Engineered Science
DOI: https://dx.doi.org/10.30919/es1688

Responses of Ecosystem Services and Biodiversity to Changes in the Land Use: A Case Study on the East Dongting Lake, China

Jiewen Yang,[1,#] Liyang Liu,[1,#] Qiaoran Tang,[1] Yang Lin,[1,*] Deming Wang,[2] Huajun Li,[3] Jiayan Zhang[4] and Ruiao Li[4]

Abstract

Wetlands serve as a vital guarantee for regional and urban development. Therefore, it is of great significance to study the changes taken place in ecosystem services as well as their contributing factors during the collaborative conservation and management of water resources across varying regions. We have studies and coupled the remote sensing image data in the years of 2000, 2009 and 2019, so as to estimate the value of ecosystem services available. Furthermore, we have evaluated the biodiversity of the East Dongting Lake Area. The findings indicate that: (1) The area of the construction land in research area has experienced increases, whereas the area of arable land has witnessed constant declines. (2) The total value of ecosystem services available in research area decreased by RMB 1.53 billion. The value of ecosystem services provided by the arable land decreased by 745 million yuan. (3) The sensitivity of the coefficient of ecosystem service value of all types of land use to the ecosystem service value does not exceed 1, revealing the lack of elasticity of the value of ecosystem services provided by research area. (4) The species diversity index measured in the construction land is lower than other areas in research area. Judging from the analysis that the changes taken place in the land use will impose a significant impact on the service value of ecosystems and biodiversity, and the reasonable development and utilization will facilitate the improvement of the service value of ecosystems and biodiversity in East Dongting Lake Area.

Keywords: Wetlands; Ecosystem service value (ESV); Sensitivity coefficient; LUCC; Species diversity index; Remote sensing; Sustainable development; East dongting lake.
Received: 27 May 2025; Revised: 01 August 2025; Accepted: 02 August 2025
Type: Research article.

1. Introduction

The ecosystem services refer to the varying sorts of material foundations and environmental conditions directly or indirectly available to humankind during its survival in the ecosystem. Biodiversity serves as a critical measure to assessing whether the ecosystem is well-functioning, whereas the value of ecosystem services could manifest the intuitive value of varying sorts of services available in the ecosystem.[1,2] At present, land use is now the main cause of global biodiversity loss.[3,4] As the carrier of the natural ecosystem, the changes taken place in the types of land use will not only undermine the self-adjustment capabilities of the ecosystem, but will also directly contribute to the changes of land productivity in a region.[5] For instance, Costanza *et al*. sought to examine the impact of land use changes on the valuation of ecosystem services. A comprehensive evaluation of the global economic value was conducted, revealing a decline over a span of 34 years.[6] Concurrently, scientists from multiple nations engaged in extensive deliberations on this proposition. In Leipzig, Germany, the total economic value has decreased by as much as 23% over the past 40 years.[7] In Changzhou, China, there has been a 19.3% decrease in the ecological service value of the region over a period of 15 years, due to changes in land use.[8] Presently, the most substantial land use change on a global scale is the expansion of farmland and pasture areas, which has had a profoundly deleterious effect on the natural ecosystem.[9] However, in the context of China, this scenario is further compounded by additional complexities. The rapid economic development has resulted in a rapid process of urbanisation, causing the built-up areas to expand at an extremely fast rate and resulting in a significant loss of arable land.[10] The inappropriate alteration of land, which disregards environmental limits, will inevitably result

[1]*Bangor College, Central South University of Forestry and Technology, Changsha, Hunan, 410004, China*
[2]*Marxism College, Central South University of Forestry and Technology, Changsha, Hunan, 410004, China*
[3]*Hunan Academy of Forestry, Changsha, Hunan, 410004, China*
[4]*Forestry College, Central South University of Forestry and Technology, Changsha, Hunan, 410004, China*
[#]*These authors contributed equally to this work.*
[*]*Email:* yanglin9098@csuft.edu.cn (Yang Lin)

Table 1: Grain Yield per Unit Area, Price and Sowing Area of Main Crops in the Years of 2000, 2009 and 2019 in the East Dongting Lake Area.

Year	Grain yield/ (t/hm ²)			Price/ (yuan/t)			Sowing area/ (hm²)		
	Rice	Cotton	Oil	Rice	Cotton	Oil	Rice	Cotton	Oil
2000	6.35	1.20	1.43	1009.5	10078.9	2415.7	143076.2	11253.2	34591.1
2009	6.06	1.47	1.52	1986.0	16949.9	4161.3	157769.1	10175.2	36749.7
2019	6.26	1.23	1.70	3108.2	33132.8	13275.3	130062.5	7714.6	35699.9

in adverse consequences, including land degradation, water pollution, deterioration of water quality, and a decline in flood regulation and storage capabilities.[11] Quantifying the value of ecosystem services provided by the East Dongting Lake and analyzing the trend of variations in the value of varying ecosystem services could provide critical statistical support to optimize the methods of land use, while offering measurement instruments for considering the assessment of land use schemes in the future.

The methods of assessing the value of ecosystem services mainly consist of the benefit transfer method, the presentation preference method and the display preference method.[12] Based on the theories of equilibrium value and effect value, Costanza *et al*.[13]have inferred the global economic value of 17 sorts of ecosystem services provided by 16 major biocommunities. In addition, other researchers have renewed their valuation for over 300 cases worldwide.[14] On the basis of the research findings of Costanza, domestic scholars including Xie *et al*.[15]have assessed the service function of the land ecosystems in China. Judging from the holistic observation of the features of China's ecosystems and the country's status-quo of socio-economic development, they have formulated the Scale of Ecosystem Service Value Equivalent per Unit Area.[16] The scale has laid a computational foundation for studying the value of regional ecosystems in China, and is thus widely applied nationwide. From the perspective of Wei *et al*.,[17] the primary factor leading to the diminishing value of regional ecosystem services is the enhanced level of urbanization. Li and Shao[18] put forward that the declining area of lands with a high coefficient of ecosystem service value constitutes the major reason behind the reduction of the total value of ecosystem services.

At present, research into ecosystem service value assessment based on remote sensing technology has been extensively applied in the field of ecology, primarily due to the unique advantages of remote sensing data in detecting changes in land cover. The multi-temporal resolution characteristic of remote sensing can precisely capture the temporal and spatial heterogeneity of the surface cover, and the long-term sequence data provide continuous temporal and spatial data for the assessment of ecosystem service value. At the technical implementation level, current research relies primarily on advanced machine learning algorithms for the interpretation and analysis of remote sensing images. To illustrate this point, classification algorithms based on random forests or deep learning are employed to convert multispectral remote sensing images into land use classification maps, with

Table 2: Coefficient of the Value of Ecosystem Services of Varying Types of Land Use in the East Dongting Lake Area.

Ecosystem service		Woodland	Meadowland	Arable land	Water body	Wetland
Provisioning service	Food production	611.325	796.575	1852.502	981.825	666.902
	Raw material	5520.451	666.901	722.475	648.375	444.603
Regulating service	Gas regulation	8002.8	2778.75	1333.800	944.775	4464.525
	Climate regulation	7539.675	2889.903	1796.925	3816.150	25101.375
	Water regulation	7576.725	2815.802	1426.425	34771.425	24897.601
Regulating service	Waste treatment	3186.301	2445.300	2574.975	27509.625	26676.001
Supporting service	Soil formation and protection	7447.050	4149.604	2723.175	759.525	3686.475
	Biodiversity conservation	8354.775	3464.175	3464.175	6354.075	6835.725
Cultural service	Providing aesthetics sight	3853.203	1611.675	314.925	8225.102	8688.225
Total/(Yuan/hm²)		52092.3	21618.675	14634.75	84010.875	101461.425

Fig. 1: Location map of the research area in the Chinese scale. (**Note:** Fig. 1 is a map that illustrates the spatial position of Hunan province where the East Dongting Lake located research area in. It adopts a specific scale where 1 centimeter (cm) on the map corresponds to 290,000 meters (m) in the real world.)

classification accuracy generally reaching over 85%.[19,20] The integration of nighttime light data with 10-metre resolution images from Sentinel-2 facilitates the effective differentiation of urban construction land from unbuilt land, thereby reducing the value deviation caused by classification errors in traditional ESV assessment.[21] Concurrently, the integration of remote sensing and Geographic Information System (GIS) technologies has engendered visualization methodologies, including Sankey diagrams and transfer matrices. These methodologies can intuitively depict the service value transfer pathways between disparate land use types, thereby facilitating profound analysis of the spatiotemporal evolution patterns of ecosystem service value.[22]

Dongting Lake ranks as the second largest freshwater lake in China, whereas the East Dongting Lake is the largest lake in the lake clusters of the Dongting Lake Area. The lake is jointly managed by Yiyang, Changde and Yueyang Municipalities. In addition, the East Dongting Lake Nature Reserve constitutes one of the 21 internationally important wetland nature reserves located in China as specified in the International Wetland Convention, covering an area of 190,000 hectares.[23] Given the extremely high coefficient of the value of ecosystem services provided by the wetland, it has become a vital part of the total value of regional ecosystem services.[24] In this study, we have assessed the value of ecosystem services and biodiversity in the East Dongting Lake Area in two stages, so as to reveal the features of time-specific variations in the ecosystem service value over the past two decades and the impact imposed by varying types of land use on the biodiversity in the surrounding areas. In addition, we intend to analyze the response of ecosystem services and biodiversity to the changes taken place in land use. This study is expected to lay a theoretical foundation for deepening the collaborative conservation and management of cross-regional ecological environment, thus providing theoretical support to and having practical implications for the optimization of land use structure and joint protection of cross-regional wetlands in the East Dongting Lake Area.

2. Materials and methods

2.1 Overview of the study area

The East Dongting Lake is located on the south side of Jingjiang River section in the middle reaches of the Yangtze River, ranging between 28°59′ and 29°38′N, and between 112°43′ and 113°15′E.[25] The East Dongting Lake is an immense water-carrying lake accepting inflow of water from Xiangjiang, Zijiang, Yuanjiang and Lijiang Rivers. The lake covers an area of 190,000 hm² in total, with the water area amounting to 65,400 hectares.[26] The East Dongting Lake Area enjoys long sunshine duration, abundant rainfall and amiable temperature mostly exceeding 17℃. In addition, the East Dongting Lake is the largest and most well-preserved natural seasonal lake in the Dongting Lake clusters, with a rich variety of habitats. Therefore, the lake has provided optimal conditions for creatures to survive and thrive.[27]

Fig. 2: Location map of the research area at the scale of Hunan Province. (**Note:** Fig. 2 focuses on showing the location of the East Dongting Lake research area within the administrative boundary of Hunan Province. The scale of this map is 1 centimeter (cm) on the map representing 60,000 meters (m) in reality.)

