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Quantifying the human wellbeing of the national wetland park: gross ecosystem product accounting of Shandong Mata Lake National Wetland Park

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National wetland parks, characterized by robust ecological functions, distinctive natural landscapes, and abundant cultural resources significantly enhance human wellbeing, serve as crucial providers of ecosystem products, and exert substantial influence on local socioeconomic development and ecological conservation. There is an urgent need to carry out the Gross Ecosystem Product (GEP) accounting and monetize the value of ecosystem products. Taking the Shandong Mata Lake National Wetland Park (SMTNWP) in China as the example, and considering the characteristics of wetland parks, this research constructed the GEP accounting index system comprising 11 secondary subjects from the perspectives of regulation and socio-cultural functions. Taking the year 2021 as the research period, the monetary value was assessed based on biophysical value accounting, and the GEP level was determined. The results showed that the GEP of SMTNWP in 2021 is CNY 74.8317 million, with a unit area GEP of 73,200 CNY/hm^2. Regulating ecosystem products constitute the core component of GEP, facilitating the sustainable development of wetland conservation and restoration, as well as eco-cultural tourism. Moving forward, efforts in wetland protection, restoration and maintenance should be sustained, and the platforms for promotion, education and scientific research should be proactively established. The research results can offer support and references for the establishment of unified accounting subjects and systems for similar ecosystems and national wetland parks, and translate the human wellbeing of national wetland parks into visual monetization, providing theoretical basis for the government to realize the value of ecosystem products, and further promoting the conversion of ecological value into economic benefits.

KEYWORDS

national wetland park, human wellbeing, gross ecosystem product (GEP), the Mata Lake, biophysical value, monetary value

1 Introduction

Since the Industrial Revolution, people's development of land resources has been continuously increasing, and the demand for ecosystem supply and service is excessive (Li, Y. and Xie, H., 2024). The importance of natural resource assets that provide ecosystem services, the accurate and detailed assessment of ecosystem service functions (Jiang and Dong, 2024), and the scientific and reasonable assessment of the contribution of ecosystems to people have become the focus of scholars' attention. Since the reform and opening up, China's urbanization and industrialization have developed rapidly, while the contradiction between humans and the natural ecological environment has gradually become prominent. Since the 18th CPC National Congress convened in 2012, China continues to promote the construction of ecological civilization, adhering to the ecological civilization ideology and concept of "clear waters and green mountains are as valuable as mountains of gold and silver." Ecosystem products refer to the goods and services provided by ecosystems and used for economic and other human activities (Hui et al., 2024). Gross Ecosystem Product (GEP, equivalent to the value of ecosystem products) accounting is an important task in evaluating the value of products or services that the ecological environment itself can provide for human and benefit humanity, and it measures the monetary value of products and services related to the ecosystem in a specific region during a certain accounting period (Zheng et al., 2023). GEP has become an accounting system that corresponds to Gross Domestic Product (GDP) and a new indicator for measuring total output, thereby better promoting the implementation of green development performance assessment and changing the economic and social development evaluation system that is solely dominated by GDP (Wang L. Y. et al., 2022).

In 2016, the Chinese Government issued *"the Guiding Opinions on the Reform of the System of Paid Use of Natural Resource Assets owned by the Whole People,"* which pointed out the need to carry out the inventory and accounting of natural resource assets owned by the whole people, and to clarify the quantity of natural resource assets owned by the whole people in China. In 2021, the Chinese Government issued *"the Opinions on Establishing and Improving the Mechanism for Realizing the Value of Ecosystem Products,"* which pointed out the need to evaluate the effectiveness of ecological protection and GEP, publish GEP accounting results, establish the GEP evaluation system, and explore GEP accounting methods for administrative and specific regional units. The implementation of the series of documents indicates that GEP accounting based on biophysical value and monetary value accounting is a necessity for realizing the value of ecosystem products, and the basis for ecological protection compensation and ecological environment damage compensation (Hui et al., 2024).

Wetlands are important natural resource assets and suppliers of ecosystem products, and the ecosystem services value of wetlands in China contributes the most to various ecosystems (Chen and Zhang, 2000), but there are also problems such as low conversion rate and low degree of marketization of wetland resource ecosystem products. It is urgent to protect, transform, and increase the value of wetland resource ecosystem products (Chen et al., 2023). National wetland parks have typical wetland ecological functions such as ecological environment restoration and living environment improvement, which can greatly satisfy people's demand for a better ecological environment and bring human wellbeing to the neighboring human beings. National wetland parks are also an important carrier for the development of cultural tourism industry and the provision of ecosystem products, which in turn have important impacts on the local socioeconomic development and ecological conservation. In August 2024, the Chinese Government issued the "*Implementation Opinions on Solidly Promoting the Construction of a Beautiful China through the Protection and Sustainable Utilization of Natural Resources*," proposing to promote the construction of national parks, improve the mechanism for realizing the value of ecosystem products, and enhance the ability of natural ecosystems to provide ecosystem products.

The concepts of "Ecosystem Product Value," "GEP," and "Gross Ecosystem Production" all originate from "Ecosystem Service Value (ESV)." In 2022, "*the Standard for the GEP Accounting (Trial)*" issued by the Chinese Government has defined the GEP refers to the sum of the monetary value of all ecosystem products provided by various ecosystems within a certain administrative region during the accounting period. At present, the academic community generally equates "Ecosystem Product Value," "GEP," "Gross Ecosystem Production," and "ESV," and the accounting indicator system mostly includes material product value, regulation service value, and cultural service value (Zhang et al., 2023).

In 1997, "*Nature's Services: Societal Dependence on Natural Ecosystems*" edited by Daily (Ouyang et al., 2013) and "*The Value of the World's Ecosystem Services and Natural Capital*" published by Costanza et al. (1997) became classic works, and the concept of ESV was proposed. The United Nations Millennium Ecosystem Assessment (MA) project aims to assess the relationship between ecosystem change and human wellbeing (Hui et al., 2024). "*The System of Environmental-Economic Accounting-Ecosystem Accounting 2012-Central Framework*" (*SEEA-EA 2012*) combines ecosystem accounting with economic accounting (Hui et al., 2024). Based on Costanza's unit value equivalent factor table in 1997 (Costanza et al., 1997) and combined with China's actual situation, Xie Gaodi, a Chinese scholar, has proposed the improved unit value equivalent factor table (Xie et al., 2008) to guide subsequent related research (Li X. K. et al., 2023).

At the academic research level, China started quantitative researches on ESV studies in the late 1990s. After the year 2012, relevant scholars (Ouyang et al., 2013) explored the concept, accounting methods, and applications of GEP. With the advancement of the national GEP accounting process, relevant research has accounted the GEP of different typical regions and ecosystems, such as typical soil desertification areas (Li, Y. Y. et al., 2023), typical reservoir areas (Cheng et al., 2024), Yangtze River Delta areas (Ji et al., 2024), and Beijing-Tianjin-Hebei region (Fan et al., 2024), which are national key strategic areas, and the research scale includes different regions such as global-level (Jiang et al., 2021), provincial-level (Hu et al., 2023; Ouyang et al., 2020), prefecture-level (Pema et al., 2017), and county-level (Shen et al., 2024; Li, Y.H. et al., 2024), as well as some specific wetland areas such as typical wetlands in large cities (Wang et al., 2024), urban scenic wetlands (Sun et al., 2024), and lake wetlands (Wang, F. et al., 2019). With the deepening of researches, current GEP research has

gradually expanded from value accounting to coupling and coordinating relationship with systems such as new urbanization (Zhang et al., 2024) and regional economy (Li, A. L. et al., 2024), exploring value realization paths and driving mechanisms (Gao and Zhu, 2024). At the practical level in various regions of China, Zhejiang Province, Shenzhen City, Wuyishan County and some other cities have carried out GEP accounting pilot exploration.

Based on scientific researches and local practice, national and local governments of China have formulated GEP accounting technical regulations. The Chinese Government issued the "*Technical Guidelines for the Accounting of Gross Ecosystem Product (GEP) of Terrestrial Ecosystems*" in 2020, and issued "*the Standard for the GEP Accounting (Trial)*" in 2022. In Shandong Province, Shenzhen City, etc., corresponding GEP accounting regulations have been formulated and issued based on their own actual conditions. The relevant regulations and guidance further improved the scientificity, normative approach and operability of GEP accounting results, promoting the verifiability and comparability of GEP accounting results.

