Pol. J. Environ. Stud. Vol. XX, No. X (XXXX), 1-17

DOI: *10.15244/pjoes/215217* ONLINE PUBLICATION DATE: 2026-07-13

Original Research

Optimizing Zoning of National Nature Reserves through the MOLA Model: The Case of Shengjin Lake, China

Yawen Cheng[1, 2], Yiyan Sun[1], Yuting Wan[1], Yongfeng Yang[3], Li Wang[1, 4], Yang Chen[1], Yuan Wang[1, 4]*

[1]School of Geography and Tourism, Anhui Normal University, Wuhu 241002, China
[2]China Railway Urban Planning and Design Institute Co., Ltd., Wuhu 241002, China
[3]Forestry and Grassland Survey and Planning Institute of the State Forestry and Grassland Administration (SFGA), Beijing 100013, China
[4]Neweco Design Co., Ltd., Shanghai 200433, China

Received: 15 October 2025
Accepted: 05 December 2025

Abstract

Scientific zoning is essential for promoting the sustainable development of protected areas. Taking the Shengjin Lake National Nature Reserve as a case study, this research develops a sub-zoning framework aimed at mitigating conflicts of interest among different stakeholders within the reserve. We first identified core stakeholder groups and the ecosystem services they prioritize, then quantitatively assessed and spatially mapped the values of these services. Using these data, we employed a Multi-Objective Land Allocation (MOLA) model to generate a "functional zones-control zones" sub-zoning scheme. The results indicated that the functional zones were divided into three zones. The strict protection zone covers 228.34 km², mainly in the main body of Shengjin Lake. The nature education and ecological experience zone covers 22.83 km², mainly in the western part of Shengjin Lake. The production and living zone covers 82.23 km², mainly in the northern farmland areas. The control zones were divided into two zones. The core protection zone covers 228.34 km², mainly in the main lake body of Shengjin Lake. The general control zone covers 105.06 km², mainly in the northern farmland areas and the western part of Shengjin Lake. This integrated approach, which combines stakeholder analysis with ecosystem service valuation, provides a robust and replicable model for resolving land-use conflicts in protected area management.

Keywords: sub-zoning, MOLA model, ecosystem service, core stakeholders, National Nature Reserve

*e-mail: oneyuan1216@gmail.com
Tel.: +86-13641601587

© 2026 This article is licensed under a Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0)

Introduction

Protected areas, a cornerstone of nature conservation since the establishment of Yellowstone National Park in 1872 [1], have expanded significantly in recent decades [2]. The Protected Planet Report 2024 reveals that 17.6% of terrestrial and inland water areas and 8.4% of marine and coastal areas worldwide are encompassed within documented protected and conserved areas [3]. It emphasizes that these areas are vital for both nature and people, playing a critical role in halting and reversing biodiversity loss. However, the effectiveness of management has not kept pace with this rapid expansion, particularly in developing countries [4]. As one of the world's major developing nations, China established 6,736 protected areas covering a total of 1,852,400 km^2 by 2022, making it a significant component of the global protected area system. Yet, alongside the rapid growth in the number of protected areas, conflicts between resource conservation and utilization within these reserves have intensified [5], largely due to the diversity of stakeholders and the multiplicity of their objectives [6]. While protected areas were originally established to conserve natural ecosystems and biodiversity, their overlap with zones of human activity has necessitated the inclusion of additional objectives. These include safeguarding local livelihoods, facilitating scientific research and education, and promoting ecotourism [7]. In this context, zoning within protected areas has emerged as a crucial strategy for reconciling these competing goals. By applying differentiated management guidelines across designated zones, it enables the spatial optimization of resource use and conservation [8]. Therefore, zoning is widely recognized as an essential tool for protected area management [9], mitigating conflicts between conservation and development by providing a structured framework for decision-making and regulating human activities [10-12]. Furthermore, it helps balance diverse stakeholder interests, thereby playing a pivotal role in the sustainable development of protected areas [13, 14].

Currently, China's nature reserves mainly follow a three-zone model, comprising a core zone, buffer zone, and transition zone, which is designed primarily to conserve species and ecosystems [15]. However, this concentric zoning model presents several limitations. At the level of zoning control, human entry into the core zone is prohibited in principle, with exceptions requiring prior approval from the Nature Reserve Management Bureau for scientific research. Similarly, access to the buffer zone for research purposes also requires approval. As a result, the core and buffer zones are managed with nearly identical intensity, leading to insufficient differentiation between them and weakening the functional role of the buffer zone [16]. At the level of zoning function, the model inadequately addresses the dual objectives of conservation and sustainable use. It often conflates protection intensity with utilization modes, leading to issues such as vague management hierarchies and ambiguous functional objectives across zones [17]. To overcome these challenges, adaptive zoning under the Natura 2000 framework proposes flexible boundaries that respond to ecological change, explicitly integrating biodiversity conservation with sustainable human uses while ensuring stakeholder participation in the zoning process. In China, the Technical Specification for Overall Planning of National Parks recommends a sub-zoning framework, including control zones and functional zones [18]. This model compensates for the shortcomings of the three-zone approach, in which control requirements and objectives are often unclear. Specifically, control zones are delineated according to the intensity of resource management, with an emphasis on the regulation and restriction of human activities. Functional zones, by contrast, are differentiated into multiple types to clarify and reinforce the dominant functions of each area, thereby enabling more precise spatial utilization and governance. As nature reserves form an essential part of China's broader national park system, adopting a similar sub-zoning model offers a promising pathway forward. By clearly defining control hierarchies and functional roles, it overcomes the limitations of concentric zoning and supports more differentiated and effective management strategies. In summary, by decoupling management intensity from utilization modes, the sub-zoning approach enhances clarity in zoning management, facilitates the integration of strict conservation with sustainable use, and ultimately contributes to the sustainable governance of nature reserves.

Existing zoning methods for nature reserves include the species distribution model [19], population viability analysis [20], landscape suitability evaluation [21], minimum cost distance calculation [22], cluster analysis [23], irreplaceability calculation [24], and equal width method [20]. These approaches are largely designed from the perspective of important species and ecosystems protection, with limited consideration of the objectives of diverse stakeholder groups in the reserve, and insufficient assessment and trade-offs of the value of different ecological processes and ecosystem services. Such neglect has, to some extent, contributed to escalating human–nature conflicts and hampered the alignment of conservation and development goals [25]. The Multi-Objective Land Allocation (MOLA) model, first introduced by Eastman et al. [26], provides a quantitative framework for resolving multi-objective land allocation problems. It integrates multiple suitability layers, each corresponding to a distinct management objective, within a multidimensional decision space. By applying stakeholder-defined constraints for each objective, the model allocates individual land units to the most appropriate use category, based on the principle of optimal land allocation. This yields a scientifically rigorous and objective zoning scheme [27]. The MOLA model has been widely applied in both domestic and international research to support the quantitative delineation of functional zones, particularly in contexts involving complex conflicts of interest [28-30]. Building on this foundation, this study adopts a stakeholder-oriented approach, quantifying the objectives of key actors in terms of ecosystem service values. By incorporating these quantified objectives into the MOLA framework, the research seeks to balance competing interests and develop a more rational, transparent, and functional sub-zoning scheme for the nature reserve.

Shengjin Lake National Nature Reserve, located in Chizhou City, Anhui Province, lies on the southern bank of the lower Yangtze River at the junction of Guichi District and Dongzhi County. It is the only national nature reserve in Anhui Province dedicated to the protection of wetland ecosystems and wintering birds. The reserve preserves one of the most intact inland freshwater lake wetland ecosystems in the lower Yangtze River basin and serves as a critical wintering ground for storks, cranes, geese, ducks, and plovers in the Asia-Pacific region. According to the Anhui Shengjin Lake International Important Wetland Ecological Monitoring 2019-2020 Annual Report, the reserve hosts 59 species of waterbirds, including three wintering species under China's Class I national protection: *Grus monacha* (16 individuals), *Grus leucogeranus* (118 individuals), and *Ciconia boyciana* (19 individuals) [31]. These species are also listed on the IUCN Red List of Threatened Species as Vulnerable, Critically Endangered, and Endangered, respectively. Shengjin Lake has long been recognized for its ecological significance. It was designated as one of China's 40 Nature Reserves of World Significance in 1992 [32], joined the Chinese Man and Biosphere (MAB) Network of Nature Reserves in 1995, was listed as an important wetland in China in 2000, became part of the Northeast Asia Crane Network in 2002, and was recognized as an internationally important wetland in 2015 [33]. These designations highlight its outstanding ecological value and global influence. However, biodiversity within the reserve is increasingly threatened by human activities, particularly local agricultural production and tourism-related research and sightseeing. Therefore, this study selects Shengjin Lake National Nature Reserve as a case study. We first identified core stakeholder groups and the ecosystem services they prioritize, then quantitatively assessed and spatially mapped the values of these services. Using this data, we employed a Multi-Objective Land Allocation (MOLA) model to generate a "functional zones-control zones" sub-zoning scheme. By clearly defining control hierarchies and functional roles, it overcomes the limitations of concentric zoning and supports more differentiated and effective management strategies. Meanwhile, MOLA's flexibility in handling complex spatial constraints and multiple objectives ensures that the land-use allocations are both ecologically sound and socially acceptable, thereby supporting the sustainable management of the reserve.

Materials and Methods

In this study, the Shengjin Lake National Nature Reserve served as the pilot area to develop a detailed set of guidelines for zoning nature reserves (Fig. 1), with potential applicability to other regions experiencing land-use conflicts.

First, the core stakeholders of the reserve were defined through the Mitchell score method [34]. Second, the ecosystem service values prioritized by these stakeholders were examined through structured questionnaires and semi-structured interviews [35-37]. Then, the ecosystem service values emphasized by different interest groups were quantitatively assessed using a combination of the MaxEnt model [38], the SolVES model, the precipitation storage method, and the market value method. Finally, based on the spatial distribution of ecosystem service values and constrained by land allocation priority and ecological space area, the MOLA model was applied to delineate the sub-zoning of the reserve.