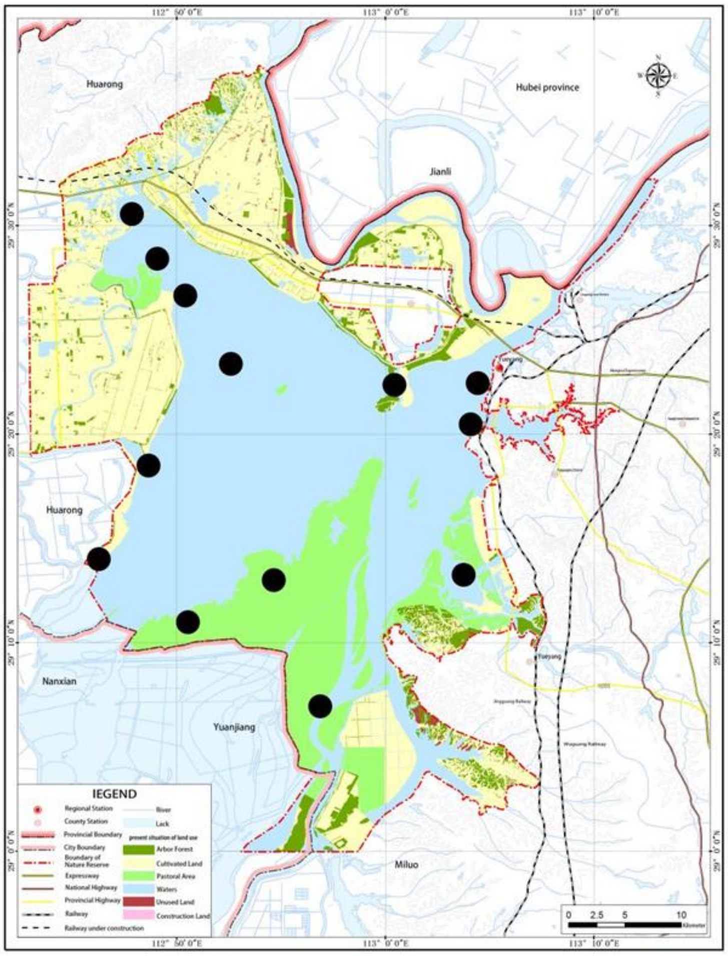

Fig. 3: Distribution Map for the Plants in the East Dongting Lake Area.

2.2 Source of data and method of processing

The data on the East Dongting Lake Area in the years of 2000, 2009 and 2019 collected by LandsatTM5 and Landsat 8 are extracted from the Geospatial Data Cloud for Computer Network Information Center, CAS (http:/www.gscloud.cn/) and the United States Geological Survey (http://earthexplorer.usgs.gov). We have collected the data of DEM by using Aster GDEM jointly developed by the National Aeronautics and Space Administration (NASA) of the United States and the Ministry of Economy, Trade and Industry (METI) of Japan for August and September. In addition, we have adopted the output value of grain crops grown in the study area in the statistical yearbooks for 2000, 2009 and 2019 specified in the official WeChat account of Hunan Statistics.[28] Supported by the Environment for Visualizing Images (ENVI), we have coupled the remote sensing images to set up the interpretative mark of the ground in the image. In addition, we have divided the types of land use in the East Dongting Lake Area into arable land, water body, meadowland, woodland and construction land.[29] Judging from the analytical results of the maximum likelihood method based on the supervised classification, the accuracy of remote sensing images amounted to above 90%.[30]

2.2.1 Dynamic index of the changes of land use

Dynamic degree of single land use: The dynamic degree of single land use refers to the index of depicting the velocity and range of variation for different types of land use in a certain period of time. The index is able to reflect the impact imposed by human activities on a single type of land use.[31,32] The formula is specified as follows:

$$k_i = \frac{S_{it1} - S_{it2}}{S_{it1}} \times \frac{1}{t_2 - t_1} \times 100 \qquad (1)$$

where, K_i refers to the dynamic degree of the ith type of land use from t_1 to t_2, S_{it1} and S_{it2} refer to the area of the ith type of land use from t_1 to t_2.

2.2.2 Calculation of the value of ecosystem services

Formula for calculating the value of ecosystem services:

$$E_a = \frac{1}{7} \sum_{i=1}^{n} \frac{m_i p_i q_i}{M} \, (i = 1 \sim n) \qquad (2)$$

where, E_a refers to the economic value of grain crops of 1hm² arable land (yuan/hm^2); i refers to the main types of crops grown in the East Dongting Lake Area, including rice, cotton, oil crops (which consist of rapeseed and peanuts); p_i refers to the national average price of the ith crop (yuan/t); q_i refers to the grain yield per hectare of the ith crop (t/hm^2); m_i refers to

Table 3: Land Use of the Dongting Lake Area from 2000 to 2019.

Duration	Dynamic degree of single land use				
	Arable land	Woodland	Meadowland	Water body	Construction land
2000—2009	-0.27	-0.16	3.92	-1.34	5.60
2009—2019	-1.64	0.80	-5.21	0.64	13.07

the area of the i^{th} crop (hm^2); M refers to the total area of n types of crops (hm^2); and $\frac{1}{7}$ refers to the value of ecosystem services per unit, which is regarded as equivalent to per unit yield of major crops in the research year of the study area.[18]

$$ESV = \sum A_k \Delta VC_k \quad (3)$$

where, ESV Eq. (3) refers to the value of ecosystem services; A_K refers to the area of distribution of the kth type of land use in the study area (hm^2); VC_k refers to the coefficient of the ecosystem value ($yuan/hm^{-2}a^{-1}$).

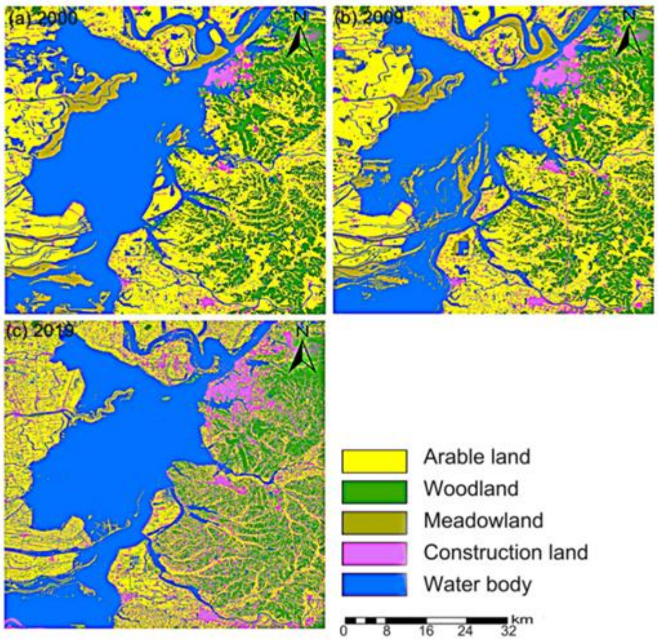

Fig. 4: (a) Types of Land Use in the East Dongting Lake Area in 2000; (b) Types of Land Use in the East Dongting Lake Area in 2009: (c) Types of Land Use in the East Dongting Lake Area in 2019.

The classification of ecosystem services is typically performed into four categories: provisioning, regulating, supporting, and cultural services.[33] As Kuyah *et al*.[34] have demonstrated, the provision of services (*e.g.* food, raw materials) yields direct material outputs. The regulation of services (for example, gases, climate regulation) is related to ecological processes that stabilise the human environment.[35] It has been demonstrated that supporting services (*e.g.* soil formation, biodiversity) underpin other services.[36,34,37] Cultural services, for example in the form of aesthetic landscapes, have been shown to offer non-material benefits.[38,39] This framework is designed to ensure global consistency, thereby facilitating cross-regional comparisons and policy application.[33] This study will interpret ESV from the above perspectives.

In this study, by calculating the grain yield per unit area, price (the prices of the respective years) and sowing area of rice, cotton and oil crops from 2000 to 2019 (as specified in Table 1), we have measured the equivalent factor of the value of single ecosystem services in the East Dongting Lake Area to reach 1852.5 yuan/hm², thereby obtaining the coefficient of the value of ecosystem services (as specified in Table 2).

2.2.3 Sensitivity analysis

We have adopted the Coefficient of Sensitivity (CS) to measure the dependence of the value of ecosystem services of varying types of land use over time.[40,41] If CS > 1, then ESV is estimated to be elastic to the Valuation Coefficient (VC), i.e, the coefficient of the value of ecosystem services. 1% of the changes taken place in VC, or the coefficient of the value of ecosystem services, can result in changes of the CS of over 1%, indicating low level of credibility and accuracy;[42,43] if CS <1, then ESV is shown to be inelastic to VC and features high credibility in its results. The formula for calculating CS is specified as follows:

$$CS = \left| \frac{(ESV_j - ESV_i)/ESV_i}{(VC_{jk} - VC_{ik})/ESV_i} \right| \quad (4)$$

where, CS refers to the Coefficient of Sensitivity; ESV_i and ESV_j refer to the total value of the initial ecosystem services and the adjusted ecosystem services, respectively. VC_{ik} and VC_{jk} refer to the initial value coefficient and the adjusted value coefficient of the K^{th} type of land use, respectively.

2.2.4 A diversity analysis

2.2.4.1 Data acquisition

We have adopted the sample method for verifying the inventory of plant communities. We have set up 14 quadrats for sampling in 14 collection points, including Nianpanzhou, Wangjunzhou, Changzhou, Tuanzhou, Xin'an, Weiguozha, Wugangzi, Liugangzi, Laogang, Lujiao, Niuchang, Taipingzui and Yueshan. In addition, we have set up each of the sampling points in 5 m × 5 m quadrat in the East Dongting Lake Area so as to calculate the number of species as well as the number of individual species in each quadrat. The distribution of the

Table 4: Changes in the Value of Local Ecosystem Services in the Dongting Lake Area from 2000 to 2020.