In summary, current researches on GEP accounting focuses on different types of ecosystems, functional areas, and administrative regions at different scales, and the accounting subjects generally refer to relevant regulations and mostly focus on product supply services and ecological regulation services. However, Currently, GEP accounting researches are mostly carried out at the scale of administrative units, and GEP accounting cases based on national wetland parks as research units are relatively weak. Wetland parks, as important carriers of ecosystem products, have become a research gap in their GEP accounting, which cannot meet the urgent needs and practical exploration of GEP accounting for specific regional units. In previous studies, there were still some cases where the selection of evaluation indicators did not take into account the actual situation of the accounting area, the values of relevant accounting parameters were mechanically applied, and the accounting results did not conform to reality. In addition, the construction of national wetland parks also requires the provision of corresponding facilities for promotion, education and scientific research, and promotional materials, and the accounting index system should consider the value of promotion, education and scientific research. In addition, the management and operation of wetland parks require a certain amount of labor costs and require social labor to engage in relevant work, which can provide certain employment opportunities and generate certain social value. However, current accounting researches have relatively weak consideration for the values of social and cultural functions such as promotion, education and scientific research, and employment promotion, resulting in inaccurate value accounting results.

Conducting research on the GEP accounting of national wetland parks, constructing the GEP accounting system for national wetland parks, exploring suitable accounting methods and data sources, and applying accounting results reasonably can not only improve the GEP accounting system and methods for specific regional units, but also explore the role of national wetland parks in socioeconomic development and ecological conservation, expand the value realization models of wetland parks such as franchising, realize the economic and market-oriented development of ecosystem products, and assist the government in building the green performance concept that integrates ecological protection, restoration, and management, and plays an important role in providing theoretical support and practical basis for exploring the value realization mechanism of GEP in national wetland parks.

Shandong Mata Lake National Wetland Park (SMTNWP), as a national ecological civilization demonstration zone of China, has a rich variety of ecosystem product types, and it is significant to clarify various ecosystem types and distribution status in the region, study and construct the GEP accounting index system for SMTNWP, determine accounting models, methods and parameters, completes ecosystem product value accounting based on biophysical value and monetary value accounting, calculate the GEP of SMTNWP, and attach the "price tag" to ecosystem products, which can provide references for exploring new paths for promoting the management and development of public and commercial ecosystem products in SMTNWP, and is of great significance for realizing the value of ecosystem products, building the unified accounting subject and system, selecting suitable evaluation methods, models and parameters for similar ecosystems, similar regions and other wetland parks in GEP accounting practice, and translating the human wellbeing of national wetland parks into quantifiable and visualized monetary value.

2 Overview of the study area and data sources

2.1 Overview of the study area

2.1.1 Natural resources conditions

SMTNWP (118°2′56.65″-118°6′47.34″E, 37°3′56.46″-37°5′37.66″N) is a scenic area of AAA level in China, located in Qifeng Town, northeast of Huantai County, Zibo City (see Figure 1). The total area of SMTNWP spans 1,021.78 ha, with a north-south span of 3.13 km and an east-west span of 5.74 km, and is part of the Xiaoqing River system in the Yellow River Basin. The overall terrain of SMTNWP is relatively flat, with fertile soil. SMTNWP receives ample sunshine, and exhibits significant seasonal variations in precipitation. Specifically, the rainfall is the most concentrated from July to October, and the dry and abundant season is more obvious. The ecosystem pattern of SMTNWP is dominated by the wetland ecosystem, with relatively rich animal and plant resources, complex plant species and high diversity.

2.1.2 Development and utilization status

SMTNWP is an important wetland and lake ecosystem in the inland regions of Shandong Province, and is one of the top ten key ecological function protection areas in Shandong Province. The park features reed marshes and lotus ponds, and along with rich cultural relics such as the Five Sages Temple, Xu Ye Bookstore, Iceberg Site, Huicheng Site, Lulian Well, and Jinqiu Pavilion in SMTNWP. The unique natural landscapes contribute to diverse cultural landscapes and folk characteristics. SMTNWP focuses on the protection and restoration of wetland ecosystems and biological habitats, adhering to the fundamental principles of "protection priority, scientific restoration, rational utilization, and sustainable development." It carries out construction projects such as protection engineering, restoration engineering, promotion, education and scientific Research,

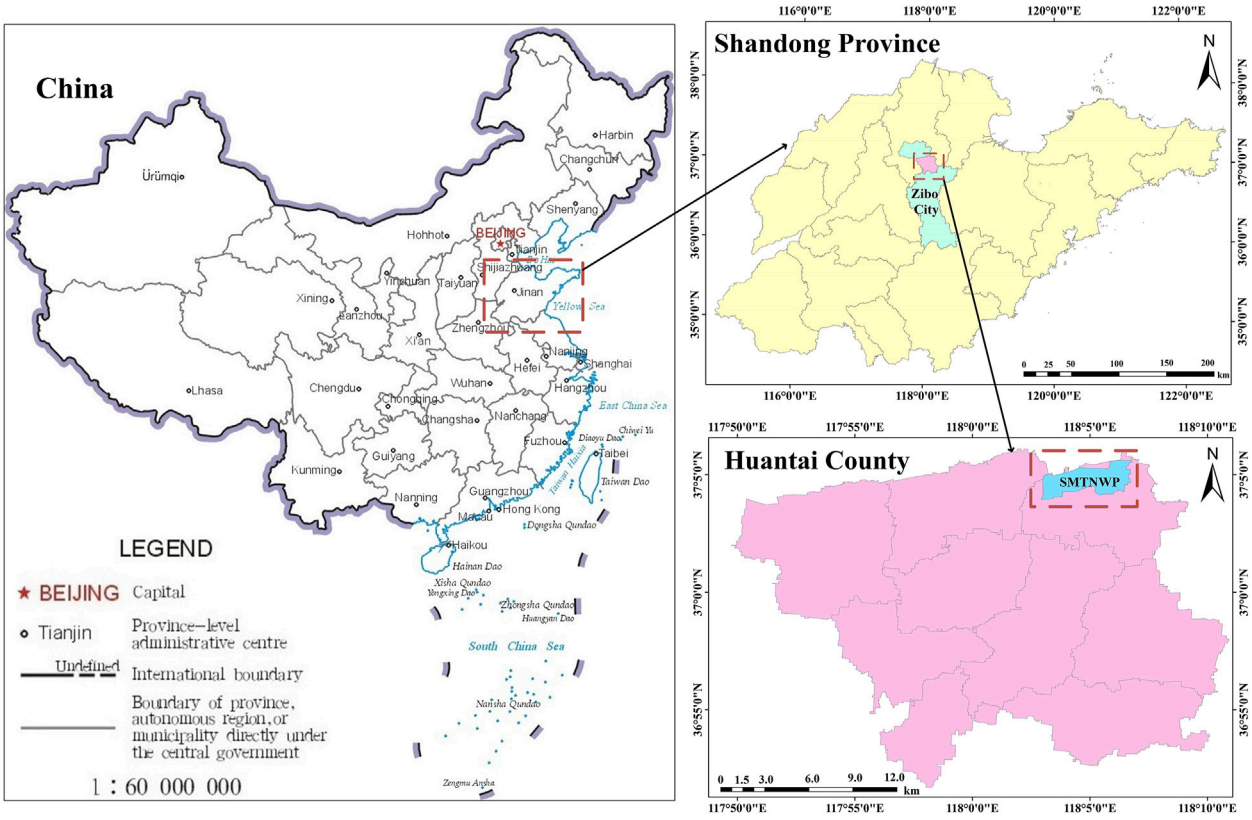

FIGURE 1
Overview of the study area (where the map of China on the left is a standard map, downloaded from the Standard Map Service System of the Ministry of Natural Resources, PRC, http://bzdt.ch.mnr.gov.cn/index.html).