Study Area

Shengjin Lake National Nature Reserve (hereinafter referred to as the reserve) is located in Chizhou City, Anhui Province, on the southern bank of the lower Yangtze River at the junction of Guichi District and Dongzhi County (116°55′-117°15′E, 30°15′-30°30′N). The reserve covers a total area of 333.40 km², of which 133.00 km² is water surface. It harbors rich biodiversity and serves as a critical wintering ground along the East Asia–Australasian migratory route for rare waterbirds [39]. The reserve is also an important agricultural landscape and home to approximately 60,000 inhabitants engaged primarily in cultivation and fisheries [40]. At present, the reserve is divided into three functional zones: a core zone (101.50 km²), which provides key habitat for rare waterbirds and acts as a water source for the middle and lower Yangtze River; a buffer zone (103.00 km²), which serves as an extension of the core bird habitats; and an experimental zone (128.90 km²), designated for activities such as environmental education, scientific research and monitoring, and ecotourism. To effectively capture the spatial heterogeneity of natural attributes and maintain the ecological integrity and originality of the reserve, this study utilized catchment units as the primary evaluation unit. These units were delineated using hydrological analysis tools in ArcGIS, based on the Digital Elevation Model (DEM) of the reserve, and were subsequently used for the spatial statistical analysis of ecosystem service values (Fig. 2).

Data Sources

In response to the ecosystem service assessment requirements and data accessibility concerns of the core stakeholders, multiple spatial datasets were collected

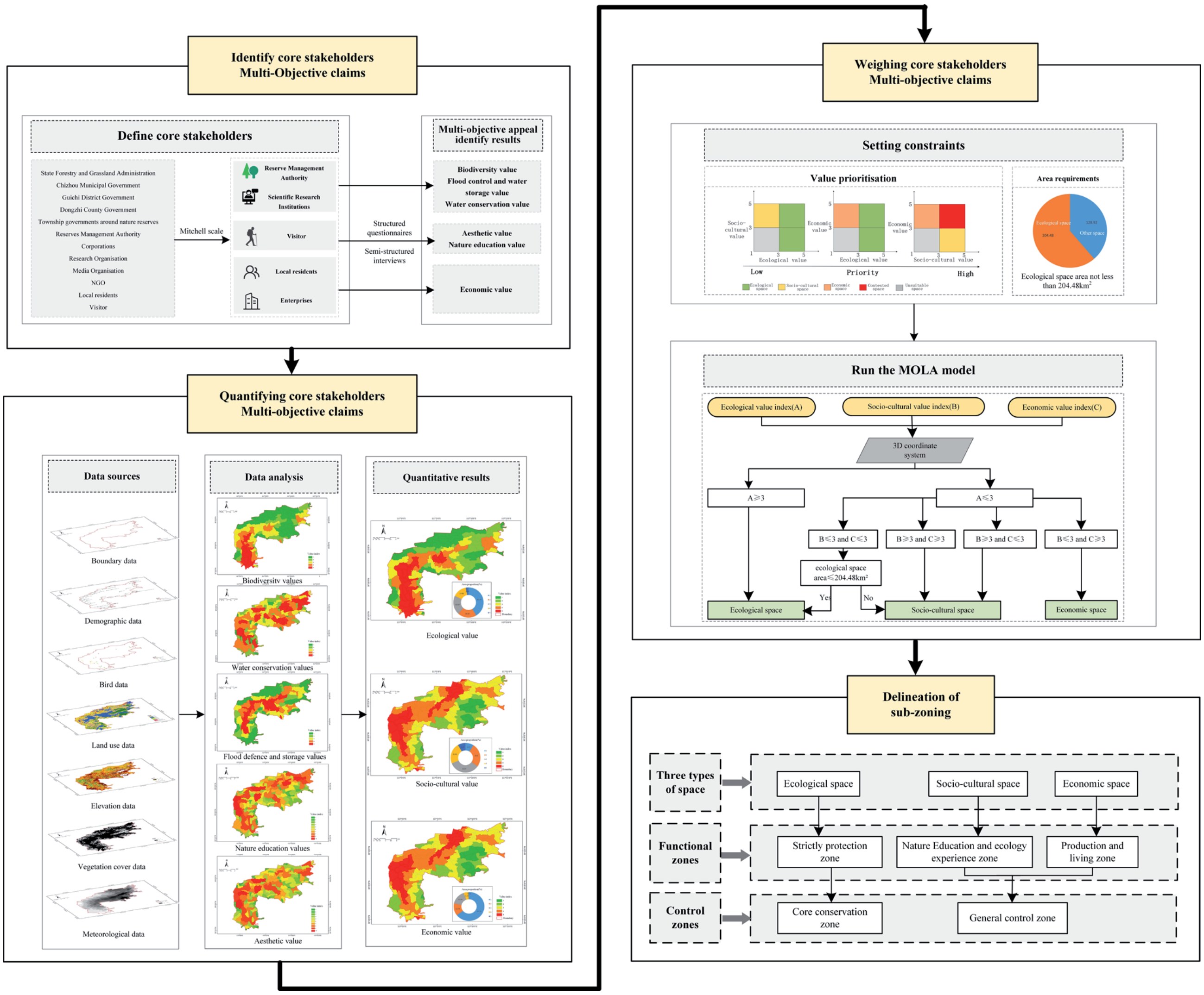

Fig. 1. Research framework.

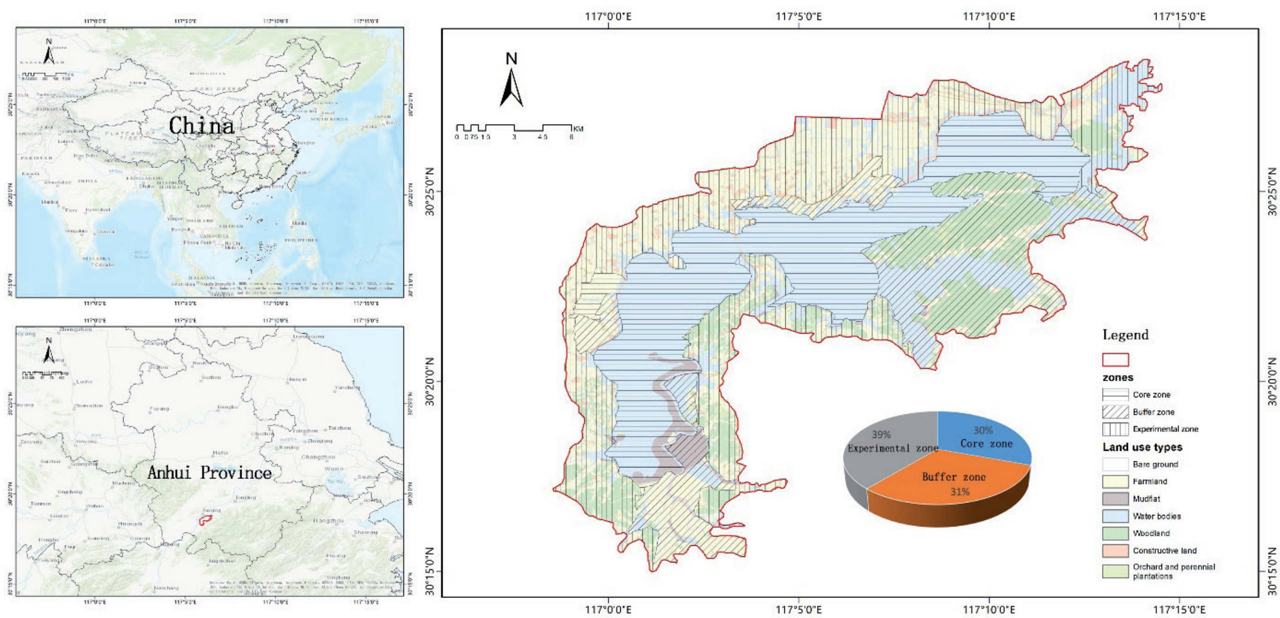

Fig. 2. Division of evaluation units in the reserve.

and organized, including reserve boundary data, meteorological data, digital elevation data, land use data, and bird distribution point data. All datasets were preprocessed to ensure consistency, standardized under the WGS-1984 UTM Zone 50N coordinate system, and resampled to a 30×30 m raster resolution (Table 1).

Identify Core Stakeholders' Multi-Objective Claims

Stakeholders within the reserve were identified through field surveys and institutional interviews, following the framework of stakeholder theory. To determine the core stakeholders, the Mitchell Scoring Method was employed, evaluating each stakeholder based on three dimensions: legitimacy, power, and urgency [41]. Each dimension was scored on a 1-5 scale, with final scores calculated as the average of expert evaluations. Core stakeholders were defined according to 2 criteria: a total score greater than half of the maximum possible score (7.5 points) and at least 2 attribute scores higher than half of the maximum possible score for a single attribute (2.5 points). Finally, the ecosystem service values prioritized by these core stakeholders in the reserve were examined through structured questionnaires and semi-structured interviews.

Quantifying Core Stakeholders' Multi-Objective Claims

(1) Ecological value assessment methods

Biodiversity is a key determinant of ecological value, as areas with higher biodiversity provide more habitat and foraging space for protected species, thereby enhancing species richness and ecological function. To quantify biodiversity, the Maximum Entropy (MaxEnt) model was employed [42]. This model predicts potential species distributions based on occurrence points and relevant environmental variables, under the framework of ecological niche theory [43-45]. In this study, three rare and endangered bird species under key protection in the reserve were selected as biodiversity indicators: *Grus monacha*, *Grus leucogeranus*, and *Ciconia boyciana* [46, 47]. Potential habitats for these species were simulated using MaxEnt. To integrate the results, the potential habitat suitability maps of the three species were assigned weights according to their respective conservation stress levels, followed by a weighted sum analysis based on the Analytic Hierarchy Process (AHP). The resulting integrated biodiversity value map was then classified into 5 levels (Grades 1-5) using the natural breaks classification method, where higher grades represent higher biodiversity value [48-50].