Types of land use	Ecosystem Service Value/(×) element 10^8			Proportion/%			Dynamic degree/%	
	2000	2009	2019	2000	2009	2019	2000-2009	2009-2019
Woodland	57.92	57.08	61.65	19.13	20.16	21.44	-0.16	0.80
Meadowland	6.31	9.75	4.62	2.08	3.44	1.61	3.92	-5.21
Arable land	40.56	39.60	33.11	13.39	13.99	11.52	-0.27	-1.64
Water body	198.02	176.70	188.13	65.40	62.41	65.43	-1.34	0.64
Construction land	0	0	0	0	0	0	5.60	13.07
Total	302.81	283.13	287.51	100	100	100	7.75	7.66

collection points of experimental data are illustrated in Fig. 3, where the collection points are marked in black circle from Plot 1 to Plot 14 in the counterclockwise direction starting from the top right corner. Specifically, we have selected the following survey index:

(1) Species richness (S): Number of species present in the quadrat

(2) Abundance: Number of individuals of an individual species in a community

(3) Margalef Index

$$D = \frac{(S-1)}{lnN} \tag{5}$$

where, S refers to the total number of species in the community and N refers to the total number of individuals of all species observed.

(4) Shannon Index

$$H' = -\sum (p_i \ln p_i) \tag{6}$$

where, H' refers to the Shannon index; P_i refers to the proportion of the significance of the i^th^ species among all species. For instance, in terms of the number of individuals, n_i refers to the number of the i^th^ individuals, whereas N refers to the total number; accordingly, we have obtained the formula $P_i = \frac{n_i}{N}$, where, S refers to the total number of species.

(5) Simpson Index

$$D = 1 - \sum \left\{ n_i \frac{(n_i - 1)}{[N(N-1)]} \right\} \tag{7}$$

where, D refers to the Simpson Index; N refers to the total number of individuals; n_i refers to the number of individuals of the i^{th} species.

(6) Importance value

$$IV = \frac{(\text{Relative abundance} + \text{Relative frequency} + \text{Relative coverage})}{3} \tag{8}$$

where, Relative abundance (RD) is defined as the proportion of individual specimens within a species that constitute the total number of individuals in the community, thereby reflecting the numerical dominance of that species. Relative frequency (RF) is defined as the percentage of occurrence of a species among all sample plots, and it characterizes the uniformity of spatial distribution. Relative coverage (RC) is defined as the percentage of a species' coverage in the total coverage of the community, thereby reflecting the resource

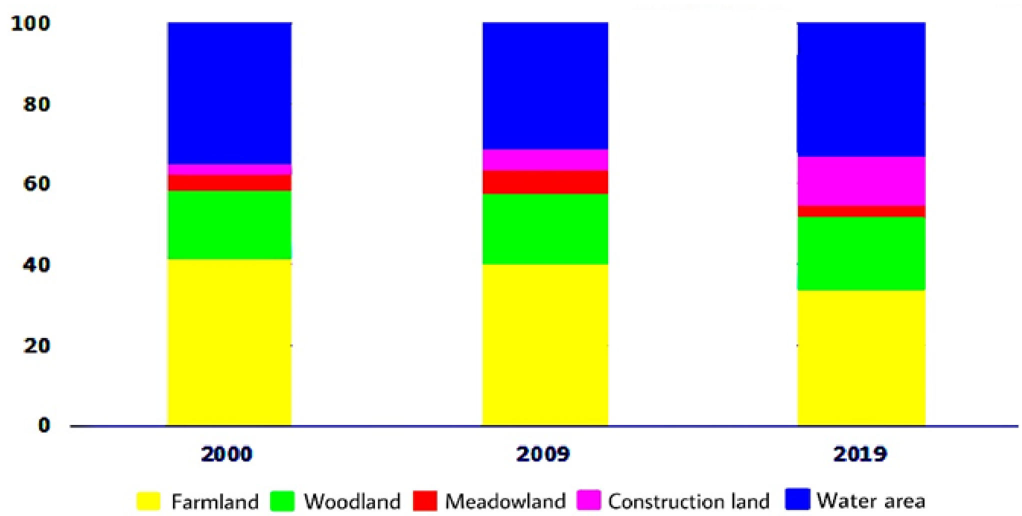

Fig. 5: Land Use Structure of the East Dongting Lake Area from 2000 to 2019.

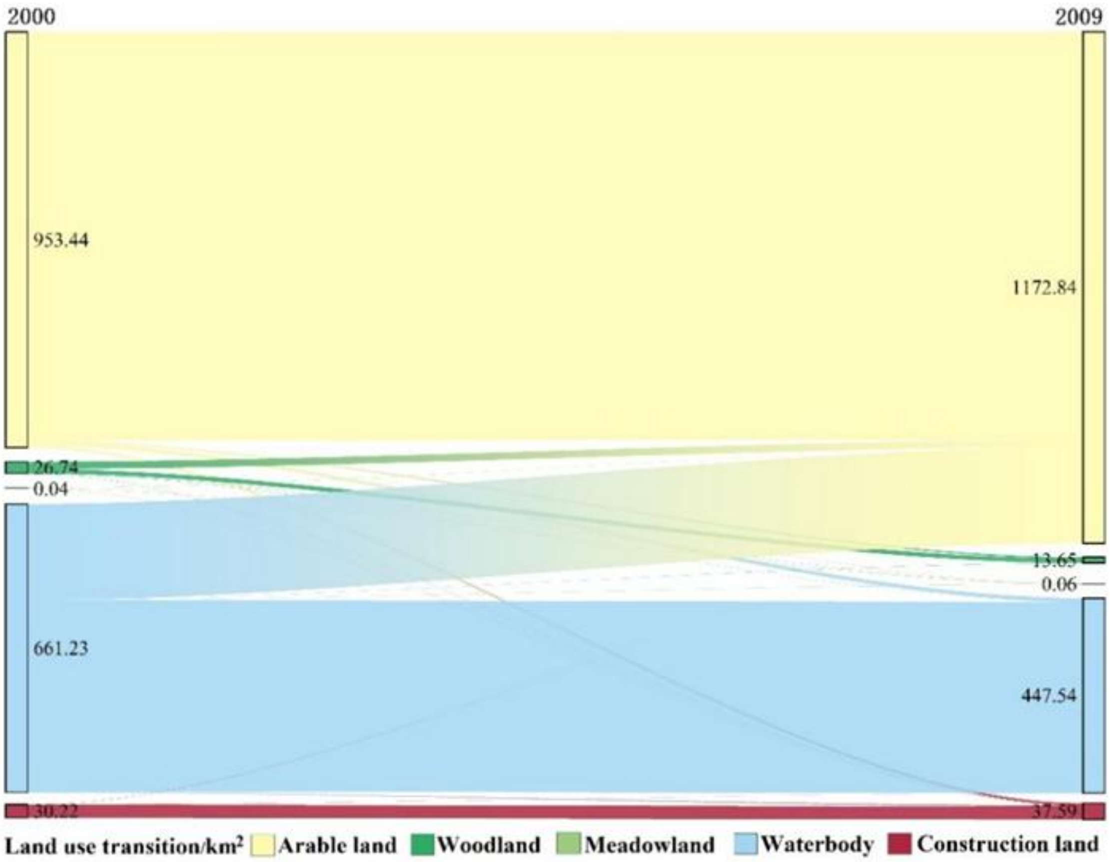

Fig. 6: LUCC in the East Dongting Lake Area from 2000 to 2009.

occupancy capacity.

3. Results analysis

3.1 Analysis of changes taken place in the land use of the dongting lake area

Judging from the distribution map of the types of land use in the Dongting Lake Area (Fig. 4), the arable land and water area account for the largest proportion of land use in the study area, which are the major types of land use, followed by water body, woodland, meadowland and construction land. Based on the data on the changes of types of land use from 2000 to 2019 in the East Dongting Lake Area and the dynamic degree of changes of land use, through the Dynamic index of the changes of land use Eq. (1), we have obtained the structural diagram of varying land use types (Fig. 5) and table on thend use dynamics (Table 3).

The decline in Dongting Lake's water area stems from combined natural and anthropogenic factors, with hydrological alterations from the Three Gorges Reservoir (TGR) being dominant. During impoundment, the TGR reduces Yangtze River inflow, it also impedes sedimentation, weakening the lakebed's siltation capacity,[44,45,46] diminishing the natural expansion capacity. Moreover, disrupted hydrological connectivity reduces high-water level duration and impairs flood storage.[46,47] Meanwhile, the loss of water bodies has been exacerbated by historical reclamation (*e.g.*, fewer lakes 0.1 km² from 1954 to 1998) and changes in land use.[48,49] Climate change is also key, as decreased precipitation and increased drought frequency lowered the West Dongting Lake multi-year average water level by 1.05 meters,[47,49] while enhanced evapotranspiration shortens water residence time.

By quantifying the rate of land use change in the study area from 2000 to 2019, the dynamic change characteristics of each land type were revealed. The water area exhibited an evolutionary trend characterised by an initial decrease, followed by a subsequent increase. The mean annual rate of change for the period 2000 to 2009 was -12.06%, with the predominant changes involving the conversion of land into meadowland and construction land. However, from 2009 to 2019, the trend underwent a reversal, with an average annual change rate of 6.4%. The arable land area underwent a consistent decrease, exhibiting an average annual change rate of -2.43% from 2000 to 2009, and subsequently accelerating to -16.4% from 2009 to 2019. The woodland area exhibited stability, maintaining proportions of 16.58%, 16.34%, and 17.65% across the three periods, with an average annual change rate of merely 3.28%. The most significant development was the expansion of construction land. The average annual change rate from 2000 to 2009 was 50.4%, and it further increased to 130.7% from 2009 to 2019. The overall dynamic degree index attained 13.07, a figure that was found to be significantly higher than that of other land types ($p < 0.01$). This change pattern is closely related to China's rapid urbanisation process. The proportion of construction land was

Table 5: Changes of the Value of Ecosystem Services in the East Dongting Lake Area from 2000 to 2019.

Ecosystems service	ESV/(× element) 10^8			Proportion/%			Change rate/%
	2000	2009	2019	2000	2009	2019	2000-2019
Food production	8.36	8.11	7.28	2.72	2.91	2.50	-12.92
Raw material	9.86	9.67	9.76	3.21	3.47	3.35	-1.01
Gas regulation	15.63	15.62	15.20	5.10	5.60	5.22	-2.75
Climate regulation	23.20	21.37	22.24	7.57	7.66	7.64	-4.14
Water regulation	95.16	86.56	90.66	31.05	31.03	31.14	4.73
Waste treatment	76.24	69.42	71.72	24.87	24.88	24.63	-5.93
Soil formation and protection	18.83	11.70	17.56	6.14	4.19	6.03	-6.74
Biodiversity conservation	34.65	33.46	32.69	11.31	11.99	11.23	-5.66
Provision of aesthetic landscape	25.01	23.10	24.04	8.16	8.28	8.26	-3.88

only 2.58% in 2000, but it increased to 12.03% in 2019, reflecting the profound impact of economic development on land use changes.