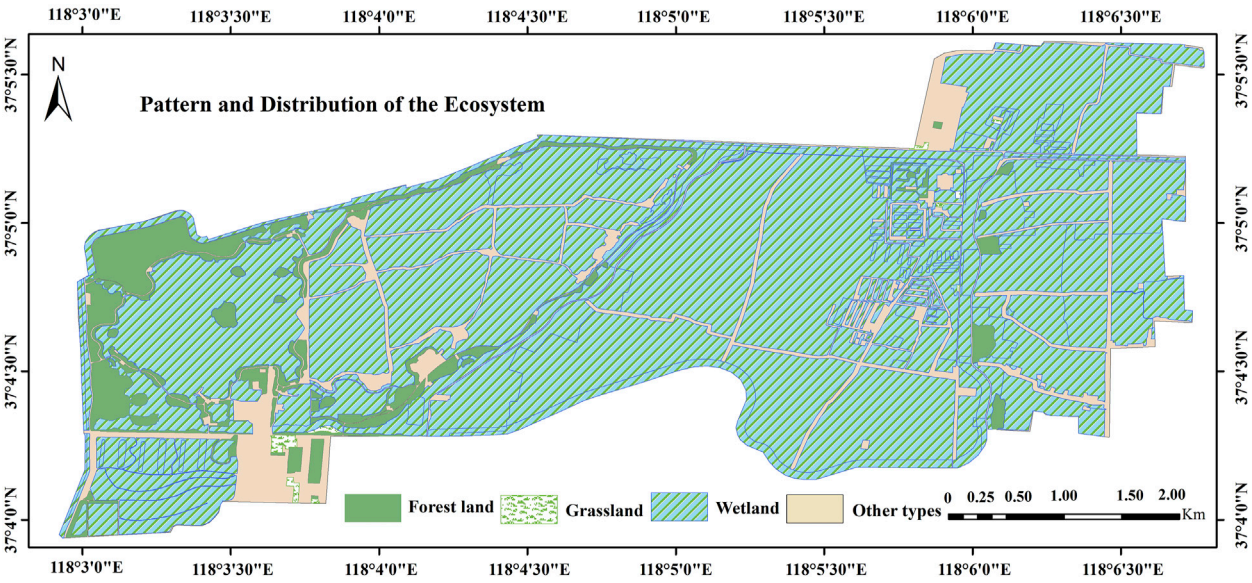

FIGURE 2
Spatial pattern of ecosystem in SMTNWP.

TABLE 1 Statistics of spatial pattern of ecosystem in SMTNWP.

Ecosystem category	Types of land use included	Area (hm^2)	Percent (%)
Grassland	Other grassland	2.78	0.27
Forest land	Other forest land	71.59	7.01
Wetland	River water surface	72.36	7.08
	Pond water surface	150.61	14.74
	Inland mudflat	613.43	60.03
Others	Other types of land use	111.02	10.87
Sum		1,021.78	100.00

infrastructure and service facilities, fully tapping into the natural and cultural landscape of SMTNWP, developing wetland ecological and cultural tourism, and attracting numerous tourists during its operation. In August 2015, SMTNWP became a member of the Yellow River Basin Wetland Protection Network. Currently, SMTNWP has been designated as the national wetland park, the national agricultural tourism demonstration site, the national water conservancy scenic area, the national ecological civilization demonstration area, the provincial-level scenic spot, the provincial-level geological park, and one of the first excellent cases of "Beautiful Rivers and Lakes" in China.

2.1.3 Spatial pattern of ecosystem

The ecosystem of SMTNWP encompasses grassland, forest land, wetland, and other types (see Figure 2; Table 1), among which the wetland ecosystem accounts for the largest proportion, with an area of 836.39 hm^2, which represents over 80% of the total area, and the inland mudflat and ponds account for a large proportion, forming an important wetland lake ecosystem. The forest ecosystem is mainly distributed in the northwest of the park, while the grassland ecosystem is mainly distributed in the southwest of the park, with sporadic distribution in the northeast. SMTNWP plays an important role in conserving regional water sources, purifying water quality, regulating regional microclimates, protecting regional ecological stability, and diluting atmospheric pollutants, in addition, it also attracts many tourists to relax, playing important natural, ecological, and social functions. Consequently, the rich and diverse ecosystem within the park provides a wide range of ecosystem services, including conservation of water sources, pollutant purification, carbon dioxide fixation and oxygen release, soil conservation, temperature regulation, flood regulation and storage, leisure and recreation, playing a significant role in ecosystem services and generating substantial potential ESV.

2.2 Data and sources

Land use data, including ecosystem spatial pattern data, are from the Natural Resources and Planning Bureau of Zibo City and the Natural Resources and Planning Bureau of Huantai County.

Meteorological data, including annual precipitation, monthly precipitation, temperature and rainstorm in the region, are from Meteorological Bureau of Huantai County, Statistics Bureau of Huantai County, National Climate Data Center (NCDC), Shandong Mata Lake Wetland Conservation Center, Shandong Mata Lake Tourism Development Co., Ltd., etc.

Field investigation data, including crown density, average depth of reservoirs, slope, expenditure on educational activities, number of tourists, ticket revenue, number of park employees and salary levels, are obtained from field research and interviews with the Shandong Mata Lake Wetland Conservation Center and Shandong Mata Lake Tourism Development Co., Ltd.

Data selected for biophysical value evaluation parameters, including pollutant purification model, carbon fixation mechanism model, oxygen release mechanism model, water quantity balance method, flood regulation and storage model, and Revised Universal Soil Loss Equation (RUSLE) used in biophysical value evaluation. The above models and methods required data including purification amount per unit area of various atmospheric and water pollutants by different ecosystems, carbon fixation rate of ecosystems, surface runoff coefficient of various ecosystems, daily rainstorm standard, rainstorm runoff regression equation of different ecosystems, soil erodibility factor and other relevant parameters. The values for these parameters are derived from the GEP accounting regulations and guidelines issued by China's national and local governments, such as the "*the Standard for the GEP Accounting (Trial)*," "*the Technical Specification for Gross Ecosystem Product (GEP) Accounting of Shandong Province of Terrestrial Ecosystem (Trial)*," "*the Technical Guidelines for the Accounting of Gross Ecosystem Product (GEP) of Terrestrial Ecosystems*," "*the Guidelines for Soil Loss Calculation of Production and Construction Projects (SL773-2018)*," and relevant literature.

Data selected for monetary value accounting parameters, including the values of pollutant treatment costs required for partial value accounting, carbon dioxide market prices, industrial oxygen production prices, reservoir unit capacity engineering costs, reservoir unit dredging engineering costs, sediment deposition coefficient, soil bulk density, and conversion coefficients for soil conservation nutrients (nitrogen, phosphorus, potassium) to urea, superphosphate, potassium chloride, etc. refer to relevant regulations such as "*the Technical Guidelines for the Accounting of Gross Ecosystem Product (GEP) of Terrestrial Ecosystems*" and literature.

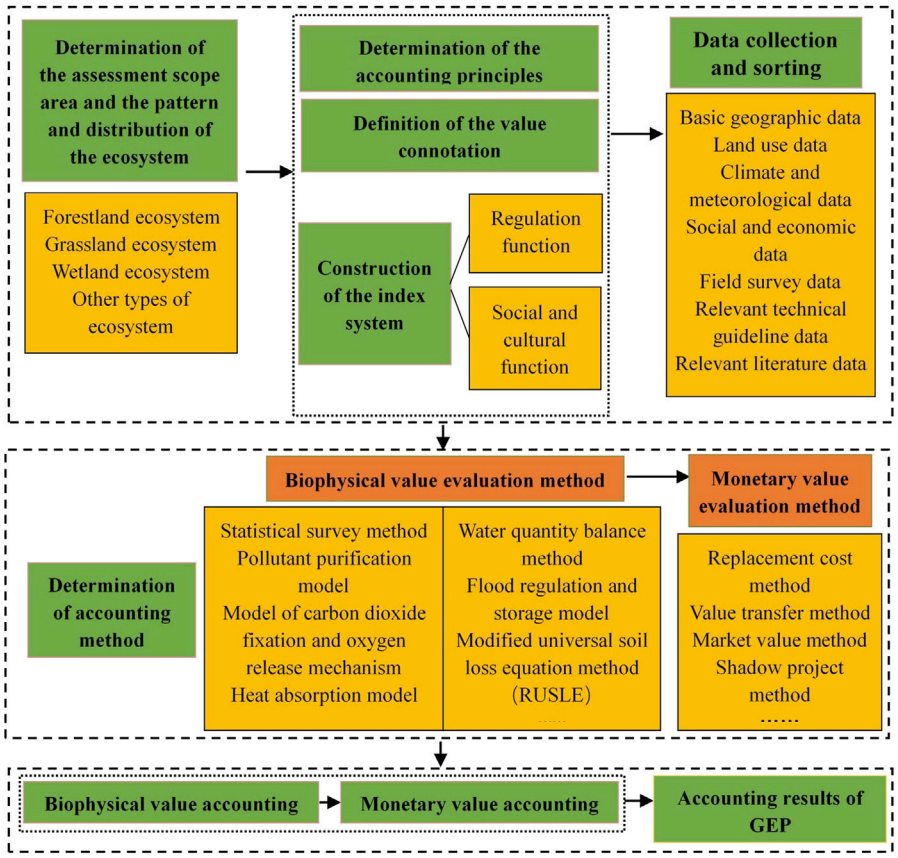

FIGURE 3
GEP accounting approach of SMTNWP.