The flood regulation and water storage capacity of Shengjin Lake are a critical indicator of its regulating ecosystem services. This capacity is jointly determined by the lake's surface area and its water level. However, due to the irregular and non-orthogonal morphology of the lake shoreline, the storage volume cannot be accurately estimated using simplified geometric formulas that relate surface area to depth [51]. To address this, hydrological observations of Shengjin Lake were used to establish the functional relationship between water surface area and storage volume, from which a regression model was derived. The resulting regression Equation is:

$$V = 2.4864 \times e^{0.041} \times A$$

where A denotes the water surface area, and V denotes the water storage volume. This model exhibited a strong goodness of fit, with an R^2 value of 0.95, confirming its predictive reliability. The regression equation was subsequently applied to supplement the missing

Table 1. Data sources.

Data	Description	Source
Boundary data	Scope of nature reserves and original functional zoning	Masterplan for Nature Reserves
Bird data	Spatial distribution points of priority bird species	Comprehensive Visit Report for Nature Reserves in 2020
Population data	Population by village	Ecological migration planning for nature reserves
Land use data	30 m resolution farmland, woodland, grassland, waters, wetlands, bare land, construction area	The change data of the third land survey of China in 2024
Elevation data	30 m resolution DEM digital elevation	Geospatial data cloud
Vegetation cover data	30 m resolution Landsat 8 Remote Sensing Image Calculation	Geospatial data cloud
Meteorological data	1 km resolution precipitation	China Meteorological Data Network
	1 km resolution mean annual temperature, isothermality, seasonal variation of temperature, maximum temperature of the hottest month, minimum temperature of the coldest month, mean temperature of the driest season, annual rainfall, precipitation of the wettest season, precipitation of the hottest season, precipitation of the coldest season	World Meteorological Database

volume data in the hydrological data and to calculate the shape parameters. Specifically, the ratio of storage volume to corresponding water surface area at different water levels was used to derive shape parameters of the shoreline. Using these parameters together with elevation-derived water surface area data, the spatial distribution of Shengjin Lake's water storage volume was determined for the flood season, normal season, and dry season in 2024. To evaluate flood control and water storage functions, the resulting capacity values across different lake zones and water levels were classified into 5 categories using the Natural Breaks Method, with higher grades indicating greater regulatory capacity.

In addition, the precipitation storage method was employed to assess the water conservation service of the ecosystem. This method assumes that an ecosystem's water conservation capacity is jointly influenced by annual precipitation and vegetation cover, and that retention occurs when vegetation cover exceeds a critical threshold and surface runoff remains lower than total precipitation input [52]. The reduction in runoff from vegetated or aquatic land types, relative to bare land, represents the water-holding capacity. The calculation is expressed as:

$$Q = A \times (J_0 \times K) \times (R_0 - R_G)$$

where Q is the amount of water conservation (m^3), A is the area of the evaluation unit (m^2), J_0 is the annual precipitation in the study area (m), K is the proportion of precipitation generating streamflow (set as 0.6) [53], R_0 is the precipitation runoff coefficient of the bare land, and R_G is the precipitation runoff coefficient of the area with different vegetation cover, in which the runoff coefficient of the water body is 0 (Table 2). The computed water conservation values were then categorized into 5 classes using the Natural Breaks Method, where higher grades denote stronger water conservation capacity.

Based on the assessment results of bio-habitat value, flood control and water storage value, and water conservation value, the 3 ecological indicators were integrated using the equal-weighted weighted sum method. The combined results were then classified into 5 grades using the natural breaks method, with higher values indicating greater overall ecological value.

Table 2. Classification of runoff coefficients corresponding to different vegetation covers.

Vegetation cover class	Vegetation cover/%	Runoff coefficient R_g
1	0-10	0.28
2	10-25	0.25
3	25-50	0.15
4	50-70	0.05
5	70-100	0.015

(2) Socio-cultural value assessment methods

The Social Value of Ecosystem Services model (SolVES model), jointly developed by the U.S. Geological Survey's Rocky Mountain Geographic Science Center and Colorado State University, was applied to evaluate the socio-cultural value of ecosystem services from a spatial perspective. The SolVES model quantifies socio-cultural values as a non-monetary value index, enabling the spatial visualization of relative importance across different value types [54]. These values are derived through questionnaire surveys and semi-structured interviews, which provide input data on stakeholders' perceptions and preferences. Within the SolVES framework, a ten-point value index is generated for each type of socio-cultural value through kernel density analysis and score standardization. This process captures the spatial heterogeneity of value distribution across the landscape [55]. To further extend the analysis, the MaxEnt model was employed to predict the potential distribution of socio-cultural value areas. In this step, existing socio-cultural value points served as occurrence data, while the associated environmental variables were used as predictors for the machine learning algorithm. This approach generated a logistic probability surface identifying areas with high potential socio-cultural value [56].

For this study, two socio-cultural value categories – aesthetic value and nature education value – were identified based on the Ecotourism Plan of Shengjin Lake National Nature Reserve and Surrounding Areas (2018-2030), field investigations, and visitor questionnaires. A total of 27 socio-cultural value points were recorded and used as input for the SolVES and MaxEnt analyses. The resulting spatial distributions of the 2 value types were integrated using the equal-weighted sum method, and the combined results were classified into 5 grades using the Natural Breaks Method, with higher categories representing greater socio-cultural value.

(3) Economic value assessment methods

The evaluation of economic value was conducted using the market value method, rooted in traditional ecological economics and statistical theory. This approach has long been applied in ecosystem service valuation, particularly for products with direct commercial value, such as rice, fruits, fish, and other biological resources [57]. The economic value of material production and raw material supply can be calculated using the following formula:

$$V_m = Y_i \times P_i$$

where V_m is the value of material production (yuan/ha), Y_i is the unit yield of the i class of material (t/ha), and Pi is the corresponding market price in the current year (yuan/t).

In this study, based on the characteristic resources of the Shengjin Lake Nature Reserve, 5 representative economic products were selected: rice, tea, fruits, forests, and fish. By evaluating the market value of these products, we derived the spatial distribution of their economic value across the reserve. Referring to the 2024 Chizhou Statistical Yearbook, the following estimates were obtained: the average price of fish is approximately 10 yuan/kg, with a yield of 342.04 kg per mu; rice is priced at around 6 yuan/kg, with a yield of 406.87 kg per mu; tea has an average price of about 300 yuan/kg, with a yield of 50.58 kg per mu; fruits are valued at approximately 3 yuan/kg, with a yield of 490.66 kg per mu; artificial commercial forests receive an ecological compensation price of about 5,000 yuan per mu; and the average ex-factory price of cement in Anhui Province is about 400 yuan/ton. Using these parameters, the economic value distribution was mapped, and the results were subsequently categorized into 5 grades through the natural breaks method, where higher grades indicated greater economic value.

Weighing Core Stakeholders' Multi-Objective Claims

(1) Construction of a multi-dimensional coordinate system

Based on the ecosystem service valuation results, value maps were generated for each objective, including ecological, socio-cultural, and economic indices. A three-dimensional coordinate system was then constructed with these 3 indices as axes, and the scores of 160 evaluation units were projected into this system as coordinates. When the ecosystem service value index is greater than or equal to 3, the appropriateness of the value can be effectively represented.

(2) Setting of constraints

Constraints are important parameters in MOLA, as they directly affect the accuracy of land allocation results. In a two-dimensional coordinate system, constraints are typically expressed as straight or oblique lines, while in practice they can be represented by suitability indices, area ratios, or differences among land-use categories (Fig. 3) [58]. To prevent a reduction in ecological land within the reserve, the ecological space area was set as a hard constraint, with its area required to be no less than the combined size of the core and buffer zones, totalling 204.48 km². In line with the principle that protection intensity should not be reduced, the priority of land allocation in the three-dimensional coordinate system was set as ecological space > socio-cultural space > economic space as the constraint in MOLA.

(3) Generation of three types of spaces

Areas with an ecological value index of 3 or above were directly designated as ecological space, regardless of their socio-cultural or economic values. If the ecological index was below 3 but either the socio-cultural or economic index reached 3 or above, the unit was classified as socio-cultural space, economic space, or contested space. When all 3 indices were below 3, the unit was defined as unsuitable space. The MOLA algorithm first assigned evaluation units with the highest ecological values to ecological space. It then checked whether the designated ecological space area met policy requirements. If not, additional evaluation units were sequentially added until the threshold was reached. Once the ecological requirements were satisfied, all remaining unsuitable spaces were classified accordingly. For contested and unsuitable spaces, the zoning priority followed the principle of socio-cultural space > economic space. Based on this priority, the spatial attributes of these areas were determined, yielding an optimal land allocation scheme that balances ecological, socio-cultural, and economic objectives.

Delineation of Sub-zoning

To capture the distinct modes of resource protection and utilization, sub-zones were delineated within each of the three spatial zones based on their dominant

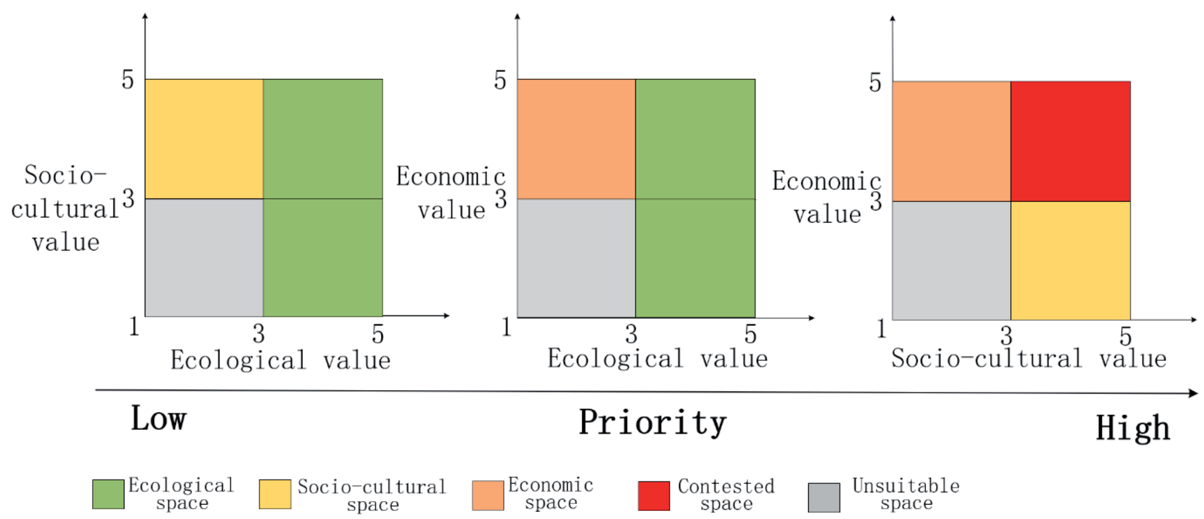

Fig. 3. MOLA 2D coordinate system analysis map.

ecosystem service functions. The ecological space, which contains the richest natural ecosystems and biodiversity, was designated as a strict protection zone. The socio-cultural space, characterized by abundant resources for environmental education and aesthetic appreciation, was defined as a nature education and ecological experience zone. The economic space, where resources such as agriculture and mining are most concentrated, was designated as a production and living zone.

