EVALUATION OF ECOLOGICAL CONSERVATION PRIORITY IN THE JIAODONG PENINSULA, CHINA: AN INTEGRATED ANALYSIS OF ECOSYSTEM SERVICES AND VULNERABILITY

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(Received 19th Mar 2025; accepted 13th May 2025)

Abstract. Ecological conservation significance serves as an integrated measure evaluating the criticality of regional ecosystems in terms of their structural configuration and functional processes. On the basis of clarifying the characteristics of the natural environment and key ecological problems of Jiaodong Peninsula in China, we comprehensively analyzed the ecological vulnerability and the importance of ecological service function, constructed the assessment index of ecological protection importance of Jiaodong Peninsula, and used GIS technology to identify the areas of great importance for protection. Geospatial analysis identifies 3304.85 km^2, or 11% of the peninsula's total area, as critical ecological conservation zones in the Jiaodong Peninsula, with the highest concentrations occurring along the northeastern coastal margins and central-southern littoral corridors. The patches with ecological protection importance level 7 and 9 were identified through multi-criteria screening as ecological priority conservation cores, and the patches with more than 10 km^2 were selected as the final ecological priority conservation cores, and 96 ecological sources were identified, collectively spanning 4609.23 km^2 and constituting 15.22% of the study area's total terrestrial surface. The findings offer actionable insights for optimizing ecological zoning and conservation policies in the Jiaodong Peninsula, while establishing an empirical foundation to advance targeted ecosystem restoration and sustainable management strategies.
Keywords: *ecological protection, ecosystem services, vulnerability, Jiaodong Peninsula, China*

Introduction

Extremely rapid industrialization and urbanization, the irrational utilization and exploitation of natural resources by humans have led to the disruption of regional ecological processes and the degradation of ecological integrity (Han et al., 2023; Kubacka, 2022). Regional and global ecological crises are becoming increasingly evident, and the functionality of ecosystem services is rapidly declining (Li et al., 2009; Lin et al., 2018). Achieving equilibrium between environmental preservation and socioeconomic advancement has become a critical research challenge (Li et al., 2022).

The determination of ecological conservation significance is fundamentally composed of two critical elements: the analysis of ecosystem service value and the appraisal of environmental fragility (Liu, 2022; Ma et al., 2022). Ecosystem services describe the ability of natural ecosystems to sustain human societal welfare, while ecological vulnerability characterizes the inherent features of ecosystems encompassing their responsive sensitivity and autonomous recovery potential when exposed to external environmental pressures (Aronson et al., 2016; Ouyang et al., 2000). The evaluation of ecosystem service importance involves a quantitative study of the services

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_72217236

provided by ecosystems to humans within specific temporal and spatial contexts (Zhao et al., 2004; Wang et al., 2024). The notion of ecosystem services originated during the mid-20th century, with early scholarly investigations centered on understanding the interconnections between ecological systems and their provision of benefits to human societies (Xiang et al., 2011). Constanza et al. (1997) characterized ecosystem services as the diverse benefits and resources derived from ecological systems for human utilization, establishing a foundational operational framework for quantifying nature's contributions to socioeconomic development. Daily (1999) characterized them as the natural environmental conditions and services provided by ecosystems, which are crucial for human survival and development.

Ecological vulnerability is conceptualized as a system's intrinsic susceptibility and adaptive capacity to external perturbations such as climatic shifts, pollutant exposure, or habitat degradation (Adger and Agnew, 2004; De Lange et al., 2010). This multidimensional characteristic arises from the synergistic interactions among endogenous ecological succession patterns, exogenous environmental stressors, and anthropogenic modifications to natural systems (Wang et al., 2024). Ecological source zones are systematically delineated through integrated spatiotemporal evaluations of ecosystem service functional significance and ecological fragility thresholds, with priority conservation hotspots subsequently designated as critical nodes for maintaining regional biodiversity integrity (Xu et al., 2023). Methodological analysis of ecological significance evaluation enables the identification of conservation prioritization frameworks, thereby facilitating the institutionalization of ecological safeguards, sustainable utilization of natural capital, and optimized spatial allocation of industrial sectors, ultimately achieving synergistic equilibrium between socioeconomic progress and environmental stewardship within integrated socio-ecological systems (Liu et al., 2003; Wei et al., 2024).