Other data, including socio-economic data, major soil types, local electricity prices, prices of fertilizers such as urea, superphosphate, and potassium chloride, and prices of organic fertilizers, are primarily sourced from the Statistical Yearbook of Zibo City, Statistical Yearbook of Huantai County, Statistics Bureau of Huantai County, and the official website of Huantai County People's Government (http://www.huantai.gov.cn/art/2015/8/19/art_4883_928665.htm), State Grid Shandong Electric Power Company Huantai County Power Supply Company, and the website of China Report Hall (https://www.chinabgao.com/).

3 Research methods

3.1 GEP accounting approach

Firstly, determine the scope of the evaluation area and the ecosystem pattern, clarify the accounting principles, define the value connotation, construct the indicator system, and collect and organize data. The spatial scope for GEP accounting of the study is defined as SMTNWP, which encompasses an evaluation area of 1,021.78 hm^2 comprising ecosystems such as grasslands, forests, and wetlands. According to the needs of accounting, determine the accounting principles, define the timing and period of the calculated value, and clarify the connotation of the calculated value. Construct the accounting indicator system, and determine accounting subjects from the aspects of regulation function, and social and cultural function. Collect the necessary data for research in order to select appropriate localization accounting parameters.

Then, determine the methods for biophysical and monetary value evaluation. Select reasonable biophysical value accounting methods and parameters, and use models and methods including statistical survey methods, pollutant purification models, carbon dioxide fixation and oxygen release mechanism models, heat absorption models, water quantity balance methods, flood regulation and storage model, and RUSLE to evaluate the biophysical value of ecosystem products and services. Then, select reasonable value accounting methods and parameters, and use ecological economic evaluation methods such as replacement cost method, value transfer method, market value method, and shadow project method to account for the monetary value of ecosystem products and services.

Finally, calculate the GEP of SMTNWP. Calculate the biophysical value of ecosystem products and services of SMTNWP, and then calculate the monetary value based on the biophysical value accounting results, and analyze the calculation results.

The GEP accounting approach of SMTNWP is shown in Figure 3.

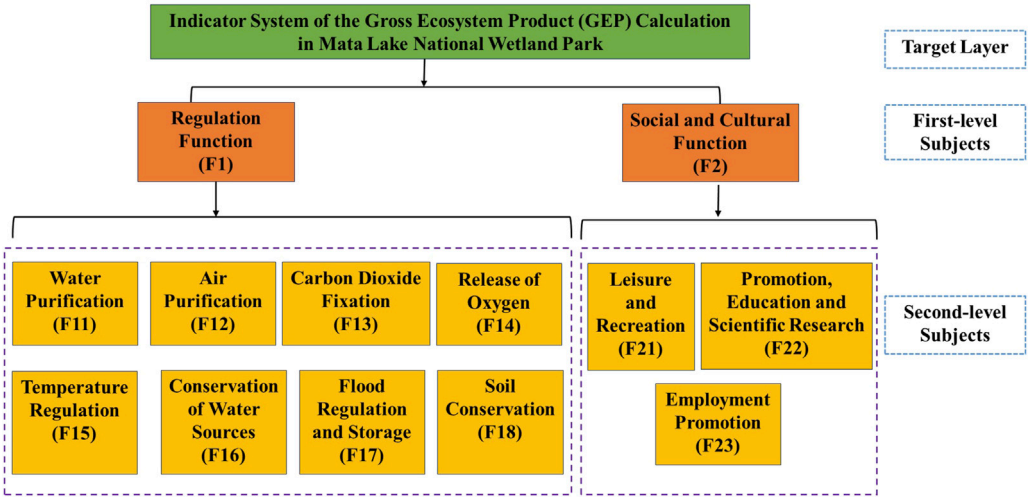

FIGURE 4
GEP accounting index system of SMTNWP.

3.2 Construction of accounting indicator system

National wetland parks, wetland nature reserves, protected communities, wetland wildlife habitats, and wetland multi-purpose management areas jointly constitute the wetland protection and management system. Different from the general meaning of protected areas, national wetland parks refer to wetland areas with wetland landscapes as the main body, wetland ecosystem protection and restoration as the core, and taking into account promotion, education and scientific research, ecological tourism and other activities of wetland ecosystem, and they contain certain cultural and aesthetic values and are artificially protected and managed, so their connotation is richer than that of general protected areas. As a result, national wetland parks not only provide supply and regulation value for wetland ecosystems, but also offer cultural values such as leisure and recreation, and promotion, education and scientific research. Additionally, the operation, maintenance and management of national wetland parks can also provide employment opportunities and generate certain social value.

SMTNWP has geological and geomorphological relics such as lakes, swamps, gullies, and hilly areas, as well as various natural ecological landscapes such as hydrology, celestial phenomena, reed marshes, lotus ponds, and bird habitats. The natural landscape is unique, the biodiversity is rich, and it has the charm of fishermen and historical and cultural relics. It integrates natural scenery, water landscape, historical sites, architectural sites, and water town charm. Therefore, it has important regulation, and social and cultural functions. Considering that SMTNWP is currently a profitable ecotourism park with limited material resources, the supply service function is not currently being considered.

On the basis of the systematic review of more than 10 GEP accounting technical specifications and guidelines issued in China and various cities both within and outside Shandong Province, this study follows the principles of objectivity, scientificity, practicability, systemization, step by step, based on exchange value, openness, etc., and comprehensively considers the consensus degree of accounting subjects to construct the GEP accounting index system of SMTNWP (see Figure 4). Due to SMTNWP being a wetland park, mainly consisting of grasslands, forests, and wetlands, ecological functions closely related to grasslands, forests, and wetlands were selected as the secondary accounting subjects for regulation functions. Considering that SMTNWP has carried out promotion, education and scientific research, and eco-tourism activities related to wetland ecosystems, providing certain employment opportunities, so the leisure and recreation indicators, etc., have been selected as the corresponding secondary accounting subjects for social and cultural functions. The final accounting index system consists of two first-level subjects of regulation function, and Social and cultural function, and 11 second-level subjects such as water purification, air purification, etc. The index system aims to reflect the real, specific and relatively stable value of the functional attributes of each ecosystem in the study area, and defines the connotation of each second-level accounting subject (see Table 2).

3.3 Determination of biophysical and monetary value accounting indicators

Based on the construction of first-level and second-level subjects, clarify the biophysical and monetary value accounting indicators and their units for GEP accounting of SMTNWP (see Table 3).

4 Accounting methods and result analysis

4.1 Accounting methods

4.1.1 Definition of GEP connotation

In the study, the GEP accounting period of SMTNWP is 2021, with a cycle of 1 year. The GEP connotation refers to the total value of various final products and services provided by various ecosystems within SMTNWP for human wellbeing and sustainable economic and

TABLE 2 Definition of GEP accounting subject connotations based on human wellbeing of SMTNWP.