In addition, control zones were established to regulate the intensity of protection and utilization, based on the level of restriction required for human activities. The core protection zone represents the most intact wetland ecosystems and the highest concentrations of rare waterfowl species and therefore requires the strictest management. Accordingly, it is classified as the central area within the strict protection zone. The general control zone, located outside the core protection zone but still within the reserve boundary, requires rigorous planning and regulation of development activities. This zone encompasses the nature education and ecological experience zones as well as the production and living zones.

Results

Ecosystem Service Value Indicator System

Through field surveys and sectoral consultations, 12 categories of stakeholders were initially identified within the reserve. Based on the Mitchell stakeholder classification framework, 5 core stakeholder groups were defined: the reserve management bureau, scientific research institutions, visitors, local residents, and enterprises (Table 3).

In November 2024, structured questionnaires and semi-structured interviews were conducted with these stakeholder groups. A total of 420 individuals participated, including 20 from the reserve management bureau, 56 from scientific research institutions, 144 visitors, 180 local residents, and 20 enterprise representatives. The survey results highlighted distinct stakeholder priorities: the reserve management bureau and scientific research institutions emphasized biodiversity conservation, flood regulation, and water retention functions; visitors prioritized aesthetic enjoyment and environmental education; local residents and enterprises were primarily concerned

Table 3. Analysis of core stakeholder definitions.

Stakeholder	Specific features	Legality	Powerlessness	Urgency
State Forestry and Grassland Administration	Responsible for the protection, restoration, and management of forests, grasslands, and other natural resources throughout the country.	3.8	2.4	1.6
Chizhou Municipal Government	Responsible for the economic construction, social development, and ecological protection of the city of Chizhou.	2.8	2.4	2.0
Guichi District Government	Responsible for economic construction, social development, and ecological protection in Guichi District.	3.0	2.4	2.0
Dongzhi County Government	Responsible for economic construction, social development, and ecological protection in Dongzhi County.	2.0	2.0	2.5
Township governments around nature reserves	Responsible for the economic construction, social development, and ecological protection of the township.	1.5	1.0	1.0
Reserves Management Authority	Responsible for, among other things, resource management and policy development for the Shengjin Lake Reserve, to protect natural ecosystems and biodiversity.	3.8	4.0	4.0
Corporations	Enterprises that legally acquire natural resources for their production operations in the Shengjin Lake Reserve.	2.8	2.4	4.0
Research Organization	An academic institution that conducts scientific research on the Shengjin Lake Reserve.	3.2	2.8	3.5
Media Organization	Reporting on the situation related to the Shengjin Lake Reserve.	1.6	1.4	2.0
NGO	Third-party non-governmental organizations are concerned with the conservation and rehabilitation of nature reserves, social development, and economic coordination.	1.4	1.7	2.4
Local residents	Aboriginal people in the Shengjin Lake Reserve are concerned about ecological conservation and their own economic income.	2.8	3.4	4.2
Visitor	Groups participating in activities such as science education, recreation, and bird watching in the Shengjin Lake Reserve.	2.4	3.4	2.8

with provisioning services such as raw materials and productive land use. Based on these differentiated concerns, together with the current ecological conditions of the reserve, an ecosystem service value indicator system was developed (Table 4, Fig. 4).

Features of Ecosystem Service Values

(1) Ecological value features

As shown in Fig. 5, areas of high ecological value cover 127.82 km², accounting for 38.34% of the total reserve area. These regions are primarily concentrated in the southern Upper Lake as well as the central and Lower Lake zones. The southern beach area of the Upper Lake serves as a critical habitat and foraging ground for migratory birds during the dry season, while also playing a vital role in flood regulation and water storage during the wet season. Similarly, the central and Lower Lakes are important for hydrological regulation. In contrast, areas with lower ecological value amount to 205.58 km², accounting for 61.66% of the total reserve area, and are mainly distributed in the agricultural landscapes surrounding Shengjin Lake. These landscapes are heavily disturbed by human activities, characterized by low vegetation cover and limited water bodies, resulting in degraded wildlife habitats and reduced ecological functionality.

(2) Socio-cultural value features

As shown in Fig. 6, the area of higher socio-cultural value covers 217.15 km², representing 65.13% of the total reserve area. These areas are primarily located in the lake body of Shengjin Lake and its northern coastal region. The northern coastal area is particularly notable for its bird-watching infrastructure, which provides excellent visibility and accessibility, while the open water of the lake offers scenic views and strong potential for environmental education. In contrast, the area of lower socio-cultural value covers 116.25 km², accounting for

Table 4. Indicator system for assessing the value of ecosystem services.

Type of value	Value indicators	Indicator characteristics
Ecological value	Biodiversity values	The ability to provide a place for birds and other animals to roost and feed.
	Flood protection and water storage value	Capable of regulating floods, supplying water, and maintaining biodiversity.
	Water conservation value	Ability to retain moisture without flooding or drought conditions.
Socio-cultural value	Aesthetic value	The ability to provide pleasing tourism resources to attract tourists.
	Educational value of nature	Rich in natural resources and able to carry out nature education activities.
Economic value	Value of material production	The ability to grow food, vegetables, and fish to provide family income.
	Value of raw material supply	Ability to provide timber, mineral resources, etc.

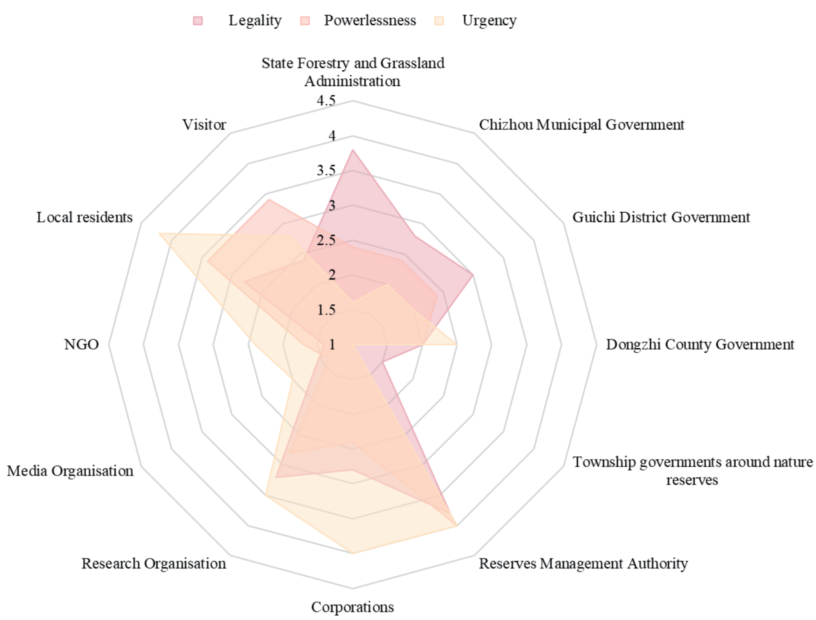

Fig. 4. Radar map of the three-dimensional characteristics of stakeholders in Shengjin Lake National Nature Reserve.

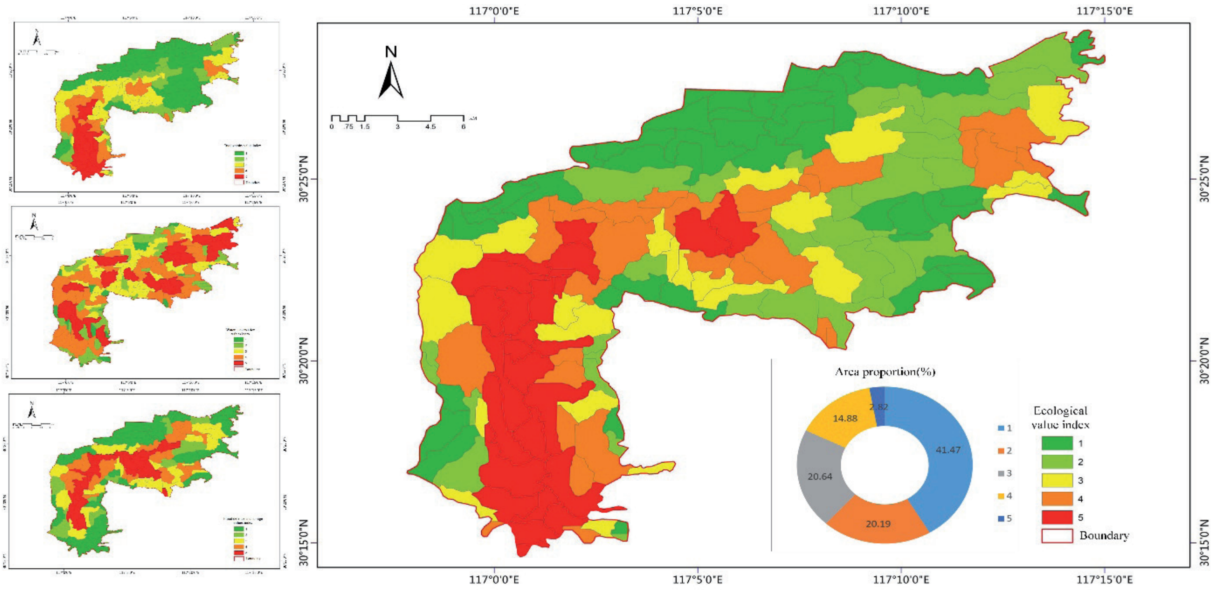

Fig. 5. Analysis of the ecological value index.