The study area of the Jiaodong Peninsula of China is situated in the coastal economic hinterland of Shandong Province, which is an important gateway for China's external development and an important area with unique location in Shandong Province's blue economy development strategy. In recent times, the rapid economic growth and premature opening of the Jiaodong Peninsula region has resulted in serious challenges to ecological issues, such as destruction of vegetation, land degradation, and desertification, which will inevitably threaten the development and stability of the region and even the country. Therefore, conducting a study to assess the ecological conservation significance in the Jiaodong Peninsula region is of great importance.

This study employs a multidimensional analytical framework, focusing on key indicators such as water conservation, soil conservation, habitat quality, and carbon stock, to quantify the ecological service importance of the Jiaodong Peninsula in China. In addition, an integrated ecological vulnerability assessment is conducted by incorporating soil erosion vulnerability and desertification vulnerability, providing a comprehensive evaluation of the region's ecological resilience. GIS technology is then utilized to identify areas of significant ecological importance for conservation. The core objective of this research is to delineate priority ecological conservation zones within the Jiaodong Peninsula, offering a scientific basis for optimizing ecological zoning and formulating targeted conservation policies. Furthermore, the findings provide an empirical foundation for advancing ecosystem restoration efforts and developing sustainable management strategies in the region.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Materials and methods

Research region overview

The Jiaodong Peninsula (35°35′–38°23′N, 119°30′–122°42′E), colloquially termed “Jiaodong,” occupies the eastern sector of Shandong Province, China, demarcated by the Jiao-Lai River as its western boundary. This peninsular landmass is strategically situated at the northeastern periphery of the North China Plain, forming a tri-coastal interface with the Bohai Sea to the north, the Yellow Sea to the southeast, and the Liaodong Peninsula across the strait. Functioning as Shandong’s prime economic engine, the region exemplifies a dual-natured spatial paradigm: a high-value industrial concentration zone specializing in advanced manufacturing and innovation-driven sectors, concurrently serving as the provincial nucleus for marine-based economic development within China’s coastal megalopolis strategy. It is governed by Qingdao, Yantai and Weihai, which together comprise 28 counties. This coastal region spans a terrestrial expanse of 30,000 km², featuring a 3345-km littoral zone that constitutes approximately one-sixth of China’s total mainland coastal interface (*Fig. 1*).