A quantitative analysis of the LUCC transfer matrix of East Dongting Lake from 2000 to 2009 (see Fig. 6) was conducted, the results of which indicate that during the study period arable land was the dominant land type, accounting for 70.16% (1172.84 km^2) of the total area, with a system retention rate of 79.81% (936.08 km^2). However, a transfer scale of 236.76 km^2 was identified, with the most significant transformation being to water bodies (220.14 km^2). The area change of water bodies exhibited a bidirectional change feature. While the total area increased by 222.23 km^2 (an increase of 33.62%), 438.60 km^2 (66.34%) remained stable within the area, and 8.72 km^2 (1.32%) reversed to cultivated land. The expansion of construction land was 7.36 km^2 (an increase of 24.36%), with 69.95% of this expansion occurring as a result of the transformation of cultivated land (5.25 km^2). This indicates a spreading trend along the periphery of the built-up area. The woodland system demonstrated a relatively high degree of stability, with a retention rate of 73.22%, however, a transformation of 3.38 km^2 (12.64%) to arable land was observed, predominantly occurring in ecologically fragile areas.

Focusing in more detail on the land use transfer between 2009 and 2019 (see Fig. 7), it was found that, compared with the 2000-2009 period, the area of arable land remained relatively stable, accounting for 69.68% (1164.53 km^2) of the total area, with a system retention rate of 95.57% (1112.86 km^2). However, a transfer scale of 51.67 km^2 was identified, with the most significant transformation being to water bodies (46.88 km^2), exhibiting a transformation rate of 4.03%. The expansion of construction land was significant, increasing by 13.31 km^2 (an increase of 35.41%), with 75.78% of this

Table 6: Coefficient of Sensitivity of the Value of Ecosystem Services Provided by Varying Types of Land Use.

Types of land use	ESV/(× element) 10^8			Coefficient of sensitivity		
	2000	2009	2019	2000	2009	2019
Woodland VC + 50%	331.77	311.67	303.34	0.0478	0.0252	0.0275
Woodland VC-50%	273.85	254.59	256.69			
Meadowland VC + 50%	305.965	288.01	289.82	0.0052	0.0086	0.0040
Meadowland VC-50%	299.66	278.26	285.20			
Arable land VC + 50%	323.09	302.93	304.07	0.0335	0.0349	0.0288
Arable land VC-50%	282.53	263.33	270.96			
Water body VC + 50%	401.82	371.48	381.58	0.1635	0.1560	0.1636
Water body VC-50%	203.8	194.78	193.45			

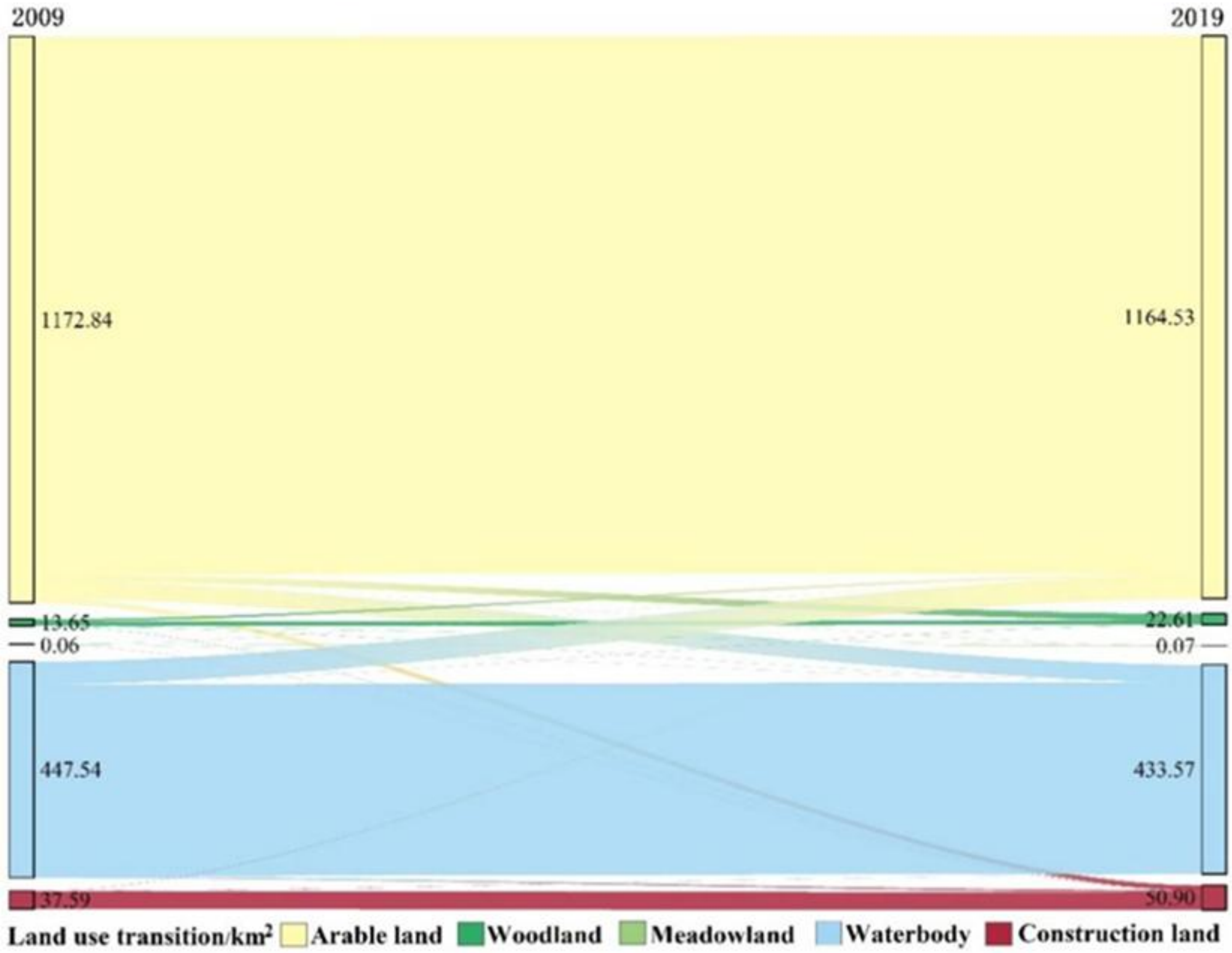

Fig. 7: LUCC in the East Dongting Lake Area from 2009 to 2019.

expansion being attributable to the transformation of arable land (10.08 km^2). This transformation exhibited a linear expansion pattern along transportation routes. The area of water bodies demonstrated a substantial decrease, with a reduction of 13.97 km^2 (representing a decline of 3.12%), whilst 36.23 km^2 (8.09%) underwent conversion to cultivated land, indicative of the reactivation of agricultural development initiatives. It is noteworthy that the woodland system underwent a substantial reverse transformation, with 13.60 km^2 (99.62%) converting to cultivated land, predominantly in ecologically fragile areas.A comparison of the transformation intensity among various land types revealed that the transformation intensity of arable land to construction land (10.08 km^2) was 294.74 times that of the 2000-2009 period, indicating a significant acceleration of the urbanisation process.

3.2 Analysis of the Value of Ecosystem Services in the Dongting Lake Area

3.2.1 Overall features of the changes in the value of ecosystem services of varying types of land

Judging from Table 4, the value of ecosystem services in the East Dongting Lake Area decreased by RMB 1.53 billion over the past two decades, whereas the values of ecosystem services in the years of 2000, 2009 and 2019 amount to RMB 30.218 billion, RMB 28.313 and RMB 28.751 billion, revealing the overall trend of decrease first before increasing in the subsequent stage. Judging from the value of ecosystem services of varying types of land use, the value of the water ecosystem services ranks as the highest, followed by woodland, arable land and meadowland. The value of water ecosystem services have shown a trend of decreasing first before increasing, which is in line with the overall value of ecosystem services in the East Dongting Lake Area. The results of the one-way analysis of variance (ANOVA) indicated that there were extremely significant differences ($p < 0.001$) in the impact of different land use types on the ecological service value. Furthermore, a multiple comparison analysis employing Tukey's HSD revealed that the disparities in ecological service value among woodland, meadowland, arable land, and water body categories were predominantly highly significant ($p < 0.001$). While the variation in value between woodland and arable land did not attain a highly significant level, a substantial difference was observed ($p < 0.05$).

Based on our analysis, the value of regional ecosystem services in the East Dongting Lake Area has revealed a *V-type growth*, whereas the stage of diminishing value of ecosystem services is directly related to the sharp reduction of the water area that features high coefficient of the value of ecosystem services. Since 2001, the urbanization in the East Dongting Lake Area has been rapidly advanced, and a vast area of water body has been transformed into construction land, resulting in a sharp decline in the value of ecosystem services by 2.132 billion yuan. In 2000, the value of ecosystem services of water body amounted to RMB 19.802 billion, accounting for 65.40% of the overall value of ecosystem services in the East Dongting Lake Area. From 2000 to 2009, the water area of the East

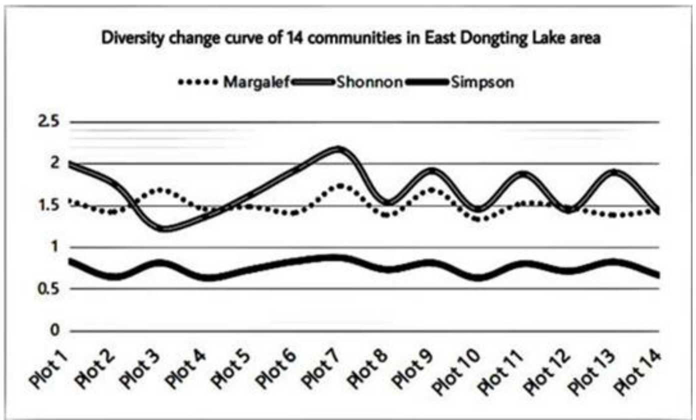

Fig. 8: Curve of Changes to the Species Diversity in the East Dongting Lake Area.