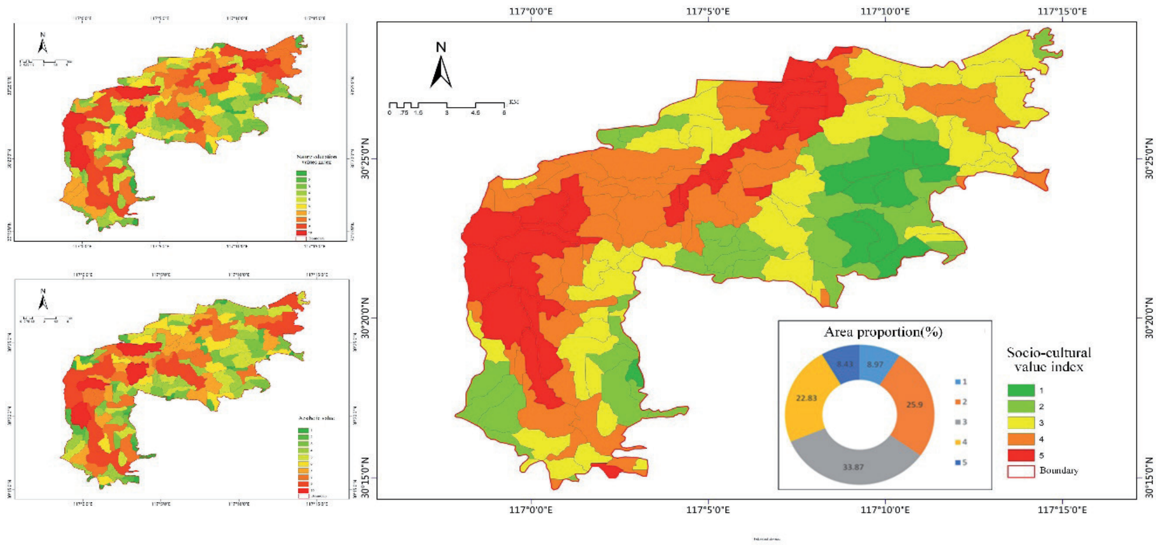

Fig. 6. Analysis of the socio-cultural value index.

34.87% of the total reserve area, and is mainly located in the northern and southeastern regions of the reserve. These areas are predominantly composed of farmland, forest land, and residential settlements, which generally lack visual appeal and offer limited opportunities for environmental education and recreation.

(3) Economic value features

As shown in Fig. 7, the area of higher economic value is 71.86 km², accounting for 21.56% of the total area of the reserve. These areas are concentrated in the southern forest area of the Lower Lake, where the mineral resources are relatively abundant. The significantly higher unit value of mineral resources compared with other products accounts for the elevated economic importance of this area. By contrast, low economic value areas occupy 261.54 km², accounting for 78.44% of the reserve, mostly consisting of farmland, bare land, and built-up land. These landscapes either lack cash crops or are dominated by crops with relatively low production values, resulting in limited economic contributions.

Features of the Three Types of Spaces

A three-dimensional coordinate system was constructed with ecological, socio-cultural, and economic values as the axes, and the scores of 160 evaluation units were projected into this system (Fig. 8). Based on the MOLA allocation principle, ecological space was given the highest priority, followed by socio-cultural space and then economic space,

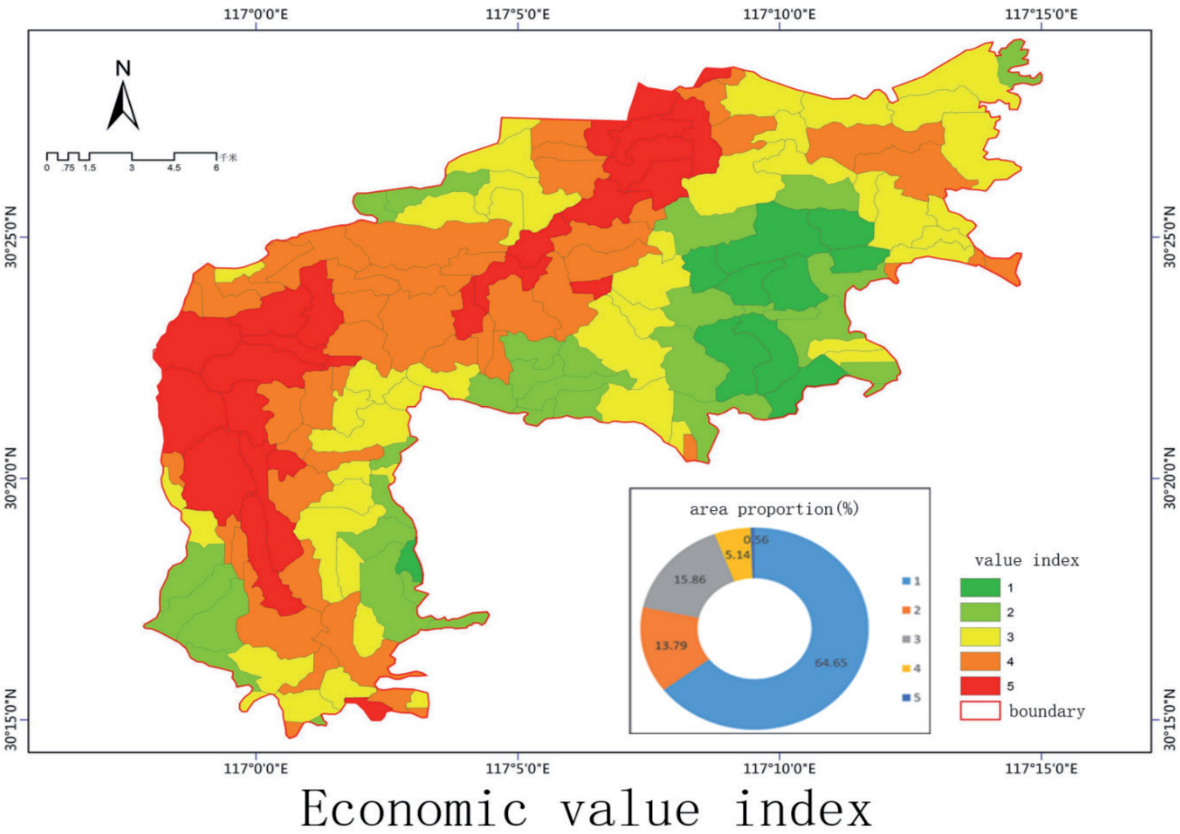

Fig. 7. Analysis of the economic value index.

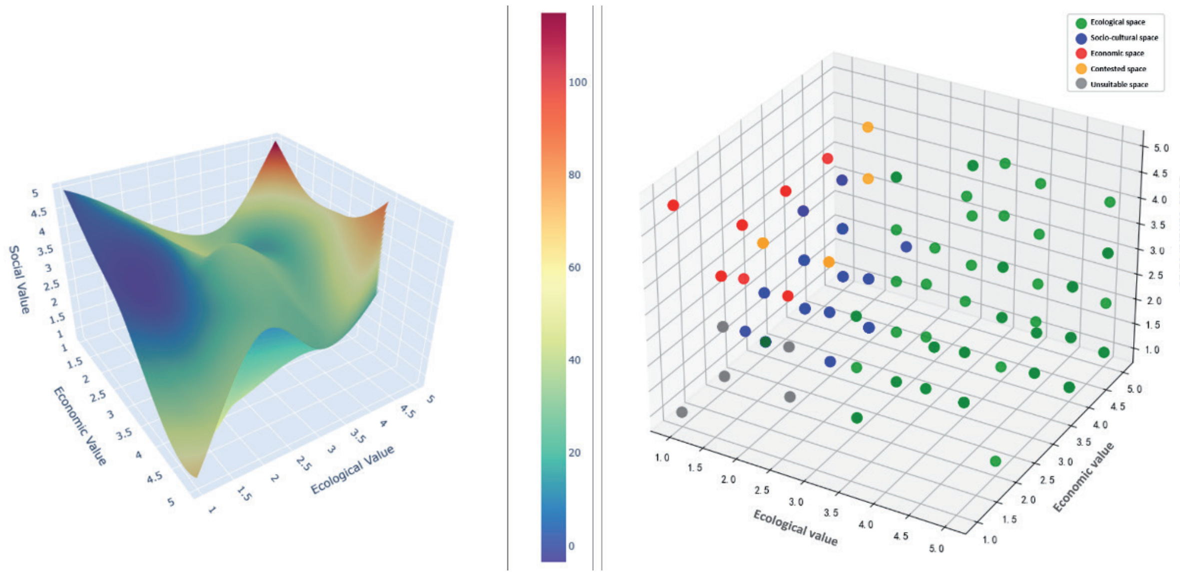

Fig. 8. Three-dimensional scatterplot of three types of value indices.

with the additional constraint that the ecological space area could not be less than 204.48 km². The results show that the ecological space covers 228.34 km², primarily located in the lake body of Shengjin Lake, the mountain forest areas south of the Middle Lake, and the river corridors east of the Lower Lake. The socio-cultural space, designated as the nature education and ecological experience zone, covers 22.83 km² and is mainly located along the western shoreline of Shengjin Lake and the southern shore of the Middle Lake. The economic space, designated as the production and living zone, extends across 82.23 km², concentrated in farmland to the north of the reserve and forested mountain areas in the southern part of the Lower Lake.

Sub-zoning Scheme

As shown in Fig. 9, the reserve was ultimately delineated into 2 levels of control: the core protection zone and the general control zone. The core protection zone covers an area of 228.34 km², accounting for 68.49% of the total reserve area. It is primarily distributed in the main lake body of Shengjin Lake, the mountain forest area to the south of the Middle Lake, and the riverine habitats east of the Lower Lake. Within this zone, a strict protection zone is designated, covering the entire 228.34 km², representing 100% of the core protection zone. This area represents the most ecologically valuable portion of the reserve and is characterized by high biodiversity and intact wetland ecosystems, thus requiring the highest level of protection. The general control zone covers 105.06 km², accounting for 31.51% of the total reserve area. It is primarily located in the northern farmland areas, the western wetlands of Shengjin Lake, the southern shoreline of the Middle Lake, and the mountain forest areas south of the Lower Lake. This zone is further divided into two functional sub-zones. The nature education and ecological experience zone extends over 22.83 km², accounting for 21.73% of the general control zone, mainly in the western part of Shengjin Lake and along the southern shore of the Middle Lake. The production and living zone covers 82.23 km², accounting for 78.27% of the general control zone, concentrated in the northern farmland and the southern forested areas of the Lower Lake. This delineation reflects the functional differentiation of land based on both ecological integrity and stakeholder needs, providing a framework for balancing strict protection with sustainable use.