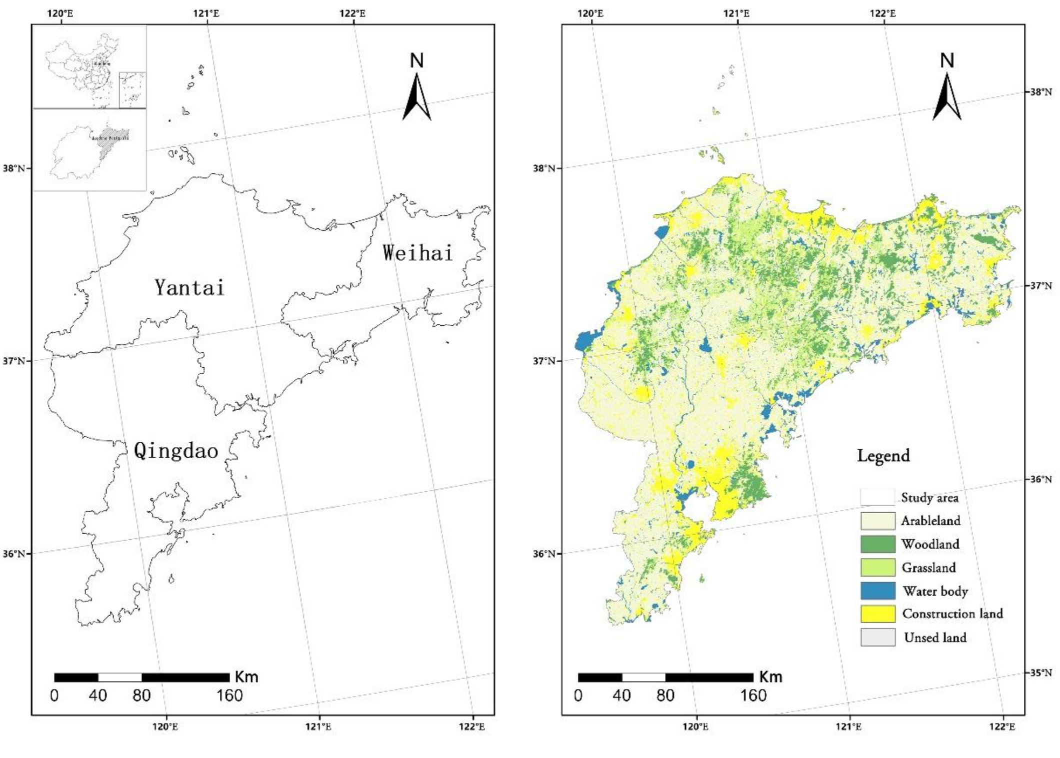

Figure 1. *The geographic location and land use classifications of the Jiaodong Peninsula. Data sources: Resource and Environmental Science Data Platform and ESRI base maps*

The coast of Jiaodong Peninsula is winding, the terrain is primarily characterized by hills and erosion-dominated plains, low-relief hill systems predominantly occupy the north and east, a few mountain ranges protrude above the hills, and the plain basins are interlaced with and surrounded by them, and most of the plains are reclaimed to a high degree. The Jiaodong Peninsula exhibits a maritime-influenced warm temperate monsoon climate shaped by its tri-coastal configuration, where sea-land thermal

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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differential drives thermal moderation with attenuated temperature extremes. Climatic parameters demonstrate an annual mean temperature range of 11-15°C and cumulative precipitation between 600-900 mm, dominated by a concentrated precipitation regime (June-August contributing 60-70% of total).

The Jiaodong Peninsula constitutes a zonal climax community dominated by Quercus-Acer mixed deciduous broadleaf assemblages, hosting 14 state-designated forest conservation reserves that sustain multilayered trophic networks. However, the Jiaodong Peninsula was developed earlier, and the ecological environment has been subjected to high intensity human activities, such as urban construction, land-source emissions, offshore engineering construction, and seawater farming, which have led to the destruction of ecological stability within the region, and the ecological environment has obvious vulnerability.

Data origins

The fundamental datasets employed in this study include land use data, net primary productivity (NPP), digital elevation model (DEM), normalized difference vegetation index (NDVI), climate data, soil data, and other multi-source geospatial datasets (*Tables 1–5*).

Table 1. *Data origins*

Datatype	Data time	Source of data	Data accuracy	Usage
Land use	2000-2020	http://www.resdc.cn/	30 m	All modules (land classification, threat sources, factor assignment)
NPP	2020	http://modis.gsfc.nasa.gov	500 m	Vegetation productivity, carbon storage, habitat quality
DEM	2020	https://www.gscloud.cn/	30 m	Water conservation (Topographic Index), erosion vulnerability (LS factor)
NDVI	2020	https://earthengine.google.com	30 m	Vegetation cover status, habitat quality, desertification vulnerability
Soils	-	http://www.fao.org/soils-portal/ Harmonized World Soil Database	1000 m	Soil texture, K factor, plant available water content (PAWC) for water conservation and erosion
Climactic	2020	http://www.cma.gov.cn/	-	Precipitation, rainfall erosivity, evapotranspiration, wind speed, temperature, aridity index
Nature reserve	2021	NSII-China National Specimen Resource Platform	-	Habitat quality, ecological protection zoning
Biophysical parameter table	-	Kang et al. (2021), InVEST Model User Guide (*Table 2*)	Literature-derived	Inputs for water conservation model (rooting depth, vegetation parameters)
Threat factor table	-	InVEST Model Guide (*Tables 3* and *4*)	Literature-derived	Habitat quality (human disturbance modeling)
Carbon density table	-	Houghton (2005), Post et al. (1982), etc. (*Table 5*)	Literature-derived	Carbon storage (C_above, C_below, C_soil, C_dead)

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Table 2. *Biophysical parameters assigned to land use types in the Jiaodong Peninsula*

