease in the core zone's arable land area, with an increase in forest and water areas. Construction land mainly increased in the experimental area, and the grassland area showed a fluctuating change of first increasing and then decreasing; ② in 2000, 2010, and 2020, the ecosystem service value of the study area was 302 million, 296 million, and 325 million yuan, respectively, showing a trend of fluctuating growth, with the value of wetland ecosystems playing a dominant role; ③ regulatory services are the main contributors to the ecosystem service value in the study area, with a contribution rate of 60%. Hydrological regulation is the ecosystem function with the highest value in wetland ecosystem services, contributing more than 35% to the ESV in all three periods; ④ in terms of spatial distribution, the core zone's ecosystem service value is dominant. Looking at the total ecosystem service value of the region, the core zone > the experimental area > the buffer zone. In terms of *ESV* per unit area, the core zone (89 000 yuan/hm^2) is significantly higher than the buffer zone (39 100 yuan/hm^2) and the experimental area (15 800 yuan/hm^2). The study can provide a basis for research and spatial management of ecosystem services in wetland ecosystems and nature reserves.

Key words Ecosystem service value (ESV); Equivalent factor method; Land use change; Wetland ecosystem; CNNR

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Ecosystems are indispensable for human well-being, health, livelihoods, and survival, providing a myriad of services that are often overlooked yet fundamentally important[1–2]. These services, though intangible, possess significant value and warrant our utmost attention[3–4]. In recent decades, the study of ecosystem service value has become a focal point in the fields of ecology[5], geography[6], and economics[7]. The research scales involved encompass global, regional, national, and nature reserve levels. The methods for valuing ecological services have also become increasingly diverse. Among them, the ecosystem service value assessment method based on land use types has been widely applied since its introduction in 1997[1], due to its convenience in calculation and the ease of conducting comparisons across temporal and spatial scales.

Human activities have altered the surface environment and have profoundly influenced changes in land use, serving as a key factor affecting the types of ecosystems and their spatial distribution[8]. The changes in land use have, in turn, changed the structure, processes, and functions of ecosystems, thereby significantly impacting the value of ecosystem services[9–10]. The variation in the value of ecosystem services also affects the efficiency of land use, which consequently influences how humans alter the structure of land use[11]. The accounting method proposed by Costanza[1], which is based on the value of ecosystem services per unit area and the area of land use, has been rapidly applied globally since its publication. Xie Gaodi *et al.*[12–13] have made improvements to this method in light of the actual ecological and socio-economic conditions in China, constructing an equivalent value for ecosystem services per unit area in China, which has been widely applied in China[14–15].

Wetland ecosystems are important regulators of global climate change. Their ecological service value is 2 – 7 times that of tropical rainforest ecosystems and 45 – 160 times that of agricultural ecosystems[16]. Globally, 64% – 71% of wetlands have been lost since 1900 AD[17]. The CNNR boasts rich biodiversity and a unique plateau wetland ecosystem, playing an irreplaceable role in maintaining regional ecological balance and promoting sustainable socio-economic development. Spatiotemporal evolution analysis is an important tool for understanding the patterns of change in the value of ecosystem services. Currently, there is a lack of systematic analysis by zoning and classification regarding the spatiotemporal evolution of ESV in nature reserves.

This study employs the equivalent factor method, revealing the spatiotemporal evolution of the ESV in the CNNR based on changes in land use. The main research content includes: ① the analysis of land use changes in the study area; ② changes in ESV of different ecosystems; ③ changes in the value of different eco-

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system service types; ④ spatial differences in ESV. The findings of this study will provide scientific guidance for the ecological protection and sustainable development of the CNNR and similar wetland ecosystems.

1 Materials and methods

1.1 Study area The CNNR is located in the central part of the Yunnan – Guizhou Plateau in the southwest of China. It is a typical plateau wetland ecosystem, and the Caohai within the reserve is one of the few high-altitude freshwater lakes on Earth[18]. The study area has an average altitude of 2 170.70 m, an average annual temperature of 10.5 ℃, and an average annual precipitation of 950.9 mm[19]. The reserve primarily protects the plateau wetland ecosystem and rare and endangered waterfowl such as the black-necked crane[20]. Based on the differences in conservation and management functions, the study area is divided into three zones: the core zone, the buffer zone, and the experimental area (Fig. 1). The core zone is the key protection area for the wetland ecosystem of the CNNR, accounting for 22.52% of the total area of the reserve; the buffer zone is the outer area of the core zone, serving as a buffer against external human activities, and it covers 5.62% of the total area of the reserve; the experimental area, located outside the buffer zone, is mainly engaged in scientific research, ecological tourism, and other activities, and it occupies approximately 71.86% of the total area of the reserve.