Dongting Lake experienced sharp decreases, whereas the area of meadowland and construction land multiplied. In addition, the value of ecosystem services of meadowland increased by a large amount with the expansion of the area of meadowland. Furthermore, the changes taken place in the land use also increased to a significant extent. In particular, the dynamic degree of changes of land use for the construction land amounted to 5.60%, the highest level from 2000 to 2009. The area of arable land and woodland experienced slow declines. From 2000 to 2009, the value of ecosystem services of water bodies in the area decreased to RMB 17.670 billion, whereas its proportion in the total value of ecosystem services also declined to 62.41%. In the East Dongting Lake Area that provides ecosystem service value mainly through water body, the overall value of its ecosystem services decreased by 1.968 billion yuan. Fortunately, during the decade from 2009 to 2019, thanks to the support from the government, the water area of the East Dongting Lake gradually increased from RMB 17.670 billion in 2009 to RMB 18.813 billion in 2019. However, compared with the value of water ecosystem services in 2000, the value of 2019 was still a decline of 4.99%. The reason is that subsequent to 2007, the return of migrant workers driven by the financial crisis led to inflow of sufficient labor in the East Dongting Lake Area. As a result, from 2009 to 2019, the construction land increased significantly, whereas the dynamic degree of the change of land use amounted to 13.07%, the maximum value over the past two decades. During this period, the area of arable land experienced declines, whereas the value of ecosystem services decreased by RMB 745 million, with the changing rate of value amounting to 18.36%. Due to the implementation of protective policies and management measures, the water area of the East Dongting Lake has been gradually recovered, whereas the total value of ecosystem services in the East Dongting Lake has been gradually increased.

3.2.2 Features of the value of individual ecosystem service in the East Dongting Lake Area

The formula for calculating the value of ecosystem services is shown in Eq. (2). The value of various types of individual ecosystem services has been calculated (Table 5). The results of one-way ANOVA indicated that there were extremely significant differences ($p < 0.001$) in the impact of different types of ecosystem services on ecosystem service value. Tukey's HSD multiple comparison analysis revealed that, with the exception of the ESV discrepancy between food production and raw material, which did not attain a significant level ($p > 0.05$), the ESV disparities among the remaining categories of ecosystem services were all found to be highly significant ($p < 0.001$). It is noteworthy that while the ESV differences between food production and gas regulation, as well as between food production and soil formation and protection, did not attain an extremely significant level, they were nevertheless statistically significant ($p < 0.05$). Among all individual ecosystem services provided by the East Dongting Lake Area, the service function of hydrological regulation has generated the greatest value, whereas the

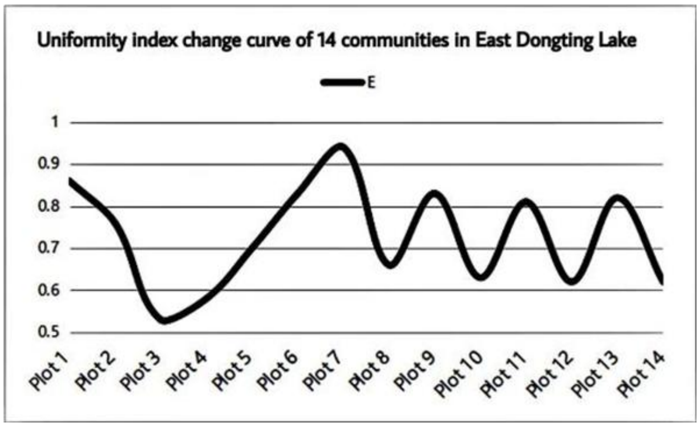

Fig. 9: Curve of Changes to the Community Uniformity in the East Dongting Lake Area.

function of waste treatment ranks second in terms of value creation. Both services are provided by the water body, which has become the primary contributor to the service value provided in the East Dongting Lake Area. From 2000 to 2009, all the value of ecosystem services in the East Dongting Lake Area experienced declines. This was mainly derived from the huge reduction of value of the main component of water body, woodland, arable land and other ecosystem services during the decade from 2000 to 2009. In particular, the water area decreased sharply, and even if the meadowland area increased, the value of all individual ecosystem services still experienced

Table 7: Species Diversity Index of the East Dongting Lake Area.

Plot names		Species diversity index			
		Margalef index	Shannon index H′/ E		Simpson index
A1-Nianpanzhou (29°29′30″N, 112°47′40″E)	Plot 1	1.55	1.99	0.87	0.84
A2-Wangjunzhou (29°27′08″N, 112°48′57″E)	Plot 2	1.43	1.76	0.76	0.68
A3-Changzhou (29°25′29″N, 112°50′12″E)	Plot 3	1.68	1.22	0.53	0.82
A4-Changzhou (29°20′40″N, 112°49′36″E)	Plot 4	1.45	1.36	0.59	0.64
A5-Xinan (29°16′58″N, 112°48′16″E)	Plot 5	1.48	1.62	0.71	0.73
A6-Weiguozha (29°11′42″N, 112°44′32″E)	Plot 6	1.41	1.92	0.83	0.83
A7-Wugangzi (29°09′16″N, 112°50′27″E)	Plot 7	1.74	2.16	0.94	0.88
A8-Liugangzi (29°11′13″N, 112°54′17″E)	Plot 8	1.38	1.53	0.67	0.74
A9-Laogang (29°05′16″N, 112°56′32″E)	Plot 9	1.69	1.91	0.83	0.82
A10-Lujiao (29°09′09″N, 113°00′19″E)	Plot 10	1.33	1.45	0.63	0.64
A11-Niuchang (29°11′26″N, 112°47′40″E)	Plot 11	1.52	1.87	0.81	0.80
A12-Taipingzui (29°18′54″N, 113°03′47″E)	Plot 12	1.47	1.45	0.62	0.72
A13-Yueshan (29°20′52″N, 113°03′50″E)	Plot 13	1.39	1.90	0.82	0.83
A14-Taipingzui (29°20′54″N, 113°00′04″E)	Plot 14	1.45	1.43	0.62	0.67

declines. A vast area of water body and woodland have been transformed into the construction land, and given that the value of ecosystem services of the construction land amounts to 0, the value of all ecosystem services has been reduced to varying extents due to the doubling of the construction land. From 2009 to 2019, the value of merely two ecosystem services decreased, including food production and gas regulation. Apart from these two sorts of services, the value of individual ecosystem services increased, including raw materials production, climate regulation, hydrological regulation, waste treatment, soil formation and protection, biodiversity conservation and provision of aesthetic landscape, with the value of hydrological regulation increasing by the largest margin, amounting to RMB 410 million. The function of gas regulation has remained basically unchanged throughout two decades. With the diminishing area of arable land, especially from 2000 to 2009, the value of individual service of food production in the study area declined significantly. This has also led to the highest rate of value change among all individual services, amounting to -12.92%.

3.3 Sensitivity Analysis

In accordance with the calculation of the coefficient of sensitivity Eq. (4), the coefficients of the value of ecosystem services of varying geotypes have been increased and decreased by 50%, respectively, in order to obtain the CS value for the years 2000, 2009 and 2019 (Table 6). Our research findings indicate that the CS value of the types of land use in the area during different years is less than 1. In other words, the value of ecosystem services is inelastic to the coefficient of the value of ecosystem services for varying types of land use. In addition, the results of calculating the value of ecosystem services feature high credibility. Through longitudinal comparison, we have found that the meadowland features the lowest sensitivity of the value of ecosystem services, with the lowest CS value amounting to 0.0040. Moreover, the water body features the highest sensitivity of the value of ecosystem services. When the value of ecosystem services increases by 1%, the total value of ecosystem service would increase by 0.1636%. The sensitivity of woodland and water body has experienced drastic declines first before increasing slowly, which is in line with the downward trend of the overall value of ecosystem services in the East Dongting Lake Area. The sensitivity of woodland amounted to 0.0478 in 2000 and decreased by 0.0226 to 0.0252 in 2009. However, the figure slowly increased to 0.0275 in 2019. In terms of the water body, its sensitivity amounted to 0.1635 in 2000 and decreased by 0.0075 to 0.1560 in 2009, while increasing to 0.1636 in 2019, basically the same level as in 2000. The diminishing sensitivity of woodland and water body from 2000 to 2009 has revealed that their impact on the overall value of ecosystem services in the East Dongting Lake Area was reduced, whereas the sensitivity of meadowland and arable land experienced increases in the same period. The results indicate that meadowland and arable land have imposed an increasingly significant impact on the overall value of ecosystem services in the East Dongting Lake Area. From 2009 to 2019, due to the implementation of policies such as returning arable land to forest and lake, the area of woodland and water body increased, whereas their impact on the overall value of ecosystem services in the East Dongting Lake Area also became immense correspondingly. In addition, the CS of all types of land use is less than 1, indicating that the coefficient of the value of ecosystem services is credible for estimating the overall value of ecosystem services in the East Dongting Lake Area.

3.4 α Diversity analysis

According to Margalef index, Shannon index and Simpson index, the calculation Eq. (5), (6), (7) and (8) respectively, and

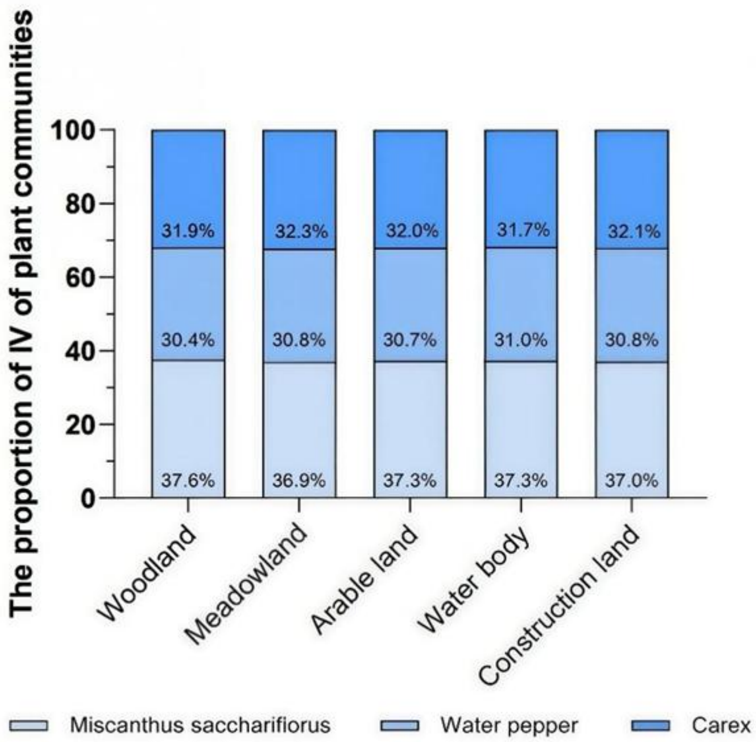

Fig. 10: The proportion of IV of plant communities in East Dongting Lake under various land use types.

we obtain Table 7, Fig. 8 and Fig. 9. Fig. 8 and 9 illustrate species diversity curves and changes in community uniformity across the 14 plant communities in the East Dongting Lake area, respectively. The Margalef index, measuring species richness, reveals higher values near Plots 7, 3, 9, and 1, indicating greater species richness in these areas compared to the wider region. Plot 7 exhibited the highest Margalef index (1.73), while Plots 6, 8, 10, and 13 showed lower values (ranked from lowest: Plot 10 < Plot 8 < Plot 13 < Plot 6), signifying areas of species paucity.