LULU	Root_Depth (mm)	Evapotranspiration coefficient
Arable land	2100	0.7
Woodland	7000	1
Grassland	2600	0.65
Water body	1000	1.2
Construction land	550	0.4
Unused land	500	0.3

Table 3. *Parameter settings for habitat threats in the InVEST model*

Threat factor	Weight	Max_DIST	Decay
Arable land	0.7	8	Linear
Construction land	1	10	Exponential
Unused land	0.2	3	Exponential

Table 4. *Sensitivity of LULC types to various threat factors in the Jiaodong Peninsula*

LULU	Habitat	L_Arable land	L_Construction land	L_Unused land
Arable land	0.5	0	0.5	0.4
Woodland	1	0.8	0.9	0.5
Grassland	0.7	0.5	0.6	0.5
Water body	0.9	0.7	0.8	0.2
Construction land	0	0	0	0
Unused land	0.1	0.1	0.2	0

Table 5. *Carbon densities of LULC types in the Jiaodong Peninsula (t/ha)*

LULC_Name	C_above	C_below	C_soil	C_dead
Arable land	4.02	0.75	98.13	2.11
Woodland	22.62	18.03	126.75	2.78
Grassland	3.6	11.7	90.43	7.28
Water body	1.59	0	64.03	3.98
Construction land	0.83	0.08	43.71	0
Unused land	0.59	0.64	28.42	0.96

Research methods

This study conducted a comprehensive assessment of ecological conservation importance in the Jiaodong Peninsula by integrating two dimensions: ecosystem service functionality and ecological vulnerability. For the evaluation of ecosystem services, four modules from the InVEST model were employed, namely: Annual Water Yield, Sediment Delivery Ratio (SDR), Carbon Storage and Sequestration, and Habitat Quality. By inputting relevant spatial environmental data, spatially explicit raster outputs were generated, reflecting the distribution and magnitude of water conservation, soil conservation, carbon storage, and habitat quality within the study area. Each ecosystem service was evaluated individually using the Jenks Natural Breaks

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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classification method, and categorized into five levels: generally, relatively, moderately, very and extremely. Subsequently, based on the existing studies by Cui et al. (2019), Li et al. (2024), and Kang et al. (2021), the four individual assessment results were weighted and integrated (*Table 6*), generating a composite index of ecosystem service importance, which was further classified into five corresponding levels.

Table 6. *Weights for ecosystem service types and justifications in the Jiaodong Peninsula*

Ecosystem service type	Weight	Justification
Water conservation	0.25	Water resources are scarce in the Jiaodong Peninsula, requiring prioritized protection
Soil conservation	0.30	The region has many mountainous areas with prominent soil erosion issues
Habitat quality	0.20	Key to maintaining biodiversity
Carbon storage	0.20	Essential for addressing climate change

(1) Water conservation

Water conservation encompasses the strategic management and preservation of terrestrial and subterranean hydrological resources within diverse ecosystems, serving as a critical mechanism for upholding biodiversity integrity and advancing long-term socio-ecological resilience (Du et al., 2022). The regional water yield is calculated using the “Annual Water Yield” module of the InVEST model the calculation formula is as follows (Bao et al., 2016):

$$Y_{(x)} = \left(1 - \frac{AET_{(x)}}{P_{(x)}}\right) \times P_{(x)} \tag{Eq.1}$$

Y(x) indicating annual water yield (mm), AET(x) signifying actual evapotranspiration (mm), and P(x) equating to annual precipitation (mm) for individual raster units.

(2) Soil conservation

Soil conservation encompasses strategies aimed at mitigating erosional processes and maintaining sedimentary deposits, as demonstrated in the following equation. Detailed computational procedures for individual components are provided in earlier research (Hu et al., 2019).

$$SEDRET_x = R_x \cdot K_x \cdot LS_x \cdot \left(1 - C_x \cdot P_x\right) + SEDR_x \tag{Eq.2}$$

SEDRETx refers to the soil retention on raster x; Rx refers to the precipitation erosivity factor on raster x; Kx refers to the soil erodibility factor on the raster; LSx refers to the slope length-slope gradient factor on raster x; and Cx and Px refer to vegetation cover control factor and the soil and water conservation practice factor on raster x.