Discussion

The Sub-zoning Model Integrating Multiple Stakeholder Objectives

The existing zoning model of the Shengjin Lake National Nature Reserve follows the traditional "core zone–buffer zone–experimental zone" framework. In principle, human access to the core zone is strictly prohibited, with exceptions granted only for scientific research activities that receive prior approval from the Reserve Management Bureau. The buffer zone permits similar activities under comparable restrictions, while the experimental zone accommodates scientific research, nature education, and low-intensity production and livelihood activities. Although this framework prioritizes biodiversity conservation, its emphasis on a rigid protection gradient outward from the core zone inadequately addresses the multi-objective demands

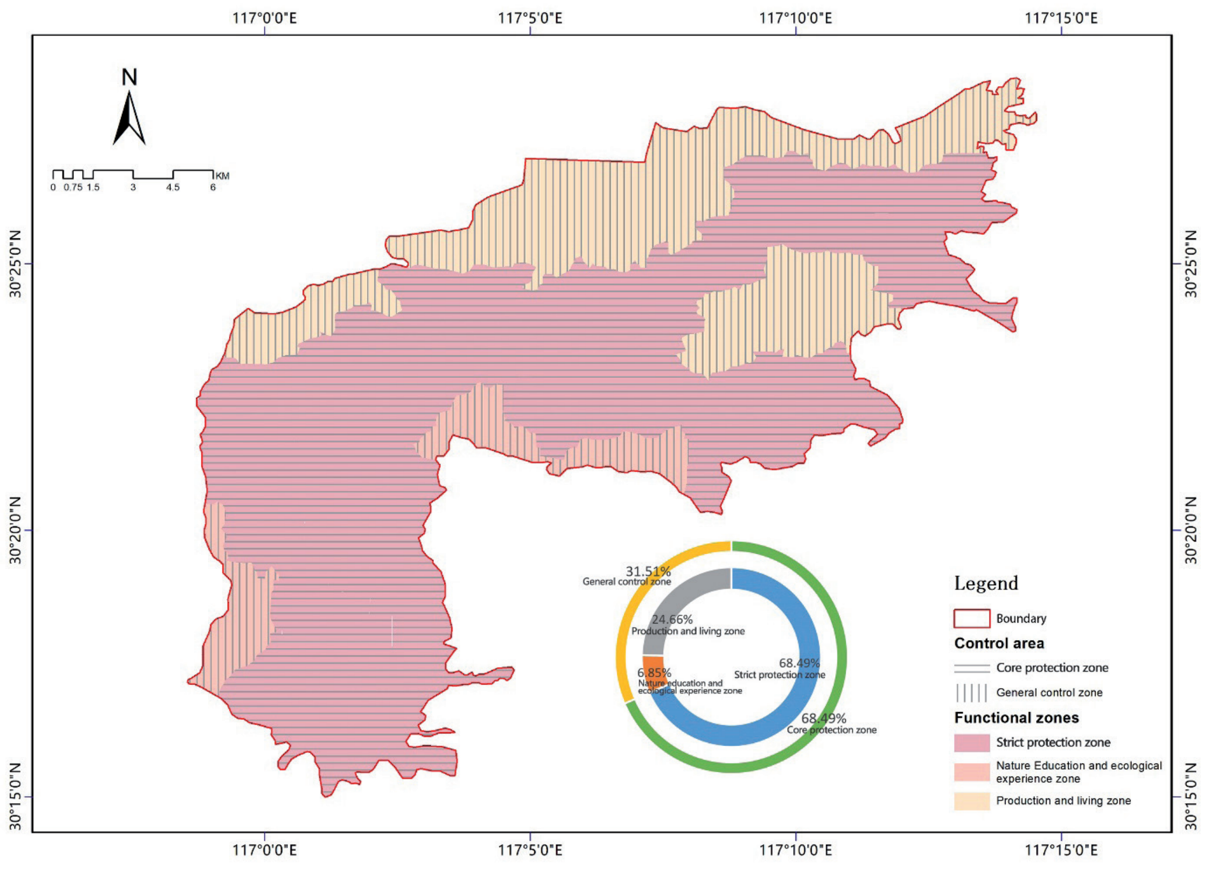

Fig. 9. Sub-zoning map.

of diverse stakeholders [59]. Moreover, the application of similar regulatory restrictions to both the core and buffer zones results in weak functional differentiation, leading to unclear zoning purposes and frequent conflicts between human activities and ecological protection.

To overcome these limitations, this study introduces a stakeholder-oriented, multi-objective sub-zoning model that differentiates zones not only by management intensity but also by the functional roles of resources and the ecosystem services they provide. The management intensity primarily reflects the degree of control over human activities, which is mandatory and legally binding. Once delineated, strict regulatory measures must be implemented to safeguard the integrity of the wetland ecosystem and maintain the rich avian biodiversity of the reserve, thereby fulfilling the objectives of the Reserve Management Bureau and the scientific research institutions. At the same time, functional zoning emphasizes flexibility and distinctiveness, aligning spatial divisions with specific ecosystem service functions. Under this refined framework, biodiversity conservation remains the foundation, but socio-cultural and economic objectives are explicitly integrated. More than 60,000 local residents can continue essential livelihood activities; enterprises such as the Conch Cement Factory are permitted non-destructive production; visitors may engage in nature education and ecological experiences. In contrast to the traditional model, which rigidly separates protection from use, the proposed sub-zoning scheme achieves a dynamic balance among ecological protection, socio-cultural values, and economic needs. This integrative approach provides a more rational, inclusive, and sustainable management system for the reserve.

Differentiated Control Strategies for Sub-Zoning

Nature reserves differ significantly in terms of conservation priorities, core ecological assets, and geographic contexts. Within a unified framework of national policies and regulations, it is essential to adopt context-specific zoning and delineation strategies that emphasize the dominant ecological functions of different areas. Implementing differentiated control measures tailored to local conditions is crucial for enhancing the effectiveness of reserve management. At the control zone level, the Shengjin Lake National Nature Reserve enforces strict protection in the core protection zone, where all human activities unrelated to ecological protection are prohibited. However, non-destructive and non-consumptive activities directly related to ecological protection are permitted. In the general control zone, construction and other potentially disruptive activities are tightly regulated, and moderate human activities may be allowed, provided they do not compromise ecosystem stability or biodiversity integrity. At the functional zone level, the strict protection zone primarily aims to conserve critical habitats for rare bird species, as well as lake and forest ecosystems. Activities such as agriculture, fisheries, pollution-generating operations, logging, burning, recreation, or any behavior that could degrade the environment are strictly forbidden. Within farmland-wetland systems in this zone, seasonal restrictions, particularly during the wintering periods of migratory birds, are enforced to align with the protection standards of other core conservation areas [60]. The nature education and ecological experience zone is designated for moderate educational and awareness activities, which must be conducted without compromising the ecological integrity of farmland-wetland systems. Management measures in this zone include strict limits on visitor numbers, clear behavioral guidelines, and the prohibition of any activities that could disturb wildlife habitats or breeding sites. The production and living zone is intended for the regulated development of low-impact industries, such as eco-friendly agriculture, controlled mineral extraction, and sustainable forestry. Permitted activities include restricted farming, agritourism, regulated mining, and managed economic forest cultivation or logging. All activities within this zone must be subject to strict regulation regarding intensity and extraction volume, ensuring they remain within the ecological carrying capacity of the reserve.

The Shengjin Lake National Nature Reserve exemplifies a representative protected area in China. Designated as one of the 40 nature reserves of global significance in 1992, and recognized as an Internationally Important Wetland in 2015, the reserve primarily focuses on conserving wintering migratory birds. At the same time, it faces significant human activity, leading to frequent conflicts between resource conservation and utilization. In this study, core stakeholders were identified, and the ecosystem service values they prioritize were quantitatively assessed. Based on the spatial distribution of these services, the MOLA model was employed to delineate the reserve into distinct zones. Compared with the adaptive zoning approach of the Natura 2000 framework, both zoning models serve to alleviate conflicts between various stakeholders. However, the sub-zoning model presented in this study is specifically tailored to the unique management needs and zoning objectives of the reserve. It effectively separates management intensity from zoning types, providing valuable insights for enhancing the clarity of zoning management within the adaptive zoning framework. This approach facilitates the integration of stringent protection measures with targeted utilization, ultimately contributing to the sustainable governance of the protected area.

Shortcomings and Prospects

Adaptive management is a systematic and iterative approach for improving resource management by emphasizing learning from management outcomes [61].

Within nature reserves, dynamic zoning represents a practical mechanism to implement adaptive management. The concept of "dynamic zoning" has been introduced in various types of spatial planning, including comprehensive land-use zoning, natural resource zoning, and ecological area zoning. However, its application within the context of nature reserve management remains limited. Existing studies primarily focus on reserves where the seasonal migration of protected wildlife constitutes the main management concern [62]. Despite its limited adoption, dynamic zoning holds significant potential for enhancing ecosystem protection, improving biodiversity richness, and mitigating human–land conflicts.

The Shengjin Lake National Nature Reserve primarily protects rare and endangered migratory bird species, including storks, cranes, geese, ducks, and plovers. In this context, stringent control measures have, to some extent, constrained the production and livelihood activities of nearby communities [63, 64]. At present, the reserve employs a static functional zoning scheme, which fails to account for the seasonal dynamics of migratory bird activities. Consequently, conflicts often emerge between ecological protection and local livelihood needs during the wintering and breeding seasons, when strict protection measures are enforced. Conversely, during non-migratory periods, certain strictly protected zones may be underutilized, resulting in inefficient land use.