The Shannon and Simpson indices, which measure species diversity, yielded similar top rankings: Plot 7 > Plot 1 > Plot 6 > Plot 9 (Shannon) and Plot 7 > Plot 6 > Plot 1 > Plot 9 (Simpson). This consistency confirms high species diversity near these four plots. Conversely, the lowest indices were Plot 3 < Plot 4 < Plot 14 < Plot 12 < Plot 10 (Shannon) and Plot 4 < Plot 10 < Plot 2 < Plot 14 (Simpson), indicating particularly low species diversity near Plots 4, 10, and 14.

Synthesizing these results, Plots 1, 6, 7, and 9 demonstrate high biodiversity, Plots 2, 5, 8, and 11 exhibit moderate community balance, and Plots 3, 4, 10, 12, 13, and 14 show low biodiversity. Plot 10 consistently ranked lowest overall (Margalef and Shannon: 14th; Simpson: 13th), while Plot 7 consistently ranked highest in Shannon and Simpson indices, confirming its exceptional species richness and diversity.

Meanwhile, an analysis and study were conducted on the distribution characteristics of the IV of three dominant plants (Miscanthus sacchariflorus, Water pepper and Carex) in five land use types (woodland, meadowland, arable land, water body and construction land) in the East Dongting Lake area (Fig. 10). The data demonstrate that the index of variation (IV) of each species remained relatively stable across different land use types. Specifically, the IV of Miscanthus sacchariflorus ranged from 36.9% to 37.6%, that of Water pepper from 30.4% to 31%, and that of Carex from 31.7% to 32.3%. It is noteworthy that the IV of Miscanthus sacchariflorus in the forest ecosystem (37.6%) was found to be significantly higher than that observed in other land use types ($p < 0.05$). Concurrently, the variation coefficients of the IV of each species in water bodies and construction land were found to be the smallest (CV < 1.5%), thus indicating that the plant community structure in these two land use types was more stable.

Comparing these diversity indices with the geographic distribution in Fig. 3 shows that plots with high biodiversity (Plots 1, 6, 7, 9) cluster in Huarong County and Yuanjiang City, where land use is predominantly arable land and woodland-types conducive to biodiversity maintenance. In contrast, plots with low diversity (Plots 3, 4, 10, 12, 13, 14) are concentrated in the northeast (Junshan District, Yueyanglou District, Yueyang County), where adjacent land is primarily developed for construction. This northeast region experienced the most significant land use changes within the East Dongting Lake area between 2000 and 2019. The substantial expansion of construction land here is the primary driver of the below-average species diversity indices near these sampling points. Regionally, species diversity decreases in the order: southwest > southeast > northwest > northeast. Moreover, a comparative analysis of the significant values of plant communities and species diversity indices in Dongting Lake revealed that arable land and forest land, as the primary land use types for sustaining regional biodiversity, exhibited a substantial positive correlation ($p < 0.05$) in the distribution of plant community important values and the optimal level of species diversity. It is imperative to acknowledge the repercussions of habitat fragmentation, precipitated by the proliferation of construction land, on the biodiversity of adjacent areas. The augmentation of the coefficient of variation (CV > 2.5%) in plant community important values in such regions signifies the cascading consequences of land use transformation on biodiversity. The types of land use in varying regions could impose a direct impact on the biodiversity of neighboring areas, whereas the transformation of the types of land originally favorable for biodiversity to the types of land harmful to biodiversity will directly lead to the diminishing biodiversity, revealing that biodiversity in the East Dongting Lake Area is subject to significant impact from the changes of land use.

4. Discussion

The value of ecosystem services in in the East Dongting Lake Area experienced declines first before increasing throughout the two decades from 2000 to 2019. According to the early administrative planning, the Dongting Lake Area was divided into Changde, Yiyang and Yueyang. Consequently, it was hard to make unified planning for further implementation. Furthermore, developers of the East Dongting Lake Area have ignored the law of the ecosystem and the area was plagued by the issue of blind growth. Coupled with the negative influence imposed by the imperfection of laws and regulations, the area encountered varying mistakes during its development, management and utilization.

The decline in the ecosystem service value (ESV) of Dongting Lake is primarily attributable to changes in land use/cover (LUCC), pollution, climate change, and habitat loss. LUCC is demonstrably dominant: from 1995 to 2020, there was a significant decrease in natural wetlands, whilst construction land expanded by 20%. This has had a detrimental effect on water conservation and carbon storage. Reclamation has been demonstrated to result in a 50% reduction in lake area, consequently causing billion-yuan ESV losses.[50] As posited by Li *et al*.[51] and Mao *et al*.,[52] elevated levels of pollution, such as those attributable to agricultural runoff and shipping, serve to impede the capacity of water quality regulation and purification processes. This is due to an increase in total nitrogen loads, water turbidity, and heavy metal accumulation. It is evident that climate change and hydrological disturbances have the capacity to alter precipitation patterns and trigger extreme events, thereby weakening water conservation. The decline in biodiversity and the fragmentation of habitats have been shown to have a significant impact on the alpha diversity of macrobenthos, with a 40% decrease observed between 1988 and 2017.[53] Additionally, the presence of non-native species has been identified as a factor contributing to a 50% reduction in aquatic vegetation coverage.[54]

In addition, the East Dongting Lake Area is mainly composed of the water body, arable land and woodland. Over the past two decades, the water area of East Dongting Lake has fluctuated by a significant margin. Since the beginning of the 21st century, the lake area experienced drastic declines in the first decade, and slow recovery during the second decade thanks to the implementation of protective policies.[55] The ecosystem service value of East Dongting Lake is principally influenced by water bodies and forests. It is evident that water bodies regulate 60% of the suitability of waterfowl habitats through hydrological processes and the provision of biological habitats. The maintenance of minimum water levels is imperative for the survival of benthic organisms and the support of water purification processes.[56] Forests contribute to enhanced ecosystem service value through carbon sequestration, climate regulation, soil and water conservation, and support for biodiversity. As demonstrated in the extant literature, an increase of 0.1 in the connectivity of the forest-wetland ecotone is associated with a 12.4% increase in species richness.[57,49] Under such circumstances, the sharp increase or decrease in the water area would lead to the increase or decrease in the overall value of ecosystem services. The rapid growth of the economy in the East Dongting Lake Area contributed to the rapid increase of construction land, which accounted for the largest proportion of land use during its respective periods.

The transformation of the types of land use such as water body and arable land into construction land is the primary cause for the declines of the overall value of ecosystem services. Given that the coefficient of the value of ecosystem services amounts to 0, the construction land is unable to contribute to the value of ecosystem services, and the growth of its area means that the value of the replaced ecosystem services experienced declines as well as the net loss of ecosystem services in the East Dongting Lake Area.

It is worth mentioning that the area of the arable land has been repeatedly reduced over the past decades, whereas the arable land mainly provides the functions of food production, waste treatment and soil formation and conservation. The sharp reduction of arable land could direct lead to the substantial reduction of the service value of food production, and its rate of changes of value amounted to as high as -12.92%, marking the maximum rate of changes for all sorts of service value. The value of the ecosystem services of area land was directly reduced by RMB 745 million. The surge in the area of comprehensive construction land has shown that the authorities ought to implement the policies of returning arable land to lake and woodland, they shall also avoid replacing the arable land by the construction land. In addition, we shall not only well protect the agricultural land by means of the macro land use planning, but more importantly, we shall pay attention to the upgrading of agricultural farming technology and product structure to keep pace with the Times. Furthermore, we shall integrate and rebuild low-yield fields and barren fields into high-quality and high-yield fields. By adopting the aforementioned measures, we are expected to further restore the wide variety of services provided by arable land in the ecosystem, so as to improve the overall value of the ecosystem services in the East Dongting Lake Area.

In terms of the varying sections of the East Dongting Lake Area, the ranking of the the species diversity index in different regions are specified as follows: southwest > southeast > northwest > northeast. In the meantime, the change of the types of land use will also impose an indirect impact on the reduction of the species diversity index, whereas the measurement of this index in the construction land is generally lower than the species diversity index of woodland, water body, arable land, among other areas. This trend shares both similarities and differences with Poyang Lake, another lake situated in the middle and lower reaches of the Yangtze River. From 1990 to 2022, Poyang Lake underwent a persistent decrease in its water area during the dry season, accompanied by vegetation community succession and expansion. The primary factors contributing to this phenomenon were as follows: rising temperatures, reduced precipitation during the dry season, and the impact of water storage in the Three Gorges Dam. In contrast to the direct impact of land use on East Dongting Lake, the alterations observed in Poyang Lake are predominantly shaped by the interplay of hydrological and climatic factors. However, both are subject to the superimposed pressure of human activities, such as agricultural encroachment.[58]

On a global scale, the Mekong Delta (a tropical monsoon wetland) presents a different pattern. The biodiversity of East Dongting Lake and Poyang Lake is directly affected by the water level regulation of dams, whereas the degradation of the Mekong Delta is more attributed to habitat fragmentation caused by intensive aquaculture and rice cultivation.[59] It is noteworthy that all three regions have exhibited a trend of vegetation simplification, as evidenced by the dominance of Carex cinerea in Poyang Lake and the proliferation of exotic Polygonum species in East Dongting Lake. This phenomenon reflects the universal law of ecosystem homogenization under intense land use. However, due to its high tropical biodiversity baseline and climate sensitivity, the Mekong Delta experiences a significantly higher rate of species turnover compared to the temperate lakes of the Yangtze River.

Therefore, while constantly expanding the area of construction land, we shall ponder over the solutions to the challenges of safeguarding the biodiversity of adjacent areas during the subsequent development of the East Dongting Lake Area. Although the expanding construction land constitutes the inevitable trend of growth for the Area, we ought to elaborate on how to achieve the equilibrium with other types of land use in the study area and increase the area of water body and woodland, which feature higher coefficients of the value of ecosystem services. Such measures will help avoid the negative impact imposed by regional development on the ecosystem as much as possible, thereby achieving a *win-win* situation favorable to the macroeconomic development and the balance of biodiversity, while guaranteeing the ecosystem services in the region in the meantime.