(3) Habitat quality

The Habitat Quality module of the InVEST model was employed to identify the threat sources within the study area. Each threat factor was assigned a specific weight

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and a maximum effective distance, reflecting its relative influence on habitat degradation. In addition, the quality of habitats under external pressure was evaluated. The resulting habitat quality values ranged from 0 to 1 (Sharp et al., 2015), with higher values indicating better habitat conditions. The specific calculation formula is presented as follows (Wu et al., 2025):

$$Q_{xj} = H_j\left[1-\left(\frac{D_{xj}^{z}}{D_{xj}^{z}+K^{z}}\right)\right] \quad \text{(Eq.3)}$$

Qxj signifies the spatially explicit habitat quality metric for grid cell x in land cover class j; Hj reflects the ecological potential of land cover class j; Dxj quantifies the cumulative threat intensity impacting grid cell x under land cover regime j; k constitutes the saturation coefficient corresponding to 50% of maximum Dxj values; z serves as the scaling factor with a standardized value of 2.5.

(4) Carbon stock

The InVEST model's Carbon module quantifies four principal reservoirs: aboveground biomass carbon, belowground biomass carbon, soil organic carbon, and carbon from dead organic matter (*Table 2*). The aggregate carbon storage (Ctotal, $t\cdot hm^{-2}$) within the study basin is determined by summing the four major carbon pools across different land types (Sun et al., 2025). The computational framework is mathematically expressed as:

$$C_{totali} = \left(C_{abovei} + C_{belowi} + C_{soili} + C_{deadi}\right)\times A_i \quad \text{(Eq.4)}$$

Ctotal signifies the overall carbon stock; Cabove denotes the aboveground carbon pool; Cbelow refers to the underground carbon pool; Csoil represents the carbon pool in the soil; Cdead indicates the dead organic matter carbon pool; i represents the average carbon stock of each land use category, and Ai signifies the extent of that land use category.

Ecosystem vulnerability is an intrinsic property of ecological systems, expressed through biocomplexity diagnostics that quantify the susceptibility and responsiveness of system components to external stressors (Weißhuhn et al., 2018). This systemic attribute enables mitigation of exogenous disturbances across spatial scales, facilitates the prioritization of core conservation zones as bioclimatic refugia (Okey et al., 2015), and enhances adaptive capacity thresholds via nonlinear resilience pathways (De Lange et al., 2010). Shandong Province, particularly the coastal ecotones of the Jiaodong Peninsula and the orographic regions of central-southern Shandong, exhibits pronounced susceptibility to soil degradation, making these areas critical hotspots for soil erosion. Consequently, this study adopted soil erosion and land desertification vulnerability as key indicators for evaluating ecological vulnerability. Aligned with the Provisional Guidelines for China's Ecological Zoning, a five-tier vulnerability classification scheme was established using the Jenks Natural Breaks algorithm within the reclassification module of ArcGIS (*Table 7*). The two individual vulnerability indices were integrated via spatial overlay analysis to produce a composite ecological vulnerability map of the Jiaodong Peninsula.

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This map was then overlaid with the ecosystem service importance index to derive a comprehensive assessment of conservation priority. Spatial modeling, conducted within the ArcGIS environment, generated hierarchical maps of conservation importance categorized into five levels: generally, relatively, moderately, very, and extremely.

Table 7. *Ecological vulnerability indicators and grading standards*

Ecological vulnerability	Indicators	Non-vulnerable 1	Mildly vulnerable 3	Moderately vulnerable 5	Highly vulnerable 7	Extremely vulnerable 9
Soil erosion vulnerability	Rainfall erosivity	<20	20–100	100–300	300–600	>600
	Soil susceptibility to erosion	<0.01	0.01–0.02	0.02–0.03	0.03–0.04	>0.04
	Relief	0–30	30–50	50–100	100–300	>300
	Vegetation cover	>0.8	0.8–0.6	0.4–0.6	0.2–0.4	<0.2
Land desertification vulnerability	Aridity index	<1	1–2	2–4	4–16	>16
	Days of sandy wind in winter and spring	<5	5–10	10–20	20–30	>30
	Soil texture	Sand/gravel	Coarse and soil/fine sand soil/clay	Sandy soil/loam	Silty clay/loam clay/sandy loam	Silt/sandy silt