Second-level Subjects		Connotation
F11	Water Purification	Wetland ecosystems including rivers, lakes, and swamps absorb, degrade, biologically transform, and transform water pollutants through physical and biochemical processes, thereby reducing the concentration of water pollutants and purifying the water environment (Wu et al., 2020)
F12	Air Purification	Ecological systems, such as forests, grasslands, and wetlands absorb, filter, block, and decompose atmospheric pollutants, thereby reducing the concentration of air pollutants, and enhancing air quality (Kong et al., 2023)
F13	Carbon Dioxide Fixation	Forests, grasslands, wetlands, and other ecosystems utilize organisms to synthesize organic matter from carbon dioxide or dissolve carbon dioxide in water bodies, thereby reducing concentration of carbon dioxide in the atmosphere (Wang, J. M. et al., 2019)
F14	Release of Oxygen	Forests, grasslands, wetlands, and other ecosystems release oxygen through plant photosynthesis, to maintain stable oxygen concentration in the atmosphere (Wang, J. M. et al., 2019)
F15	Temperature Regulation	Ecosystems such as forests and grasslands absorb energy through vegetation transpiration, occlusion, and evaporation, thereby regulating temperature and enhancing the comfort of human living environments (Zhao et al., 2019)
F16	Conservation of Water Sources	Ecosystems such as forests, grasslands, and wetlands intercept and store precipitation, enhance soil infiltration and accumulation, thereby achieving the goal of conserving soil moisture, replenishing groundwater, regulating surface runoff and river flow, and effectively redistributing precipitation (Hu et al., 2021)
F17	Flood Regulation and Storage	Forests, grasslands, reservoirs, lakes, and other ecosystems absorb and store precipitation, regulate stormwater runoff, reduce flood peak during rainstorm, to mitigate the threat and loss caused by flood peak in flood season and mitigate flood hazards (Ping and Zeng, 2023)
F18	Soil Conservation	Ecosystems such as forests and grasslands slow down the erosion of topsoil by rainwater, and increase soil resistance by retaining soil through root systems, thereby reducing sedimentation and soil loss, and maintaining soil nutrients (Wang W. J. et al., 2022)
F21	Leisure and Recreation	Wetland parks provide services such as recreation, sightseeing, entertainment, and landscape appreciation, allowing visitors to relax mentally and achieve non-material benefits such as emotional pleasure (Liu et al., 2023)
F22	Promotion, Education and Scientific Research	Wetland parks provide public education and promotion of wetland functions and values to the public, while universities and research institutions can conduct comprehensive studies on wetland ecology, and provide venues and services for educational and scientific research activities (Liu et al., 2023)
F23	Employment Promotion	Wetland parks require social labor for their daily management and operation, providing employment opportunities for relevant groups (Li et al., 2020)

social development in 2021, including the monetary value of natural elements and final services provided by various ecosystems such as grasslands, forests, and wetlands in the region related to their regulatory and socio-cultural functions. The GEP accounting process involves both biophysical and monetary value assessments.

4.1.2 Biophysical value accounting methods

4.1.2.1 Biophysical value of regulation function accounting methods

The wetland ecosystem area of SMTNWP comprises more than 80% of the total park area, and can play a role in adsorbing, degrading, and converting water pollutants such as COD, total nitrogen, and total phosphorus. This study calculates the water purification capacity of the ecosystem to characterize the amount of pollutants purified by the wetland ecosystem.

The ecosystems of SMTNWP, including grassland, forest, and wetland comprise nearly 90% of the entire park, and can absorb, filter, block, decompose, and reduce atmospheric pollutants such as SO_2, NO_2, and dust, playing a role in air purification. This study calculates the air purification capacity of ecosystems to characterize the amount of pollutants purified by ecosystems.

The ecosystems of SMTNWP, including forest, grassland, and wetland utilize photosynthesis to absorb carbon dioxide and mitigate greenhouse effects. This study quantifies the total amount of carbon dioxide fixation through the carbon sequestration mechanism model.

Plant photosynthesis facilitates the release of 1 mol of O_2 for every 1 mol of CO_2 absorbed. SMTNWP is abundant in plant resources, enabling significant oxygen release, which is beneficial for maintaining the stability of oxygen in the atmosphere and improving the living environment. This study calculates total amount of oxygen supply through the oxygen release mechanism model.

The ecosystems of SMTNWP, including forest and grassland absorb solar energy through transpiration and evaporation to regulate temperature and improve living environment comfort. This study calculates the total heat absorbed by ecosystems through the heat absorption model.

The ecosystems of SMTNWP, including forest, grassland, and wetland can conserve soil moisture, regulate rainstorm runoff, supplement groundwater, supplement water resources, and play the role of water conservation. This study uses the water quantity balance method and flood regulation model to separately calculate the flood regulation and storage capacity of vegetation, reservoirs, and rivers and lakes.

The forests and grasslands of SMTNWP can reduce soil erosion and sediment deposition through the role of ecosystems, while maintaining soil nutrients and playing a role in soil conservation.

TABLE 3 Biophysical and monetary value accounting indicators and units of SMTNWP's GEP.

First-level subjects	Second-level subjects	Biophysical value indicators		Monetary value indicators	
		Indicator description	Unit	Indicator description	Unit
F1	F11	Total amount of COD, total phosphorus, and total nitrogen for purifying water pollutants	t/a	Water purification value	CNY
	F12	Total amount of SO_2, NO_2, and dust for purifying air pollutants	t/a	Air purification value	
	F13	Total amount of carbon dioxide fixation	t·CO_2/a	Carbon dioxide fixation value	
	F14	Total amount of oxygen supply	t·O_2/a	Oxygen release value	
	F15	The total heat absorbed by ecosystems	kW·h	Temperature regulation value	
	F16	Total amount of water sources conservation	m^3/a	Conservation of water sources value	
	F17	Total amount of flood regulation and storage	m^3/a	Flood regulation and storage value	
	F18	Total amount of ecosystem's soil conservation	t/a	Sediment accumulation reduction value	
				Soil fertility preservation value	
F2	F21	Total amount of leisure and recreation personnel	person/a	Leisure and recreation value	
	F22	Activities carried out for promotion, education and scientific research	—	Promotion, education and scientific research value	
	F23	The total number of social labor engaged in wetland park related work	person/a	Employment promotion value	

This study uses the RUSLE method to calculate biophysical value of soil conservation function.

The accounting methods of the biophysical value of regulation functions are shown in Supplementary Table S1.

4.1.2.2 Biophysical value of social and cultural function accounting methods

4.1.2.2.1 Biophysical value accounting of leisure and recreation function. SMTNWP not only boasts a unique ecological and geographical environment, but also possesses a rich historical and cultural heritage, wetland landscapes, and cultural resources. According to surveys, there are more than 2,100 boat lanes of various sizes in the lake area of the park, interconnected both vertically and horizontally, forming a complex network. There are 30 bridges of different shapes and colors, 7 pavilions, 5 islands in the lake, 16 docks, and 10 boardwalks. The ecological and cultural landscapes have attracted many tourists to visit and have certain leisure and recreational functions. This study uses the total number of leisure and recreation people in the accounting year, namely the park pedestrian flow (ESQ_9), as the biophysical value accounting indicator of leisure and recreation function, and it was about 740,000 people in the year 2021.

4.1.2.2.2 Biophysical value accounting of promotion, education and scientific research function. SMTNWP has also carried out multiple publicity and popularization activities on wetland functions and values for the public, providing a comprehensive knowledge research and practical platform for wetland ecology for college students, and has certain promotion, education and scientific research functions.

4.1.2.2.3 Biophysical value accounting of employment promotion function. SMTNWP provides employment opportunities for surrounding residents through its daily management and operation process, and thereby promoting local employment. This study employs the number of social laborers engaged in related work of the wetland park throughout the accounting year (ESQ_{11}) as biophysical value accounting indicator of employment promotion function. In 2021, there were 67 social laborers engaged in related work of the wetland park.

The above data related to the biophysical value accounting of social and cultural function are all collected from on-site data by the Shandong Mata Lake Wetland Conservation Center and Shandong Mata Lake Tourism Development Co., Ltd.

4.1.3 Monetary value accounting methods

Based on biophysical value accounting, ecological economics methods, including replacement cost method, value transfer method, market value method, and shadow project method are employed to assess the monetary value of the regulation function, and statistical survey method, travel expense method, and other methods are used to calculate the monetary value of social and cultural function (see Supplementary Table S2).

4.2 Analysis of accounting results

4.2.1 Comprehensive analysis of GEP total value

The monetary value accounting for was conducted based on the biophysical value accounting of various ecological functions of SMTNWP in 2021, and subsequently, the proportion of the value

TABLE 4 Biophysical and monetary value accounting results of various ecosystem products in SMTNWP.