Judging from our analysis of the remote sensing images and the statistical yearbooks of 2000, 2009 and 2019 we may conclude that we are able to advance the macroeconomic development while enhancing the value of ecosystem services in tandem. From 2009 to 2019, the area of construction land increased at a faster pace than in the previous decade. Due to implementation of regulatory policies, the overall value of ecosystem services in the East Dongting Lake Area in 2019 was higher than the total value of ecosystem services in 2009. Therefore, it is possible to reasonably plan varying types of land so as to achieve a win-win situation between human and nature.

In view of the decline in species diversity observed in the vicinity of construction areas, future research should address three significant impediments: the absence of long-term monitoring data, obstacles to interdisciplinary approaches, and the disconnection between policy translation and implementation. It is recommended that future studies concentrate on methodology, system integration, and policy orientation. In particular, the development of coupled models, the conducting of multi-scale experiments, and the exploration of sustainable governance tools should be prioritised.

5. Conclusion

Based on the status-quo of the East Dongting Lake, we have leveraged the big data available in social media database and coupled our analysis with the remote sensing technologies to correct the value equivalent of ecosystem services of the region, so as to assess its service value and estimate the biodiversity of the East Dongting Lake Area through the α diversity analysis. In addition, we have elaborated on the response and drivers of the value of ecosystem services and biodiversity to the changes of land use under varying types of land use, and come to the main conclusions specified as follows:

(1) From 2000 to 2019, the East Dongting Lake experienced evident changes to its types of land use. The area of water body and woodland in the East Dongting Lake Area has revealed the trend of *declining first before increasing*, which features the same trend as the changes of the total value of ecosystem services in the East Dongting Lake Area. The area of arable land has been constantly reduced over the past two decades, whereas the area of construction land has doubled. Our research findings of the value of ecosystem services in the region have shown that from 2009 to 2019, the value of ecosystem services for the water body first decreased by RMB 2.132 billion and then increased by RMB 1.143 billion. The change of the value of ecosystem services of other types of land use amounted to an increase of RMB 373 million for woodland, a decrease of RMB 169 million yuan for meadowland, and a decrease of RMB 745 million for arable land. The coefficients of the value of ecosystem services in the

East Dongting Lake Area are smaller than 1 as to the value of ecosystem services, indicating that the value of ecosystem services is inelastic in the East Dongting Lake Area.

(2) The regional ranking of the species diversity index in the East Dongting Lake Area is specified as follows: southwest > southeast > northwest > northeast, whereas the lands where construction accounts for a larger share<the lands where construction accounts for a smaller share. The species diversity index of the construction land is generally lower than that of woodlands, water body, arable land, among other types of land use.

(3) The estimated results of the value of ecosystem services and biodiversity in the East Dongting Lake Area indicate that the changes of land use would impose a significant impact on the value of ecosystem services and biodiversity in the area. Supported by measures of rational development and proper protection, the authorities are advised to balance the value of ecosystem services of varying types of land use, increase the proportion of lands that feature high coefficients of the value of ecosystem services and are favorable to biodiversity conservation, so as to achieve the collaborative development of the overall value of ecosystem services, biodiversity and macroeconomic operation in the East Dongting Lake Area.

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors read and approved the final manuscript.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

There is no conflict of interest.

Acknowledgements

The research was supported by the general projects of the Nature Science Foundation provided by the Science and Technology Department of Hunan Province, China [grant number S2019JJMSXM0531].

The authors are grateful to the Forestry Bureau of Hunan Province (FBHP) for providing the case study data. The authors would like to thank the reviewers for helping to substantially improve the quality of the article. The authors would also like to thank the Editage consultant team for reviewing the English language of the manuscript and for their helpful suggestions.

Supporting Information

Not applicable.

CRedit Statement

Jiewen Yang: Conceptualization, Methodology, Formal Analysis, Writing-Original Draft, Investigation. **Liyang Liu:** Investigation, Data Curation, Validation, Writing-Review & Editing. **Qiaoran Tang:** Software, Visualization, Validation, Resources. **Yang Lin:** Supervision, Writing-Review & Editing, Project Administration, Conceptualization. **Deming Wang:** Resources, Formal Analysis, Investigation. **Huajun Li:** Funding Acquisition, Resources, Writing-Review & Editing. **Jiayan Zhang:** Data Curation, Validation. **Ruiao Li:** Data Curation, Writing-Review & Editing.

References

[1] Y. Guo, B. Fu, P. Xu, Y. Wang, X. Liu, Mapping regional differences in payment for ecosystem service policies to inform integrated management: Case study of the Yangtze River Economic Belt, *Journal of Environmental Management*, 2021, **278**, 111396, doi: 10.1016/j.jenvman.2020.111396.

[2] H. Chen, The ecosystem service value of maintaining and expanding terrestrial protected areas in China, *Science of the Total Environment*, 2021, **781**, 146768, doi: 10.1016/j.scitotenv.2021.146768.

[3] S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. R. Chowdhury, Y.-J. Shin, I. Visseren-Hamakers, K. J. Willis, C. N. Zayas, Pervasive human-driven decline of life on Earth points to the need for transformative change, *Science*, 2019, **366**, eaax3100, doi: 10.1126/science.aax3100.

[4] H. M. Pereira, L. M. Navarro, I. Santos Martins, Global biodiversity change: the bad, the good, and the unknown, *Annual Review of Environment and Resources*, 2012, **37**, 25-50, doi: 10.1146/annurev-environ-042911-093511.

[5] J. Zhao, Y. Yan, H. Deng, G. Liu, L. Dai, L. Tang, L. Shi, G. Shao, Remarks about landsenses ecology and ecosystem services, *International Journal of Sustainable Development & World Ecology*, 2020, **27**, 196-201, doi: 10.1080/13504509.2020.1718795.

[6] R. Costanza, R. de Groot, P. Sutton, S. van der Ploeg, S. J. Anderson, I. Kubiszewski, S. Farber, R. K. Turner, Changes in the global value of ecosystem services, *Global Environmental Change*, 2014, **26**, 152-158, doi: 10.1016/j.gloenvcha.2014.04.002.

[7] S. Lautenbach, C. Kugel, A. Lausch, R. Seppelt, Analysis of historic changes in regional ecosystem service provisioning using land use data, *Ecological Indicators*, 2011, **11**, 676-687, doi: 10.1016/j.ecolind.2010.09.007.

[8] F. Li, Y. P. Ye, B. W. Song, R. S. Wang, Y. Tao, Assessing the changes in land use and ecosystem services in Changzhou municipality, Peoples' Republic of China, 1991–2006, *Ecological Indicators*, 2014, **42**, 95-103, doi: 10.1016/j.ecolind.2013.11.012.

[9] M. Liu, H. Tian, China's land cover and land use change from 1700 to 2005: Estimations from high-resolution satellite data and

historical archives, *Global Biogeochemical Cycles*, 2010, **24**, 2009GB003687, doi: 10.1029/2009gb003687.
[10] Z. Yang, J. Bai, W. Zhang, Mapping and assessment of wetland conditions by using remote sensing images and POI data, *Ecological Indicators*, 2021, **127**, 107485, doi: 10.1016/j.ecolind.2021.107485.
[11] T. Tian, L. Sun, S. Peng, F. Sun, Y. Che, Understanding the process from perception to cultural ecosystem services assessment by comparing valuation methods, *Urban Forestry & Urban Greening*, 2021, **57**, 126945, doi: 10.1016/j.ufug.2020.126945.
[12] R. Costanza, R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, M. van den Belt, The value of the world's ecosystem services and natural capital, *Nature*, 1997, **387**, 253-260, doi: 10.1038/387253a0.
[13] E. M. Martín-González, E. T. Kolkovska, A. Murillo-Salas, Approximation of the equilibrium distribution *via* extreme value theory: an application to insurance risk, *Methodology and Computing in Applied Probability*, 2021, **23**, 753-766, doi: 10.1007/s11009-020-09779-w.
[14] X. Gaodi, Z. Caixia, Z. Changsun, *et al*, The value of ecosystem services in China, *Resources science*, 2015, **37**(9), 1740-6, CNKI:SUN:ZRZY.0.2015-09-008
[15] R. Y. Wang, C. N. Ng, X. Qi, The Chinese characteristics o f payments for ecosystem services: a conceptual analysis of wate r eco-compensation mechanisms, *International Journal of Water Resources Development*, 2020, **36**, 651-669, doi: 10.1080/0790 0627.2019.1605889.
[16] H. Wei, W. Zhao, X. Zhang, X. Wang, Regional ecosystem service value evaluation based on land use changes: A case study in Dezhou, Shandong Provience, China, *Acta Ecologica Sinica*, 2017, **37**(11), doi: 10.5846/stxb201603300581
[17] Z. Li, T. Shao, An improved ecological services valuation model in land use project, *International Journal of Environmental Research and Public Health*, 2019, **16**, 1474, doi: 10.3390/ijerph16081474.
[18] A. Vali, S. Comai, M. Matteucci, Deep learning for land use and land cover classification based on hyperspectral and multispectral earth observation data: a review, *Remote Sensing*, 2020, **12**, 2495, doi: 10.3390/rs12152495.
[19] Ö. Akar, O. Güngör, Classification of multispectral images using Random Forest algorithm, *Journal of Geodesy and Geoinformation*, 2012, **1**, 105-112, doi: 10.9733/jgg.241212.1.
[20] C. Ünsalan, K.L. Boyer, Land Use Classification via Multispectral Information, *Multispectral Satellite Image Understanding, Advances in Computer Vision and Pattern Recognition*, Springer, London, 2011, doi:10.1007/978-0-85729-667-2_7.
[21] S. Shrestha, K. N. Poudyal, N. Bhattarai, M. B. Dangi, J. J. Boland, An assessment of the impact of land use and land cover change on the degradation of ecosystem service values in kathmandu valley using remote sensing and GIS, *Sustainability*, 2022, **14**, 15739, doi: 10.3390/su142315739.
[22] P. Zhang, Y. Zou, Y. Xie, H. Zhang, X. Liu, D. Gao, F. Yi, Shifts in distribution of herbivorous geese relative to hydrological variation in East Dongting Lake wetland, China, *Science of the Total Environment*, 2018, **636**, 30-38, doi: 10.1016/j.scitotenv.2018.04.247.
[23] H. Zhang, Q. Yang, Z. Zhang, D. Lu, H. Zhang, Spatiotemporal changes of ecosystem service value determined by national land space pattern change: a case study of Fengdu County in the Three Gorges Reservoir area, China, *International Journal of Environmental Research and Public Health*, 2021, **18**, 5007, doi: 10.3390/ijerph18095007.
[24] X. Wang, Y. Qian, Spatial modeling of $PM_{2.5}$ concentrations using an optimized land use regression method in Jiangsu, China, *IOP Conference Series: Earth and Environmental Science*, 2019, **227**, 052045, doi: 10.1088/1755-1315/227/5/052045.
[25] X. Dai, G. Yang, R. Wan, Y. Li, The effect of the Changjiang River on water regimes of its tributary Lake East Dongting, *Journal of Geographical Sciences*, 2018, **28**, 1072-1084, doi: 10.1007/s11442-018-1542-5.
[26] J.-Y. Hu, Y.-H. Xie, Y. Tang, F. Li, Y.-A. Zou, Changes of vegetation distribution in the east Dongting Lake after the operation of the Three Gorges Dam, China, *Frontiers in Plant Science*, 2018, **9**, 582, doi: 10.3389/fpls.2018.00582.
[27] Y.-A. Zou, Y. Tang, Y.-H. Xie, Q.-H. Zhao, H. Zhang, Response of herbivorous geese to wintering habitat changes: conservation insights from long-term population monitoring in the East Dongting Lake, China, *Regional Environmental Change*, 2017, **17**, 879-888, doi: 10.1007/s10113-016-1087-z.
[28] E. Malkoç, M. Rüetschi, C. Ginzler, L. T. Waser, Countryw ide mapping of trees outside forests based on remote sensing dat a in Switzerland, *International Journal of Applied Earth Observ ation and Geoinformation*, 2021, **100**, 102336, doi: 10.1016/j.ja g.2021.102336.
[29] S. De Roda Husman, J.J. Van Der Sanden, S. Lhermitte, *et al*, Integrating intensity and context for improved supervised river ice classification from dual-pol Sentinel-1 SAR data, *EGU21*, 2021, **101**, 102359, doi: 10.1016/j.jag.2021.102359.
[30] X. Shu, Y. Li, L. Feng, *et al*, Soil heavy metal accumulation in response to land use and landscape patterns, *Environmental Science*, 2019, (5), doi: 10.13227/j.hjkx.20190556.
[31] H. Liao, E. Sarver, L. H. Krometis, Interactive effects of water quality, physical habitat, and watershed anthropogenic activities on stream ecosystem health, *Water Research*, 2018, **130**, 69-78, doi: 10.1016/j.watres.2017.11.065.
[32] C. Raudsepp-Hearne, G. D. Peterson, E. M. Bennett, Ecosystem service bundles for analyzing tradeoffs in diverse landscapes, *Proceedings of the National Academy of Sciences of the United States of America*, 2010, **107**, 5242-5247, doi: 10.1073/pnas.0907284107.
[33] S. Kuyah, I. Öborn, M. Jonsson, Regulating ecosystem services delivered in agroforestry systems, *Agroforestry*, Springer Singapore, 2017, 797-815, doi: 10.1007/978-981-10-7650-3_33.
[34] D. K. Petsch, V. de Mello Cionek, S. M. Thomaz, N. C. L. dos Santos, Ecosystem services provided by river-floodplain