(1) Soil erosion vulnerability

Soil erosion vulnerability quantifies the multifaceted expression of landscape pressure response thresholds and the self-regulatory capacity of the landscape under erosional forcing mechanisms, and is a fundamental determinant in the broader framework of ecosystem vulnerability. The soil erodibility factor is derived by classifying soil types based on organic matter content, soil structure, and soil texture. The evaluation data of each individual factor are multiplied using spatial analysis in ArcGIS, as shown in the following formula:

$$SS_i = \sqrt[4]{R_i \times K_i \times LS_i \times C_i} \quad \text{(Eq.5)}$$

The composite pedo-erosion susceptibility index (SSi) integrates four geospatial determinants: precipitation aggressiveness coefficient (Ri), pedodiversity erodibility quotient (Ki), terrain amplification index (LSi), and vegetation coverage factor (Ci) (Yang et al., 2022).

(2) Land desertification vulnerability

Desertification susceptibility characterizes the propensity of dryland ecosystems, including arid, semi-arid, and dry sub-humid zones, to undergo accelerated land degradation when exposed to exogenous stressors or anthropogenic perturbations (Wei et al., 2024). The following formula is employed to assess it:

$$D_i = \sqrt[4]{I_i \times W_i \times K_i \times C_i} \quad \text{(Eq.6)}$$

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$$Ii = 0.16\frac{Annual Accumulated Temperature \geq 10^{\circ}C}{Annual\ Precipitation during \geq 10^{\circ}C\ Period} \quad \text{(Eq.7)}$$

The desertification sensitivity index (Di) is calculated through the integration of four key parameters: aridity index (Ii), high-velocity wind occurrence (Wi threshold > 6 m s^{-1}), pedological composition (Ki), and vegetative canopy density (Ci).

Results

Importance of ecosystem services

Figure 2 delineates the conservation priority assessment of ecosystem service significance within the Jiaodong Peninsula's matrix. Extremely important areas with important water containment functions (*Fig. 2a*) account for 20% and 32% of the total area of the Jiaodong Peninsula, running through the east-west and south-south coastal areas of the Jiaodong Peninsula, and the extremely important areas are mainly distributed along the Jialai River. The extremely and very important areas of habitat quality (*Fig. 2c*) cover 39% of the Jiaodong Peninsula, and the extremely important carbon stock regions (*Fig. 2d*) represented 18.6%, primarily focused in the regions of the mountain ranges such as Dazhe Mountain, Asan, Kunmu Mountain and Laoshan Mountain.