To address these mismatches, future research should explore the establishment of a seasonally responsive dynamic zoning model. Such a model would enforce strict protection of critical habitats during key migratory and breeding seasons, while permitting moderate, well-regulated livelihood activities during non-critical periods. Areas not requiring stringent protection in a given season could be temporarily designated for sustainable human use, such as eco-agriculture, community-based practices, and subsequently restored to conservation functions as needed. This flexible management approach would facilitate a more coordinated balance between ecological protection and resource utilization, safeguarding both the ecological integrity of the reserve and the livelihood security of local residents. Ultimately, dynamic zoning has the potential to maximize land-use efficiency and promote the long-term coexistence of biodiversity conservation and human well-being. To ensure the scientific validity and practical effectiveness of dynamic zoning management in the Shengjin Lake Reserve, long-term monitoring of biodiversity and ecosystem health should be conducted to capture trends in ecological change. Moreover, integrating these monitoring data with actual management needs will support systematic pilot studies on dynamic zoning, providing empirical evidence and practical experience for the broader implementation and replication of this adaptive management model.

Conclusions

This study takes the Shengjin Lake National Nature Reserve as an example. First, core stakeholders of the reserve were defined by the Mitchell scoring method. Second, the ecosystem service values prioritized by different core stakeholders in the reserve were explored through structured questionnaires and semi-structured interviews. Then, these ecosystem service values were quantitatively assessed by combining the MaxEnt model, the SolVES model, the precipitation storage method, and the market value method. Finally, based on the MOLA model, sub-zoning of the reserve was quantitatively delineated by considering the priority of land unit allocation and the ecological space area as constraints, combined with the spatial distribution of ecosystem service values, in order to provide some references for the zoning of the same type of nature reserve.

The main conclusions of this study are as follows: (1) The core stakeholders of the reserve comprise 5 groups, namely the reserve management bureau, scientific research institutions, visitors, local residents, and enterprises. Among these, the reserve management bureau and scientific research institutes prioritize biodiversity conservation, flood regulation, and water retention; visitors focus on aesthetic and nature education values; and local residents and enterprises are primarily concerned with material production and raw material supply. (2) The areas of high ecological value cover 127.82 km², accounting for 38.34% of the total reserve area. These areas are mainly located in the southern part of the Upper Lake, the Middle Lake and Lower Lake regions. The areas of high social and cultural value cover 217.15 km², accounting for 65.13% of the total reserve area. These areas are mainly located in the lake body of Shengjin Lake and its northern coastal area. The areas of high economic value cover 71.86 km², accounting for 21.56% of the total reserve area. These areas are predominantly located in the mountain forest area of the southern Lower Lake, where the mineral resources are concentrated. (3) The reserve's zoning framework comprises 2 hierarchical levels: functional zones and control zones. The functional zones were divided into 3 zones. The strict protection zone covers an area of 228.34 km², accounting for 68.49% of the total reserve area, mainly in the main lake body of Shengjin Lake. The nature education and ecological experience zone extends over 22.83 km², accounting for 6.85% of the total reserve area, mainly in the western part of Shengjin Lake. The production and living zone covers 82.23 km², accounting for 24.66% of the total reserve area, mainly in the northern farmland areas. The control zones were divided into 2 zones. The core protection zone covers an area of 228.34 km², accounting for 68.49% of the total reserve area, mainly in the main lake body of Shengjin Lake. The general control zone covers 105.06 km², accounting for 31.51% of the total reserve area, mainly in the northern farmland areas and the western part of Shengjin Lake.

Acknowledgments

This research was funded by the Anhui Provincial Natural Science Foundation (2508085MC050), the Anhui Province Philosophy and Social Science Planning Key Project (AH-SKZ2022D09), and the U.S. National Geographic Air and Water Conservation Fund (GEFC29-16).

AI Usage Disclosure Statement

During the preparation of this work the authors used ChatGPT in order to improve language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Conflict of Interest

The authors declare no conflict of interest.

References

1. HUMMEL C., POURSANIDIS D., ORENSTEIN D., ELLIOTT M., ADAMESCU M.C., CAZACU C., ZIV G., CHRYSOULAKIS N., VAN DER MEER J., HUMMEL H. Protected Area management: fusion and confusion with the ecosystem services approach. Science of The Total Environment, **651**, 2432, **2019**.
2. WATSON J.E.M., DUDLEY N., SEGAN D.B., HOCKINGS M. The performance and potential of protected areas. Nature, **515** (7525), 67, **2014**.
3. UNEP-WCMC, IUCN. Protected Planet Report 2024. UNEP-WCMC & IUCN, **2024**.
4. YUAN J., YANG D., LIU N., GAO C. A local-scale participatory zoning approach to conflict resolution in protected areas. Landscape and Urban Planning, **232**, 104677, **2023**.
5. FU Y. Progress of research on conflicts between construction and management of nature reserves in China and mitigation strategies. World Forestry Research, **36** (4), 107, **2023** [In Chinese].
6. ZHANG Y., XU J., YAO Y., YAN Z., TENG M., WANG P. What is the relationship between natural protected areas and stakeholders? Based on literature analysis from 2000–2021. Forests, **13** (5), 734, **2022.**
7. ASFAW T., GEBRESENBET F., SILLERO-ZUBIRI C., LEIRS H., GIZAW G., TSEGAYE A., ABATE W., BAUER H. Mammalian community structure varies with distance between protected areas in the Omo Valley, Southwest Ethiopia. Ecology and Evolution, **15** (4), e71248, **2025**.
8. ZHU J., LI Z., YANG J., YU K., ZHANG D., ZHONG J. Ecological space management and control zoning of Giant Panda National Park from the perspective of ecosystem services and land use. Scientific Reports, **14** (1), 19951, **2024**.
9. CHEN J., WANG J., LI H., XU J., HUANG J., DENG Y. Optimizing functional zoning for Dalingshan Forest Park in China through microcosmic human disturbance evaluation. Environmental Science and Pollution Research, **31** (1), 1195, **2024**.
10. PRISTUPA A.O., TYSIACHNIOUK M., MOL A.P., LEEMANS R., MINAYEVA T., MARKINA A. Can zoning resolve nature use conflicts? The case of the Numto Nature Park in the Russian Arctic. Journal of Environmental Planning and Management, **61** (10), 1674, **2018**.
11. YOUNG J., WATT A., NOWICKI P., ALARD D., CLITHEROW J., HENLE K., JOHNSON R., LACZKO E., MCCRACKEN D., MATOUCH S., NIEMELA J., RICHARDS C. Towards sustainable land use: identifying and managing the conflicts between human activities and biodiversity conservation in Europe. Biodiversity & Conservation, **14** (7), 1641, **2005**.
12. PULIDO-CHADID K., VIRTANEN E., GELDMANN J. How effective are protected areas for reducing threats to biodiversity? A systematic review protocol. Environmental Evidence, **12** (1), 18, **2023.**
13. ZHAO L., DU M.X., ZHANG W., LI C.J., LIU Q., KANG X., ZHOU D. Functional zoning in national parks under multifactor trade-off guidance: A case study of Qinghai Lake National Park in China. Journal of Geographical Sciences, **10**, 1969, **2022**.
14. KOK F., SISMAN-AYDIN G. Evaluation of Management Effectiveness of an Outstanding Marine Protected Area in Southwest Coast of Türkiye: On the Road to 30 by 30. Sustainability, **17** (5), 1905, **2025**.
15. MEI H. On the Chinese Programme for the Classification and Zoning Control of Marine Nature Reserves. Journal of Ocean University of China (Social Science Edition), **5**, 40, **2024** [In Chinese].
16. SUN H.Y., YU L., CAI F., LUO W.X., TANG F.L. On the “control-function” sub-zoning of national parks. Forestry Construction, **3**, 1, **2019** [In Chinese].
17. YE Y.H., ZHANG J.Y. Discussion on method of controlled zoning and functional zoning of national parks: Take Shennongjia National Park System Pilot Area as an example. Journal of Natural Resources, **38** (4), 1075, **2023** [In Chinese].
18. National Forestry and Grassland Administration. Technical specification for national park masterplanning. National Forestry and Grassland Administration, **2017** [In Chinese].
19. BENNETT D., DIEKÖTTER T. Using species distribution modelling in identifying locations for habitat restoration, relocations and potential ecological traps for the sand lizard, Lacerta agilis, in Northern Germany. European Journal of Wildlife Research, **71** (4), 68, **2025**.
20. ZHANG N., ZHOU J.B., LIU S., CHEN Y., WANG H. Analysis and comparison of zoning methods for nature reserves. Journal of Anhui Agricultural University, **44** (5), 862, **2017** [In Chinese].
21. ALMASIEH K., MOHAMMADI A. Assessing landscape suitability and connectivity for effective conservation of two semi-desert ungulates in Iran. Conservation Science and Practice, **5** (12), e13047, **2023**.
22. ZHANG Q., ZHANG Z., LIU J.J., SONG R.Z., YANG Z.H. Construction of ecological security pattern in Hangzhou based on MSPA technology and InVEST model. Environmental Science, **47** (1), 494, **2026** [In Chinese].
23. ZHANG Y., QIU Y., ZHANG D., DAI X.A. Identification of ecological function zoning based on ecosystem