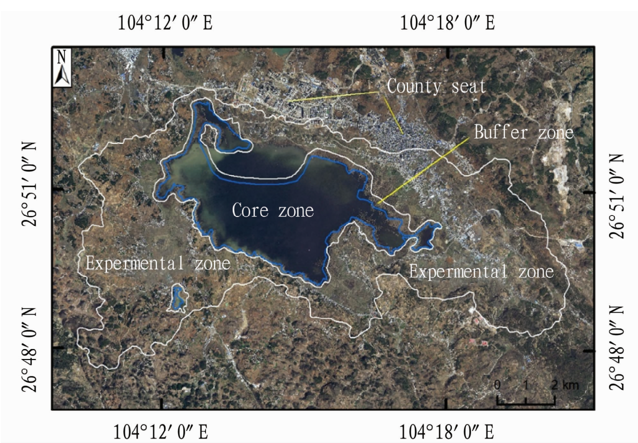

Fig. 1 Location of the study area

1.2 Data source Using the equivalent factor method to account for the value of ecosystem services requires the collection of data including the area planted with major grain crops, yield, and unit price in the county where the study area is located. Among them, the types of major grain crops, planting area, and production data for Weining County come from the *Bijie Statistical Yearbook* 2023 (https://www.bijie.gov.cn/bm/bjstjj/zwgk/tjsj/tjnj/), and the price data for major grain crops mainly comes from the National Food and Strategic Reserves Administration, Bijie Municipal Bureau of Agriculture and Rural Affairs, *etc.*, which are authentic and reliable sources. According to the *Bijie Statistical Yearbook* 2023, the main grain crops in Weining County include three categories: cereals, legumes, and tubers, which consist of winter wheat, corn, buckwheat, soybeans, red beans, potatoes, and others. Based on the sown area and production data of the main grain crops in Weining County, the per unit area output value for each grain crop is calculated. Combined with the price data of grain crops from the National Food and Strategic Reserves Administration, Bijie Municipal Bureau of Agriculture and Rural Affairs, *etc.*, the planting area, yield, and unit price of the main grain crops in Weining County are obtained (Table 1).

Table 1 Planting area, yield and unit price of major food crops in Weining County

Crop type	Planting area//hm^2	Yield per unit//kg/hm^2	Unit price yuan/kg
Wheat (winter wheat)	1 373.73	2 391.30	3.21
Corn	33 073.07	6 127.37	3.30
Buckwheat	5 093.73	2 210.95	11.40
Soybeans	6 699.87	2 115.41	5.65
Red bean	2 450.27	1 118.65	9.00
Potato	95 138.40	4 464.09	2.36

1.3 Methods

1.3.1 Standard unit equivalent value calculation. The standard unit equivalent value in the study area refers to the economic value generated from cultivating corresponding crops per unit area of farmland in Weining County, where the CNNR is located. Generally, the value of one unit equivalent factor is defined as 1/7 of the market value of grain crops per unit area[21]. Since the types of grain crops and their unit prices vary slightly within the county, to accurately account for the standard unit equivalent value in the study area, the unit price of grain crops in Weining County, where the CNNR is situated, is used as the grain crop unit price for the study area (Table 2). The calculation model is as follows:

$$V_a = \frac{1}{7}\sum_{i=1}^{n}\frac{a_i p_i q_i}{A} \quad i=1, 2, \cdots, n \tag{1}$$

In the formula, V_a represents the economic value generated per unit area of farmland in the study area when cultivating a certain crop (in yuan per hm^2, yuan/hm^2; i indicates the type of crop grown in the study area; p_i represents the purchase price of the i^{th} crop in the study area for a given year (yuan/kg); q_i indicates the yield of the i^{th} crop per unit area in the study area (kg/hm^2); a_i denotes the total planted area of the i^{th} crop in the study area (kg/hm^2); A represents the total planted area of all types of crops in the study area (hm^2). After calculation, the V_a for the CNNR is determined to be 1 901.75 yuan.

1.3.2 Equivalent factor coefficient correction for ecosystem services. Based on the *Classification of Land Use Status* (GB/T 21010 –2017), the land use of CNNR is divided into five categories: cultivated land, forest land, grassland, construction land, and water area. Due to the fact that construction land is not included in the value of ecosystem services, the value of construction land is usually not calculated in the accounting of ecosystem service value[22]. Therefore, this study involves four types of land use: arable land, forest land, grassland, and water, corresponding to dry land, mixed coniferous and broad-leaved forests, grasslands, and wetlands in the ESV equivalent table. On the basis of the standard unit equivalent value in the study area, referring to the equivalent table of ecological service value per unit area of Chinese terrestrial ecosystems proposed by Xie Gaodi *et al.* [4], the coefficient of ecological service value in the study area is modified (Table 3), and the calculation formula is as follows:

$$VE_{ij} = C_{ij} V_a \quad i = 1, 2, \cdots, n \qquad (2)$$

In the formula, VE_{ij} represents the ESV coefficient (yuan/hm^2) of the j^{th} ecological service function contained within the i^{th} ecosystem type in the study area; C_{ij} indicates the value of the j^{th} service function contained within the i^{th} ecosystem type in the study area relative to the economic value of 1 unit area of farmland in the county where the study area is located; i denotes the types of ecosystems present within the study area; j refers to the service functions corresponding to each ecosystem type within the study area; V_a represents the economic value generated by cultivating crops on 1 unit area of farmland in the county where the study area is located (yuan/hm^2).