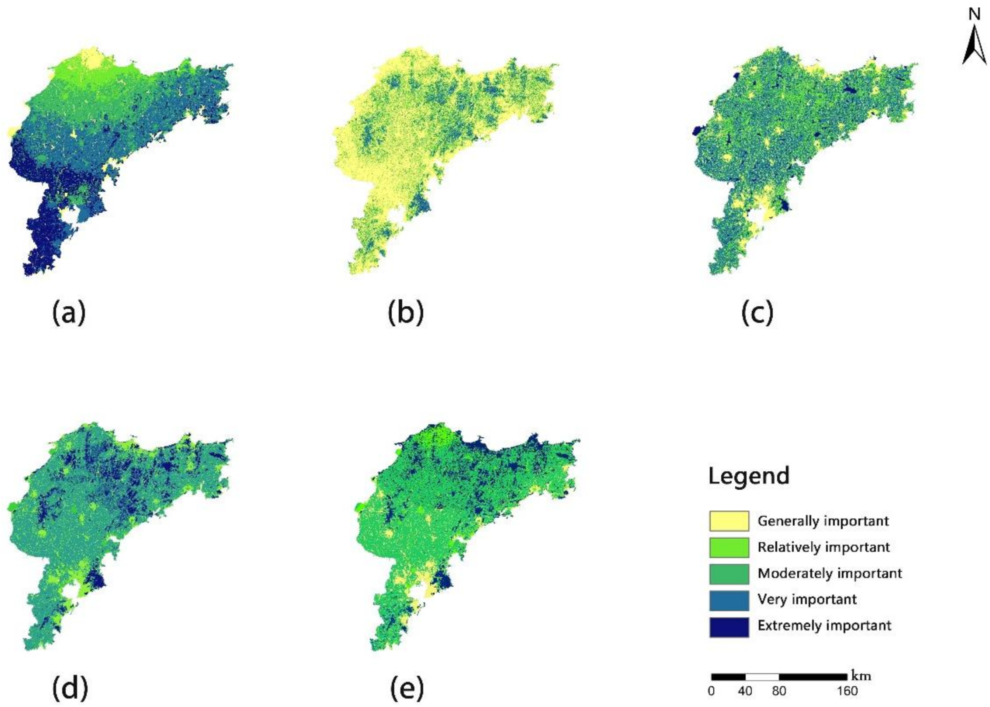

Figure 2. *Geospatial distribution of ecosystem service significance: (a) Water conservation; (b) soil conservation; (c) habitat quality; (d) carbon stock; and (e) composite conservation priority assessment*

The hierarchical valuation of ecological service priorities, derived through univariate analytical protocols, reveals distinct spatial stratification as visualized in

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Figure 2e. The critical conservation zones in the extremely important areas encompass 4929.03 km², accounting for 16.27% of the Peninsula's terrestrial domain, predominantly concentrated within the coastal ecosystems of northern Jiaodong and orographic systems, including Wulian, Laoshan, Ashan, and Dazhe massifs. Priority sectors in the very important areas occupy 892.2 km², or 3.00% of the study region's terrestrial expanse, while moderately, relatively, and generally important areas collectively constitute 80.73% of the regional territory, as quantitatively detailed in *Table 8*.

Table 8. *Surface extent and proportional contribution of each ecosystem service importance level*

Level	Area/km²	Proportions/%
Generally important	3535.64	11.67
Relatively important	1775.51	5.82
Moderately important	19153.80	63.24
Very important	892.20	3
Extremely important	4929.03	16.27

Ecological vulnerability assessment

The ecological fragility assessment outcomes for the Jiaodong Peninsula are presented in *Figure 3*. Quantitative analysis identified extremely vulnerable and very vulnerable zones for soil erosion vulnerability (*Fig. 3a*), spanning 329.39 km² and 4620.34 km², respectively, collectively constituting 16.3% of the peninsula's total terrestrial surface. These regions are primarily distributed in the southeastern coastal areas of Yantai City, littoral zones along Qingdao's southern coastline, and the Lai River watershed encompassing southwestern peri-urban catchments.

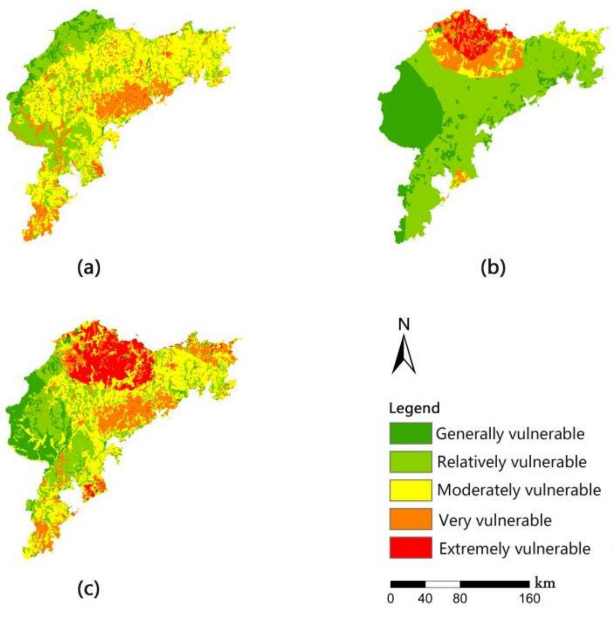

Figure 3. *Geographical distribution of ecological vulnerability. (a) Soil erosion vulnerability (b) land desertification vulnerability; and (c) ecological vulnerability*

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Regarding land desertification, the areas categorized as extremely vulnerable and very vulnerable cover 1410.07 km² and 3392.26 km², respectively, representing 16.2% of the peninsula's terrestrial surface. These zones are primarily situated in the northern areas of Yantai City and the southeastern coastal regions of Qingdao City.