First-level Subjects	Second-level Subjects	Biophysical Value Indicators	Biophysical Value	Monetary Value Indicators	Monetary Value (×10^4 CNY)	Percent (%)	Total Monetary Value (×10^4 CNY)	Total proportion (%)
F1	F11	COD purification capacity/(t/a)	923.63	COD purification	480.29	6.42	587.68	7.85
		Total phosphorus purification capacity/(t/a)	71.59	Total phosphorus purification	35.80	0.48		
		Total nitrogen purification capacity/(t/a)	71.59	Total nitrogen purification	71.59	0.96		
	F12	SO_2 purification capacity/(t/a)	61.55	SO_2 purification	18.47	0.25	20.70	0.28
		NO_2 purification capacity/(t/a)	1.73	NO_2 purification	0.69	0.01		
		Dust purification capacity/(t/a)	90.56	Dust purification	1.54	0.02		
	F13	Total amount of carbon dioxide fixation/(t/a)	2098.81	Carbon dioxide fixation	12.42	0.17	12.42	0.17
	F14	Total amount of oxygen supply/(t/a)	1,526.41	Oxygen release	152.64	2.04	152.64	2.04
	F15	Total heat absorbed by ecosystems/(kW·h)	319,522.19	Temperature regulation	17.47	0.23	17.47	0.23
	F16	Total water sources conservation capacity/ (×10^4 m^3/a)	198.04	Conservation of water sources	1,210.14	16.17	1,210.14	16.17
	F17	Total flood regulation and storage capacity/ (×10^4 m^3/a)	600.21	Flood regulation and storage	3,667.68	49.01	3,667.68	49.01
	F18	Total ecosystem's soil conservation capacity/(t/a)	9,211.83	Sediment accumulation reduction	2.99	0.04	143.15	1.91
				Soil fertility preservation	140.16	1.87		
F2	F21	Total amount of leisure and recreation personnel/ (×10^4 person/a)	74.00	Leisure and recreation	968.73	12.95	968.73	12.95
	F22	Activities carried out for promotion, education and scientific research	—	Promotion, education and scientific research	166.56	2.23	166.56	2.23
	F23	Total number of social labor engaged in wetland park related work/ (person/a)	67.00	Employment promotion	536.00	7.16	536.00	7.16
Total					7,483.17	100.00	7,483.17	100.00

of each second-level subject to the total GEP value was calculated (see Table 4). It is evident that in 2021, SMTNWP fully realized its regulation and socio-cultural functions of ecosystem products, with a total GEP of CNY 74.8317 million and a unit area GEP of 73,200 CNY/hm^2. Specifically, the value of regulation function, and social and cultural function were CNY 58.1188 and 16.7129 million, respectively.

The ranking of the value of first-level subjects in GEP accounting is as follows: regulation function > social and cultural function. The ranking of the value of second-level subjects in GEP accounting is as follows: flood regulation and storage > conservation of water sources > leisure and recreation > water purification > employment promotion > promotion, education, and scientific research > release of oxygen > soil conservation > air purification > temperature regulation > carbon dioxide fixation. From the perspective of some lowest-level indicators, in terms of water purification function, the ranking of the value is as follows: the purification of COD > the purification of total nitrogen > the purification of total phosphorus water pollutants; in terms of air purification function, the ranking of the value is as follows: the purification of SO_2 > the purification of dust > the purification of NO_2; in terms of soil conservation function, the ranking of the value is as follows: the maintaining of soil fertility > the reducing of sediment deposition.

Overall, the flood regulation and storage function holds the highest value, accounting for nearly 50%; the values of conservation of water sources, and leisure and recreation are both relatively high, each exceeding 10% of the total; the values of promotion, education and scientific research, release of oxygen, and soil conservation are average, with significant room for improvement; the values of air purification, temperature regulation, and carbon dioxide fixation are relatively low, offering the greatest potential for exploration.

In recent years, SMTNWP has intensified its investment in technology and engineering. By implementing water system connectivity projects, dredging of the river channel, and seasonal diversion of the Yellow River project, the water use of wetlands in the park have been effectively regulated, ensuring abundant water supply throughout the year and enhancing the function of the conservation of water sources. By implementing sewage control and interception projects, and the artificial wetland project such as artificial wetlands at the entrance of Zhulong River and Wuhe River, and based on the existing natural wetlands, the SMTNWP has aimed to improve the biodiversity and system stability of the wetland ecosystem through ecological restoration or moderate artificial reinforcement measures, enhance the level of water purification function, and sewage has been turned into "treasures." The projects not only ensured the daily supply of water to the wetlands in the park, but also improved water quality and enhanced the water resources situation. In addition, the constructions of vegetation restoration projects and bird habitat improvement projects have made the regional microclimate in the park increasingly prominent, and the temperature regulation function has become more prominent. The increase in the number of wild animals and plants, particularly bird populations, has not only created a high-quality environment for their growth and reproduction, but also transformed the park into a wintering ground and migration hub for various bird species.

"The Overall Plan of Shandong Mata Lake National Wetland Park" proposes to carry out the construction of wetland promotion, education and exhibition facilities and activities, to show the natural landscape, cultural landscape, wetland culture, and wetland functions of SMTNWP to the public. The plan includes constructing the Mata Lake Wetland Experience Hall, Reed Sculpture Garden, Artificial Wetland Water Purification Exhibition Area, Wetland Resources Exhibition Area, Bird Watching Pavilion and other facilities. The construction of these facilities will not only promote wetland education, but also attract more tourists to come and watch, enhancing the value of leisure, and recreation, and promotion, education and scientific research. At present, SMTNWP is conducting scientific research cooperation with some universities in Shandong Province. The university research teams has taken SMTNWP as the study area to investigate and study wetland soil, hydrology, water quality, wildlife and plants, aquatic organisms, and other wetland resources. Researches on the planting of aquatic plants in artificial wetlands is carried out, and plans are proposed to establish wetland water quality monitoring points, plant observation points, bird observation points, management centers, comprehensive monitoring rooms, research centers, etc. The above constructions of wetland monitoring facilities are conducive to enhancing the value of promotion, education and scientific research.

It is evident that after years of implementing a series of wetland protection, restoration technologies and engineering measures in the park, as well as investing in publicity, education, scientific research and service facilities projects, the ecosystem functions and ecological environment of SMTNWP have been significantly optimized. The value of social and cultural function, including leisure and recreation, promotion, education and scientific research, and employment promotion has also been fully demonstrated, and especially the value of regulating ecosystem products has been fully realized. Due to the decrease in the number of tourism and employment during the COVID-19 epidemic in 2021, the value of social and cultural function accounting is not high. Wetland protection and economic development need to be coordinated. The development of tourism formats and the increase in the number of tourists will bring challenges to wetland ecosystem protection and rational utilization of wetland resources. Balancing economic and social development and sustainable utilization of wetlands, and balancing regulation function and enhancement of social and cultural function value represented by leisure and recreation function are of great significance to promote the GEP enhancement and value realization of SMTNWP.

4.2.2 Analysis of each GEP value component

4.2.2.1 Analysis of regulation function value

The value of SMTNWP's regulation function ecosystem products is CNY 58.1188 million, accounting for 84.91% of the total GEP. The main value components are values of flood regulation and storage, and conservation of water sources, which are CNY 36.6768 million and 12.1014 million, respectively, accounting for 49.01% and 16.17% of the total GEP. The wetland ecosystem of the park covers an area of 836.39 hm^2, accounting for more than 80%. There are also grassland, woodland and other types of ecosystems, which rely on its unique hydrological and physical properties, the park absorbs and accumulates precipitation during rainstorm, mitigating potential flood peak losses, and can also regulate storm runoff, reduce flood peak, mitigate flood hazards, conserve

water and increase available water resources. At the same time, ecosystems such as forests and grasslands also account for a large proportion in SMTNWP, and they rely on the structure and processes of the canopy layer, litter layer, root system, and soil layer to intercept and store precipitation, enhance soil infiltration and accumulation, conserve soil moisture, supplement groundwater, fully regulate surface runoff and river discharge, play the function of accumulation and redistribution of precipitation, and also alleviate the threat and loss caused by flood peaks during the flood season, reduce flood hazards, and effectively play the ecological regulatory role of precipitation accumulation and redistribution. In addition, the abundant water resources of SMTNWP enable the full adsorption, degradation, biological absorption or transformation of water pollutants such as COD, total nitrogen, and total phosphorus, reducing pollutant concentrations and purifying the water environment, playing an important role in water quality purification, especially in purifying COD. Therefore, the value of COD purification is also significant.