ecosystems, *Hydrobiologia*, 2023, **850**, 2563-2584, doi: 10.1007/s10750-022-04916-7.

[35] A. M. Villamagna, P. L. Angermeier, E. M. Bennett, Capacity, pressure, demand, and flow: a conceptual framework for analyzing ecosystem service provision and delivery, *Ecological Complexity*, 2013, **15**, 114-121, doi: 10.1016/j.ecocom.2013.07.004.

[36] X. Deng, K. Xiong, Y. Yu, S. Zhang, L. Kong, Y. Zhang, A review of ecosystem service trade-offs/synergies: enlightenment for the optimization of forest ecosystem functions in Karst desertification control, *Forests*, 2023, **14**, 88, doi: 10.3390/f14010088.

[37] M. E. Krasny, S. R. Crestol, K. G. Tidball, R. C. Stedman, New york city's oyster gardeners: memories and meanings as motivations for volunteer environmental stewardship, *Landscape and Urban Planning*, 2014, **132**, 16-25, doi: 10.1016/j.landurbplan.2014.08.003.

[38] H. Rey-Valette, J.-M. Salles, T. Blayac, Perceptions of ecosystem services and bonds with nature: the case of fish-farming ponds in France, *Ecological Economics*, 2024, **217**, 108049, doi: 10.1016/j.ecolecon.2023.108049.

[39] S. Yin, Y. Zhao, L. Han, *et al*, The time gap in the service value of Qinling forest ecosystem, *Journal of Applied Ecology*, 2016, **27**(12), doi: 10.13287/j.1001-9332.201612.023.

[40] X. Li, H. Chen, H. Liao, W. Hua, S. Sun, H. Ma, X. Li, C. Gao, S. Zhu, Potential effects of land cover change on temperature extremes over Eurasia: current *versus* historical experiments, *International Journal of Climatology*, 2017, **37**, 59-74, doi: 10.1002/joc.4976.

[41] J. Feng, L. Ding, J. Wang, *et al*, Case-based evaluation of forest ecosystem service function in China, *Chinese Journal of Applied Ecology*, 2016, doi: 10.13287/j.1001-9332.201605.015.

[42] K. Yuan, F. Li, H. Yang, Y. Wang, The influence of land use change on ecosystem service value in Shangzhou district, *International Journal of Environmental Research and Public Health*, 2019, **16**, 1321, doi: 10.3390/ijerph16081321.

[43] X. Lai, H. Chen, Y. Hou, B. Finlayson, M. Li, J. Chen, Lowering water level of Dongting lake of the Mid-Yangtze River in response to large-scale dam construction: A 60-year analysis, *Geomorphology*, 2021, **391**, 107894, doi: 10.1016/j.geomorph.2021.107894.

[44] J. Zhang, T. Huang, L. Chen, D. Z. Zhu, L. Zhu, L. Feng, X. Liu, Impact of the Three Gorges Reservoir on the hydrologic regime of the river-lake system in the middle Yangtze River, *Journal of Cleaner Production*, 2020, **258**, 121004, doi: 10.1016/j.jclepro.2020.121004.

[45] Z. Tian, L. Wang, Y. Li, B. Zheng, Z. Chu, Changes of phosphorus delivery from Yangtze River to Dongting Lake under new water and sediment conditions, *Journal of Cleaner Production*, 2021, **316**, 128248, doi: 10.1016/j.jclepro.2021.128248.

[46] Y. Yang, H. Yin, M. Li, W. Liu, K. Li, W. Yu, Effect of water depth and waterway obstructions on the divergence and confluence areas of Dongting Lake and the Yangtze River after the operation of the Three Gorges Project, *River*, 2023, **2**, 88-108, doi: 10.1002/rvr2.31.

[47] Y. Du, H.-P. Xue, S.-J. Wu, F. Ling, F. Xiao, X.-H. Wei, Lake area changes in the middle Yangtze region of China over the 20th century, *Journal of Environmental Management*, 2011, **92**, 1248-1255, doi: 10.1016/j.jenvman.2010.12.007.

[48] J. Tan, D. Yu, Q. Li, X. Tan, W. Zhou, Spatial relationship between land-use/land-cover change and land surface temperature in the Dongting Lake area, China, *Scientific Reports*, 2020, **10**, 9245, doi: 10.1038/s41598-020-66168-6.

[49] R. Wang, X. Wu, X. Zhou, A Management Strategy for Dongting Lake Wetland Regarding Ecological Security, *Wetland Science & Management*, 2017, **13**(4) 5, doi: 10.3969/j.issn.1673-3290.2017.04.03.

[50] J. Li, B. Xie, C. Gao, K. Zhou, C. Liu, W. Zhao, J. Xiao, J. Xie, Impacts of natural and human factors on water-related ecosystem services in the Dongting Lake Basin, *Journal of Cleaner Production*, 2022, **370**, 133400, doi: 10.1016/j.jclepro.2022.133400.

[51] L.-L. Mao, Y.-M. Chen, X. Li, Characterizing ship-induced hydrodynamics in a heavy shipping traffic waterway *via* intensified field measurements, *Water Science and Engineering*, 2020, **13**, 329-338, doi: 10.1016/j.wse.2020.11.001.

[52] Y. Zhang, D. Huang, X. Jin, L. Li, C. Wang, Y. Wang, L. Pellissier, A. C. Johnson, F. Wu, X. Zhang, Long-term wetland biomonitoring highlights the differential impact of land use on macroinvertebrate diversity in Dongting Lake in China, *Communications Earth & Environment*, 2024, **5**, 32, doi: 10.1038/s43247-024-01203-2.

[53] C. Künzer, J. Li, B. Yang, S. Dech, The Dynamics of Dongting Lake, China – a Yangtze River floodpath lake, Proceedings of the *34th International Symposium for remote Sensing of the Environment*, Sydney, Australia, 10-15 April 2011. https://elib.dlr.de/70386/

[54] Y. Long, R. Tang, C. Wu, C. Jiang, S. Hu, Estimating real-time water area of Dongting Lake using water level information, *Water*, 2019, **11**, 1240, doi: 10.3390/w11061240.

[55] Y. Zhu, H. Wang, W. Guo, The impacts of water level fluctuations of East Dongting Lake on habitat suitability of migratory birds, *Ecological Indicators*, 2021, **132**, 108277, doi: 10.1016/j.ecolind.2021.108277.

[56] J. Zhao, S. Liu, Z. Wang, H. Gao, S. Feng, B. Wei, Z. Hou, F. Xiao, L. Jing, X. Liao, The impact of land use and landscape pattern on ecosystem services in the Dongting Lake Region, China, *Remote Sensing*, 2023, **15**, 2228, doi: 10.3390/rs15092228.

[57] H. Zhen, C. Tang, S. Zhang, H. Wang, C. Wu, J. Sun, W. Liu, Exploring the vegetation changes in Poyang Lake wetlands: succession and key drivers over past 30 years, *Remote Sensing*, 2025, **17**, 1370, doi: 10.3390/rs17081370.

[58] S. Liu, X. Li, D. Chen, Y. Duan, H. Ji, L. Zhang, Q. Chai, X. Hu, Understanding Land use/Land cover dynamics and impacts of human activities in the Mekong Delta over the last 40 years, *Global Ecology and Conservation*, 2020, **22**, e00991, doi: 10.1016/j.gecco.2020.e00991.