Table 2 Revised *ESV* coefficient of different land types in CNNR yuan/hm^2

Service		Farmland (dry land)	Forest (mixed coniferous and broad-leaved forest)	Grassland (meadow)	Wetlands (wetlands)
Supply services	Food production	1 616.49	589.54	418.39	969.89
	Raw material production	760.70	1 350.24	627.58	950.88
	Water supply	38.04	703.65	342.32	4 925.53
Regulating services	Gas regulation	1 274.17	4 469.11	2 168.00	3 613.33
	Climate regulation	684.63	13 369.31	5 743.29	6 846.30
	Purify the environment	190.18	3 784.48	1 901.75	6 846.30
	Hydrological regulation	513.47	6 675.14	4 202.87	46 079.41
Support services	Soil conservation	1 958.80	5 439.01	2 643.43	4 393.04
	Maintain nutrient circulation	228.21	418.39	209.19	342.32
	Biodiversity	247.23	4 944.55	2 415.22	14 795.62
Cultural services	Aesthetic landscape	114.11	2 168.00	1 064.98	8 995.28

1.3.3 ESV calculation per unit area. Combining the aforementioned standard equivalent factors and value equivalent tables, the ESV of the CNNR is calculated using the ESV calculation model[23]:

$$ESV = \sum A_k E_k \qquad (3)$$

In the formula, *ESV* represents the total value of ecosystem services (yuan/a) for the study area; A_k represents the area (hm^2) of land category k in the study area; E_k represents the ecosystem service value [yuan/(hm^2 · a)] corresponding to one unit area of land category k.

After calculation, the ecosystem service value of the CNNR in 2000, 2010, and 2020 were 302 million, 296 million, and 325 million yuan, respectively.

Table 3 Land use changes in the CNNR from 2000 to 2020 hm^2

Zone	Land type	2000	2010	2020
Core zone	Farmland	308.71	353.88	213.79
	Forest	0	19.03	0.24
	Grassland	1.54	112.07	12.76
	Construction land	0	0	0.25
	Waters	1 794.45	1 619.72	1 877.67
Buffer zone	Farmland	446.25	420.21	358.41
	Forest	0	1.47	0.66
	Grassland	0.07	40.24	18.35
	Construction land	0	0	1.96
	Waters	129.09	113.49	196.03
Experimental zone	Farmland	5 334.26	4 834.63	4 545.35
	Forest	234.05	286.82	281.32
	Grassland	1 165.03	1 614.50	1 546.44
	Construction land	203.15	201.67	521.35
	Waters	302.39	301.25	344.42

2 Results

2.1 Land use change The CNNR has undergone significant changes in land use types and areas over the past 20 years. From 2000 to 2020, there have been shifts in the areas of cultivated land, forest land, grassland, construction land, and waters (Fig. 2). These changes reflect the adjustments in the management strategies of the reserve and the succession of the natural environment.

In terms of cultivated land, from 2000 to 2010, there was a reduction in the area of cultivated land in the core and buffer zone of the CNNR, while a significant increase was observed in the experimental zone. This may be due to adjustments in the land management policies within the reserve, aimed at reducing the ecological pressure on the core and buffer zone, while allowing moderate agricultural development in the experimental zone. However, by 2020, the area of cultivated land in the experimental zone had decreased, likely due to an increased awareness of environmental protection and the implementation of ecological restoration projects. The changes in forest land showed different trends. The area of forest land in the core zone increased from no forest land in 2000 to small patches of forest land in 2010 and 2020, indicating the reserve's efforts in afforestation. The forest land area in the buffer and experimental zones also increased, possibly to enhance the stability and biodiversity of the ecosystem. The area of grassland in the core zone showed a trend of initial increase followed by a decrease from 2000 to 2020, which may be related to the natural succession of grasslands and human management measures. Due to the protection and rational use of grassland resources, the grassland

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to be further verified through statistical analysis of several individual cases. At the same time, if the scope is expanded to the central part of Inner Mongolia, and the threshold of the ground temperature and air temperature after snow melting can be studied after the increase of observation stations.

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