However, other ecosystem products of regulation function such as air purification, carbon sequestration, oxygen release, temperature regulation, and soil conservation have also improved local microclimates, optimized the air environment, and enhanced the comfort of the park environment. However, the value of their ecosystem products is not relatively high, and their effectiveness requires further enhancement. Affected by factors such as increased use of fertilizers and pesticides on surrounding farmland and increased human activities in cities, the water quality and ecological environment of SMTNWP need to be protected, and pollution control should be the key focus. Otherwise, it will affect the enhancement of the functional values such as air purification, carbon dioxide sequestration, and release of oxygen.

4.2.2.2 Analysis of social and cultural function value

The value of social and cultural ecosystem products is CNY 16.7129 million, accounting for 15.09% of the total. The primary components are the values of leisure and recreation, and employment promotion, which are CNY 9.6873 million and 5.36 million respectively, representing 12.95% and 7.16% of the total GEP. Leisure and recreation are important cultural and ecosystem products of SMTNWP. The SMTNWP boasts a unique ecological environment, advantageous geographical location, and a rich historical and cultural heritage, featuring diverse wetland landscapes and cultural resources. There are numerous boat lanes of different sizes in the lakes of the park, connected vertically and horizontally, interweaving into a network. There are also bridges, pavilions, islands in the lake, docks, and boardwalks of various shapes and colors, with "Jiangnan in the North" as the tourism feature. The lake water in the park is rippling with blue waves, and plant landscapes such as reed marshes, lotus ponds, roadside lotus trees, and willows are distributed, and the poetic and wild charm is strong, and the rich cultural relics such as the Five Sages Temple, Xu Ye Bookstore, and Iceberg Site in the park enhance the cultural heritage. Ecotourism is conducted with a focus on natural ecology and regional cultural characteristics. Adhering to the principles of environmental protection and sustainable development. While ensuring ecological benefits, it also creates huge economic benefits and plays a significant role in value generation. In addition, SMTNWP is operated and managed by Shandong Mata Lake Tourism Development Co., Ltd., providing employment opportunities such as promotion, planning and tourism service management for surrounding residents, increasing employment opportunities for residents, maintaining social stability, and playing a certain social function. However, affected by the COVID-19 in the year 2021, the number of tourists and employees has decreased, the value of ecosystem products for leisure and recreation, and employment promotion was relatively low, and the value of social and cultural function still have greater room for improvement.

SMTNWP has also played a notable role in promotion, education and scientific research value, actively distributing promotional materials, setting up exhibition boards, carrying out publicity activities such as World Wetland Day, World Wildlife Day, and laws related to wetland conservation, conducting research activities related to water resources protection, organizing publicity activities such as the Wetland Photography Competition, Knowledge Competition of SMTNWP, and Style Painting and Calligraphy Exhibition, which have been reported by mainstream media multiple times. SMTNWP has actively provided publicity and science popularization lectures on wetland functions and values to the public, while also invested in the development and construction of a wetland experience hall, which is open to the public, aiming to promote wetland functions and wetland protection knowledge. Additionally, Shandong Mata Lake Tourism Development Co., Ltd. has collaborated with two universities to provide social practice, curriculum practice, and research platforms for university students, supporting teaching and research activities, and playing a crucial role in scientific research. However, the implementation of wetland science popularization and education activities and the fulfillment of wetland park social responsibility require a certain period. It is understood that the number of educational activities currently carried out in SMTNWP are still relatively small, and there is a relative lack of professional activity planning and wetland protection personnel. The facilities and equipment for wetland monitoring and protection are not advanced enough. Therefore, the value of promotion, education and scientific research is only 1.6656 million yuan, indicating significant potential for further exploration and improvement.

5 Discussion and conclusion

5.1 Discussion

5.1.1 Study value

In the context of the current government performance evaluation model, which primarily focuses on GDP as the core indicator, the introduction of GEP accounting adds a critical layer of insurance for local ecological protection, evaluates the contribution of natural ecosystems to human wellbeing, improve the evaluation system of composite ecosystems including the aspects of social, economic, and natural, and help decision-makers recognize the monetary value and importance of ecosystem products. GEP accounting provides essential references for government asset management, enabling local governments to seek economic development from the perspective of harmonious coexistence

between humans and nature, transforms the erroneous behaviors of neglecting any aspect in economic development and ecological protection, and makes GEP accounting results a hard constraint and direction guide for government decision-making. It transforms the "GDP only" performance view, achieving balanced accounting, operation, and dual improvement of GDP and GEP. China is constantly improving the value accounting scheme of ecosystem products, promoting the realization of the value of ecosystem products, and taking the development path of ecological protection and economic development that complement each other, and the behaviors are all beneficial explorations of ecological civilization construction, and important practices of implementing the concept of green development, promoting high-quality development, and can help to realize Chinese modernization.

National wetland parks in China serve as key specific geographical units for natural resource protection and ecological security, providing robust ecosystem products and services for economic and social development, and containing enormous value of ecosystem products. In the conservation practice of national wetland parks, faced with the trade-off between the interests of resource development and construction, and park production and operation, it is necessary to transform the human wellbeing of national wetland parks into quantifiable and visualized monetary values, and to fully understand the potential value of wetland parks for ecological conservation and socioeconomic development. GEP accounting at the scale of national wetland parks is a fundamental component of the value realization mechanism for ecosystem products. It is imperative to conduct accounting studies, develop an evaluation index system, clarify accounting process standards and parameter selection, and enhance the application of value accounting results. Efforts should be made to integrate accounting results into the evaluation system of national wetland park contributions and performance, promote accounting results into planning, projects, decision-making, and policies, provide a basis for government green performance and ecological protection effectiveness assessment, and promote the overall value realization of ecosystem products through the value realization of national wetland parks' ecosystem products.

5.1.2 Study characteristics

This study aims to address the practical needs of GEP accounting at the specific regional unit scale of national wetland parks, as well as the relatively weak status of related studies. By constructing the GEP accounting index system of SMTNWP and using ecological economics methods to account for the monetary value based on biophysical value accounting, the GEP of SMTNWP has been calculated. Prior to GEP accounting, this study considered the provision of educational facilities and promotional activities in the development, construction, and daily operation of national wetland parks, and incorporated the value of promotion, education and scientific research into the GEP accounting indicator system. Given that the management and operation of wetland parks require social labor engaged in related work, providing certain employment opportunities and exerting certain social value, the employment promotion value has been included in the GEP accounting indicator system. In the process of GEP accounting, giving the characteristics of specific regional unit scale of the study area, utilizing small-scale statistical data and monitoring data obtained from field investigations, combining with accurate land use data provided by relevant government departments, this study has scientifically selected evaluation models and methods to form the GEP accounting parameter database of SMTNWP by referring to several GEP accounting procedures and guidelines issued at the national and local levels in China, and relevant researches at home and abroad, and efforts have been made to achieve scientific GEP accounting as much as possible.

5.1.3 Study suggestions

The GEP accounting results indicate that after years of development, construction, and specialized management, SMTNWP has achieved significant progress in ecological security, ecological tourism development, park operation and management, publicity and market promotion, and the values of regulation and socio-cultural functions are relatively high. In the future, it is recommended to continue to strengthen professional, scientific, and standardized operation and management, strengthen supervision of park operation companies' activities related to wetland park construction and management, ensure that SMTNWP enhances and fully utilizes its ecological functions on the basis of water quality safety and ecological safety, prevent the value of ecosystem products from decreasing, and promote the improvement of SMTNWP's ecosystem product values, such as air purification, temperature regulation, and carbon dioxide fixation. Additionally, the brand value and comprehensive benefits of national wetland parks should be enhanced, and teaching and research academic exchange platforms should be established to continuously improve their value of promotion, education and scientific research. It is necessary to ensure the protection and benign utilization of wetland parks, guarantee the virtuous cycle and sustainable development of their ecological functions, to achieve the unity of ecological, social and economic benefits, and a favorable situation of coordinated and win-win protection and development.