service clusters: an example from the Northwest Sichuan Ecological Demonstration Area. Environmental Science, **46** (11), 7258, **2025** [In Chinese].
24. WANG S., YAO W., MA Y., SHANG E., ZHANG S., CHEN F., ZENG Y. Optimizing natural boundary definition and functional zoning in protected areas: an integrated framework encompassing species, landscapes and ecosystems. Global Ecology and Conservation, **49**, e02781, **2024**.
25. HUANG Q.Y. Analysis of Stakeholder Impacts on the Value of Ecosystem Services : A Case Study of Guangdong Province. Guangzhou University, **2023** [In Chinese].
26. EASTMAN J.R., JIANG H., TOLEDANO J. Multi-criteria and multi-objective decision making for land allocation using GIS. In: Beinat, E., Nijkamp, P. (eds) Multicriteria Analysis for Land-Use Management. Environment & Management, Springer, Dordrecht. **9**, 227, **1998**.
27. SETIAWAN I., MAHMUD A.R., MANSOR S., MOHAMED SHARIFF A.R., NURUDDIN A.A. GIS-grid-based and multi-criteria analysis for identifying and mapping peat swamp forest fire hazard in Pahang, Malaysia. Disaster Prevention and Management: An International Journal, **13** (5), 379, **2004**.
28. JOORABIAN SHOOSHTARI S., JAHANISHAKIB F. Estimating the severity of landscape degradation in future management scenarios based on modeling the dynamics of Hoor Al-Azim International Wetland in Iran–Iraq border. Scientific Reports, **14** (1), 11877, **2024**.
29. QIU Y., ZHOU A., LI M., GUO Y., MA C. Territorial spatial usage regulation based on resources endowment and sustainable development: A case of Wuhan, China. Journal of Cleaner Production, **385**, 135771, **2023**.
30. WANG X.L., WANG X. Study on spatial zoning of key ecological function areas based on the MOLA method of "town, agriculture and ecology" – Taking Shennongjia forest area as an example. Land Resources Science and Technology Management, **35** (4), 1, **2018** [In Chinese].
31. Anhui Shengjin Lake National Nature Reserve Administration. Anhui Shengjin Lake Internationally Important Wetland Ecological Monitoring 2019–2020 Research Annual Report. **2020** [In Chinese].
32. YUAN X. Introduction to Shengjin Lake National Nature Reserve. Anhui Forestry Science and Technology, **1**, 1, **2004** [In Chinese].
33. WANG L., XU J., JIANG Y., JIN Y., WANG Y. Land use decision-making and ecosystem service trade-offs: A case study of Anhui Shengjin Lake National Nature Reserve, China. Polish Journal of Environmental Studies, **33** (4), 3903, **2024**.
34. KANG W.Q. Research on the rural water supply difficulties and their resolution paths from the perspective of stakeholder theory – An empirical investigation based on Y Village, Youxian District, Mianyang City, Sichuan Province. Agricultural Science Technology and Information, **5**, 98, **2024** [In Chinese].
35. BALDESSARI S., DE MEO I., CANTIANI M.G., PALETTO A. Social relevance of ecosystem services provided by urban green infrastructures: A mixed qualitative–quantitative case study approach. Land, **14** (2), 230, **2025**.
36. MULATU D.W., AHMED J., ETSEHIWOT S., TIRUWORK A., TINEBEB Y., AKWANY L.O. Correction: Stakeholders, institutional challenges and the valuation of wetland ecosystem services in South Sudan: The case of Machar Marshes and Sudd Wetlands. Environmental Management, **69** (5), 1050, **2022**.
37. KOKO I.A., MISANA S.B., KESSLER A., FLESKENS L. Valuing ecosystem services: stakeholders' perceptions and monetary values of ecosystem services in the Kilombero wetland of Tanzania. Ecosystems and People, **16** (1), 411, **2020**.
38. QIU X., HE W., ZHANG S. Research on ecological network identification in rare animal habitats based on the MaxEnt model and ant colony algorithm: A case study of Giant Panda National Park, China. Biodiversity and Conservation, **33** (11), 3207, **2024**.
39. YANG Y., LI W.T., ZHOU Z.Z., LI C.L. Study on the relationship between landscape pattern and water level in the wetland of Shengjin Lake. Journal of Biology, **36** (2), 61, **2019** [In Chinese].
40. WANG L., LU L., YANG Y.F., CHENG Y.W., WANG Y. Functional zoning of nature reserves based on ecosystem service trade-offs – Anhui Shengjin Lake National Nature Reserve as an example. National Parks, **1** (3), 151, **2023** [In Chinese].
41. YACHENG G., YEHUI T., RAN W., TINGTING W. Traditional fair built heritage protection based on stakeholder analysis: A case study of Licun Fair in Qingdao. China City Planning Review, **32** (4), **2023**.
42. REHAN M., HASSAN A., ZEB S., ULLAH S., AHMAD F., BOHNETT E., BOSSO L., FIDA T., KABIR M. Application of species distribution models to estimate and manage the Asiatic black bear (Ursus thibetanus) habitat in the Hindu Kush Mountains, Pakistan. European Journal of Wildlife Research, **70** (3), 62, **2024**.
43. UMEHARA A., HARADA H., NAKAI S., NISHIJIMA W. Prediction of macrobenthos distribution using the MaxEnt and simplified estimable environmental variables in the Seto Inland Sea, Japan. Plankton and Benthos Research, **20** (1), 46, **2025**.
44. XU J., ZHAO Y., WANG C., YAN Y., WEN Y. From current to future projections: Modeling habitat suitability changes for Hibiscus syriacus L. in China using MaxEnt under climate change. Frontiers in Plant Science, **16**, 1551684, **2025**.
45. FU A., GAO E., TANG X., LIU Z., HU F., ZHAN Z., WANG J., LUAN X. MaxEnt modeling for predicting the potential wintering distribution of Eurasian spoonbill (*Platalea leucorodia leucorodia*) under climate change in China. Animals, **13** (5), 856, **2023**.
46. YOUSEFI M., NICOLAÏ M.P., BOSSO L., KAFASH A., NEZAMI B., RASTEGAR-POUYANI E. Global-scale high-resolution habitat suitability modeling of avifauna providing pollination service (sunbirds, *Nectariniidae*). Scientific Reports, **15 (1)**, 9489, **2025**.
47. JIANG F., SONG P., ZHANG J., WANG D., LI R., LIANG C., ZHANG T. Assessment approach for conservation effectiveness and gaps for endangered species based on habitat suitability: A case study of alpine musk deer in western China. Ecological Indicators, **170**, 113080, **2025**.
48. HE Z., ALI H., WU J., LIU Z., WEI X., ZHUO Z. Impact of climate change on the distribution of *Isaria cicadae* Miquel in China: Predictions based on the MaxEnt model. Frontiers in Microbiology, **16**, 1509882, **2025**.
49. LI H., PENG X., JIANG P., XING L., SUN X. Prediction of potential suitable distribution for sweet cherry (*Prunus avium*) based on the MaxEnt model. PLoS ONE, **19** (7), e0294098, **2024**.
50. YANG H., ZHANG H., WANG Y., JIA X., HAO L., JIN K., SONG J. Urban bird diversity conservation plan based on the MaxEnt model and InVEST model: A case study of Jinan, China. Ecological Indicators, **174**, 113463, **2025**.

51. FENG Y., ZHANG H., TAO S., AO Z., SONG C., CHAVE J., LE TOAN T., XUE B.L., ZHU J.L., PAN J., WANG S.P., TANG Z.Y., FANG J.Y. Decadal lake volume changes (2003–2020) and driving forces at a global scale. Remote Sensing, **14** (4), 1032, **2022**.
52. LI Y.Y., MA X.S., WU H.P. Multi-source remote sensing inversion and spatial and temporal change analysis of water conservation volume – An example of Huangshan City. Journal of Gansu Agricultural University, **55** (4), 104, **2020** [In Chinese].
53. ZHANG H.B., ZHANG M.Y., WANG K.L., QIN X.J., FU J. Characteristics of changes in water-sourcing function in the southern hilly mountain belt. Research on Agricultural Modernisation, **35** (3), 345, **2014** [In Chinese].
54. SHERROUSE B.C., SEMMENS D.J., ANCONA Z.H. Social Values for Ecosystem Services (SolVES): Open-source spatial modeling of cultural services. Environmental Modelling & Software, **148**, 105259, **2022**.
55. DUAN S., XU N. Assessing social values for ecosystem services in rural areas based on the SolVES model: A case study from Nanjing, China. Forests, **13** (11), 1877, **2022**.
56. MA Q. Socio-cultural value assessment of wetland ecosystem services based on SolVES model. Northwest University, **2018** [In Chinese].
57. LIU H.X., CAO X.Y., ZHANG C.C. Research progress on the valuation of ecosystem services. Green Technology, **26** (3), 273, **2024** [In Chinese].
58. FENG X., TAO Z., NIU X., RUAN Z. Multi-objective land use allocation optimization in view of overlapped influences of rail transit stations. Sustainability, **13** (23), 13219, **2021**.
59. GONZALEZ-URANGO H., LIGARDO-HERRERA I., JACOME-ENRIQUEZ W., GÓMEZ-NAVARRO T. Designing participatory planning processes for protected areas, promoting the social and economic development of the stakeholders involved: The case of Cotopaxi National Park (PNC) in Ecuador. Regional Environmental Change, **25** (2), 55, **2025**.
60. BYJU H., RUBEENA K.A., SHIFA C.T., ATHIRA T.R., JISHNU K., SINGH J., SOHIL A., KUSHWAH S., KUMAR A., ANAND J., RAJANEESH K.M., MANOKARAN S., GIJJAPPU D.R., RESHI O.R., ILYAS O., SHARMA N., JUNAINA K.K., RAVEENDRAN N., MUMTHAZ T.M.V., NASSER M., MUZAFFAR S.B., NEFLA A., RAHMAN S.M., AARIF K.M. Transitioning wintering shorebirds to agroecosystems: A thorough evaluation of habitat selection and conservation concern. Diversity, **16** (1), 23, **2023**.
61. MÅNSSON J., ERIKSSON L., HODGSON I., ELMBERG J., BUNNEFELD N., HESSEL R., JOHANSSON M., LILJEBÄCK N., NILSSON L., OLSSON C., PÄRT T., SANDSTRÖM C., TOMBRE I., REDPATH S.M. Understanding and overcoming obstacles in adaptive management. Trends in Ecology & Evolution, **38** (1), 55, **2023**.
62. GAO Y. Model study on dynamic zoning of national parks and their control strategies. Southeast University, **2023** [In Chinese].
63. MA L., WU J., ZHANG H., LOBORA A., HOU Y., WEN Y. Conflict governance between protected areas and surrounding communities: willingness and behaviors of communities – empirical evidence from Tanzania. Diversity, **16** (5), 278, **2024**.
64. FIDA T., MOHAMMADI A., ALMASIEH K., BOSSO L., UD DIN S., SHAMAS U., NAWAZ MA., KABIR M. Species distribution modelling and landscape connectivity as tools to inform management and conservation for the critically endangered Himalayan brown bear (Ursus arctos isabellinus) in the Deosai National Park, Pakistan. Frontiers in Ecology and Evolution, **12**, 147748, **2025**.