The goal of conducting GEP accounting for national wetland parks is to establish a mechanism for realizing the value of ecosystem products of national wetland parks. Propose the following policy recommendations to promote the realization of ESV for national wetland parks. Firstly, clarify the wetland ecosystem product system and accurately evaluate the ESV of various ecosystem functions. National wetland parks should have a clear understanding of the ecological resources, gradually form a list and database of ecosystem products, accurately calculate the GEP level, clarify the ownership, utilization, and contracted management rights of ecological resources on the premise of protecting ecological functions, free up management rights, vigorously develop ecological industries, such as weaving reeds, grass, wood, willows, and cattails within the wetland area into various storage products and decorative items, gradually forming an ecological industry chain, and promoting the green transformation of the industry. Secondly, innovate the ecological compensation and trading modes of wetland carbon sinks based on the value of wetland carbon dioxide sequestration and oxygen release functions. Establish a diversified ecological protection and restoration investment mechanism, coordinate wetland resources within the region, utilize wetland parks for "wetland carbon dioxide sequestration," unify storage and

collection through the "Two Mountains Bank," build a wetland carbon trading platform, and encourage market entities to actively participate in the purchase of carbon dioxide sequestration indicators. Thirdly, encourage multi-party participation in the operation and management of national wetland parks, and improve the market operation mechanism. Under the main responsibility of the government to build the national wetland parks, enterprises and other social capital should be properly introduced to create franchised ecological products, and multiple entities should participate in the operation, investment, development and construction, so as to jointly build and share the value of ecosystem products, support the surrounding residents to actively participate in the operation and management of the wetland park tourism industry, and promote the realization of the common prosperity goal. Fourthly, actively develop and broaden the new tourism formats of the wetland parks. Relying on the natural and cultural landscape of wetlands, develop wetland ecological culture tourism, improve infrastructure, layout wetland related tourist attractions, plan tourist routes, actively carry out wetland ecological protection science popularization and public welfare activities, promote the value transformation and appreciation of ecosystem products, and guard against tourism damaging the ecological environment around the wetland parks. Fifthly, strengthen the construction of wetland related research platforms. Forming think tank resources in the fields of ecological function enhancement, GEP accounting, ecological protection and restoration management, realization and appreciation of the ESV, and development and utilization of ecological resources for wetland parks.

5.1.4 Study prospects

SMTNWP, as a special regional unit, differs from a complete administrative unit. In terms of obtaining localized parameters, SMTNWP lacks relevant small-scale statistical yearbook data for direct reference, which makes the calculation relatively challenging. For example, data such as the number of lake water changes, the average content of nitrogen, phosphorus, potassium, and organic matter in soil are difficult to collect and investigate in the field. The selection of universal parameters will affect the accuracy of accounting results and increase the uncertainty of accounting results. In this study, the GEP accounting index system was established according to the characteristics of the study area and the collection of data. However, SMTNWP is not limited to the GEP accounting subjects quantified in this study, for example, in the accounting process, the quantification and expression of characteristic cultural services and products have not fully been considered, especially in terms of the more scientific and accurate quantification methods for social and cultural functional values such as promotion, education, and scientific research, and employment promotion, and the pertinence of the accounting results needs to be improved. Therefore, in the future, in-depth studies will be strengthened in the selection of accounting indicators and precision determination of parameters, and according to the characteristics of the study area, accounting subjects that can reflect the characteristics of ecosystem products will be selected to achieve the comprehensive GEP characteristic expression of specific regional units; various models, methods and parameters should be applied to conduct GEP accounting, and the optimal models, methods and parameters should be screened to achieve accurate GEP accounting for specific regional units, and the GEP accounting results for different years will be timely updated, the accounting results will be compared to analyze the temporal evolution characteristics of GEP for specific regional units.

5.2 Conclusion

This study selected SMTNWP as the research area, analyzed the spatial pattern of ecosystems, constructed the GEP accounting index system that included regulation, and social and cultural functions, determined biophysical and monetary value accounting indicators, methods and models, and used ecological economics related methods to calculate the total GEP of SMTNWP in the year 2021 as CNY 74.8317 million and a unit area GEP of 73,200 CNY/hm^2. A comprehensive analysis of the total GEP value and each GEP value component was conducted. The study aims to provide support and references for the construction of unified accounting subjects and systems for similar ecosystems and national wetland parks, and provide theoretical basis for quantifying the human wellbeing of national wetland parks, better utilizing the overall ecosystem value of wetlands, helping to realize the value of ecosystem products, and further promoting the transformation of ecological value and economic benefits, and the following conclusions were drawn:

(1) In terms of ecosystem spatial pattern, the SMTNWP encompasses grassland, forest land, and wetlands, with wetlands constituting the predominant type, covering more than 80% of the park's total area. Wetland and lake ecosystems play an important role in conserving water sources, purifying water quality, regulating regional microclimates, protecting regional ecological stability, and diluting atmospheric pollutants.
(2) In terms of constructing the GEP accounting indicator system and its results, the system comprises 2 first-level subjects, including regulation function, and social and cultural function, and 11 second-level subjects such as water purification and air purification. Based on biophysical value accounting, ecological economics methods are used to calculate the monetary value. Overall, the flood regulation and storage function holds the highest value, followed by water conservation and leisure and recreation, which have relatively high values., the values of promotion, education and scientific research, release of oxygen, and soil conservation are all average, while those for air purification, temperature regulation, and carbon dioxide fixation are relatively low.
(3) In terms of regulation function value, due to the natural background ecological conditions of SMTNWP and the construction of wetland protection and restoration engineering measures in the later stage, the value of ecosystem products related to park regulation functions is high, which is the core part of ecosystem product supply. Due to the extensive coverage of the wetland ecosystem in SMTNWP, the values of flood regulation, and conservation of water sources account for more than 60% of the total. The

value of the ecological function that the wetland plays the major role is relatively high, which fully reflects that the wetland ecosystem, as a "natural sponge" and "kidney of the earth," plays an important role in accumulating and redistributing precipitation, absorbing and storing precipitation, regulating rainstorm runoff, reducing flood peaks, conserving water sources, and improving water quality.

(4) In terms of social and cultural functional value, leisure and recreation, and employment promotion values are the main components of SMTNWP's social and cultural ecosystem product value. Since the park's development and construction, Shandong Mata Lake Wetland Conservation Center and Shandong Mata Lake Tourism Development Co., Ltd. have actively developed cultural tourism while ensuring ecological stability. On the basis of protecting and restoring the wetland ecosystem of the park, they have fully explored the natural and cultural landscapes, developed ecological and cultural tourism of the wetland, carried out wetland park sightseeing experience activities, provided certain employment opportunities, and generated substantial ecological and social benefits.

(5) In terms of future GEP improvement, among SMTNWP's regulating ecosystem products, the values of air purification, temperature regulation, and carbon dioxide fixation functions are relatively low and have the greatest potential for exploration. There is significant room for improvement in the value of promotion, education and scientific research of social and cultural ecosystem products. Relevant wetland management departments should continue to implement wetland protection, restoration technologies and engineering measures, continuously improve the ecosystem and ecological environment of the park, enhance the comfort of the environment, and promote the value improvement of air purification, temperature regulation, and carbon dioxide fixation. Simultaneously, these departments can accelerate the scientific research work related to the wetland ecosystem of the park, actively build the platform for scientific research and academic exchanges, strengthen cooperation with relevant colleges and social groups, continue to carry out investigation and monitoring of wetland resources, make full utilization of wetland investigation and monitoring results to guide the protection, management and operation of the park, thereby promoting the continuous improvement of the value of SMTNWP's promotion, education and scientific research functions.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

Author contributions

JL: Conceptualization, Data curation, Formal Analysis, Methodology, Software, Validation, Writing–original draft, Writing–review and editing. MX: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing–original draft. AW: Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Supervision, Validation, Writing–review and editing. TS: Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing–review and editing. CZ: Investigation, Resources, Supervision, Writing–review and editing. XC: Investigation, Resources, Supervision, Writing–review and editing. PZ: Data curation, Investigation, Supervision, Writing–review and editing.

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Conflict of interest

Author CZ was employed by Shandong Deyun Land Real Estate Appraisal Consulting Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2025.1500075/full#supplementary-material

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