Using single-factor analysis stratified the Jiaodong Peninsula's ecological vulnerability into distinct tiers (*Fig. 3c*), The extremely vulnerable areas span 3870.13 km², representing 12.78% of the total area, with construction land being the predominant land use type. Spatial distribution patterns demonstrate concentrated vulnerability along the peninsula's northern and southern littoral interfaces. Moderately vulnerable zones span 5418.32 km^2, representing 17.9% of the study area, with principal concentrations in Yantai's southern agrarian belt, Weihai's northern jurisdictional precincts, and Qingdao's southwestern coastal administrative units. Cumulatively, lower-tier vulnerability classes (moderately/relatively/generally categories) represent 69.32% of the region's total landmass, as verified through spatial chi-square tests (*Table 9*).

Table 9. *Area and percentage of each level of ecological vulnerability*

Level	Area/km²	Proportions/%
Generally vulnerable	4350.86	14.36
Relatively vulnerable	6716.37	22.17
Moderately vulnerable	9930.50	32.79
Very vulnerable	5418.32	17.9
Extremely vulnerable	3870.13	12.78

Ecological conservation importance

The integrated conservation prioritization framework for the Jiaodong Peninsula was established through a methodological synthesis of ecosystem service importance and ecological vulnerability assessments. This geospatial synthesis protocol, executed using raster algebra operations in ArcGIS, culminated in optimized zoning through the application of Jenks' natural breaks optimization algorithm (*Fig. 4a*).

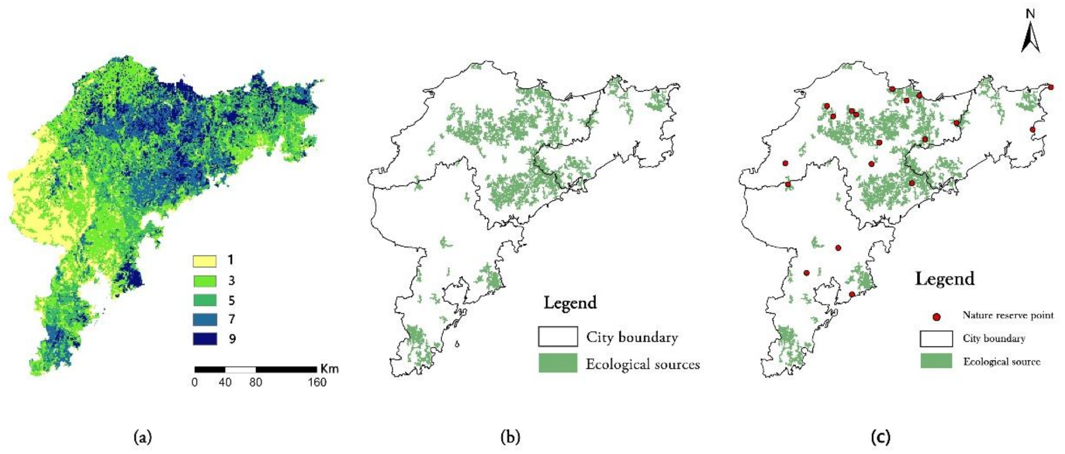

Figure 4. *Spatial arrangement of ecological conservation priority areas. (a) Ecological importance; (b) ecological conservation priority areas; (c) Nature reserves and ecological sources*

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The critical important areas for ecological conservation cover 3304.85 km², accounting for 11% of the peninsula's aggregate surface. These priority conservation zones exhibit pronounced geospatial clustering within the central hinterlands and northeastern littoral belt, and the southern coastal areas of the peninsula. Regions with moderate ecological conservation importance cover 4829.86 km², accounting for 16.8% of the overall area. These areas are predominantly located in the central, eastern coastal, and southwestern coastal regions of the peninsula, with Yantai City occupying the largest share.

Quantitative assessment of conservation priority across ecosystem typologies revealed distinct spatial prioritization patterns (*Table 10*). Forest biomes demonstrated superior ecological criticality, where priority conservation zones classified as 56.03% and 21.69% dominated the spatial configuration. Grassland ecosystems followed, the conservation areas were categorized with 15.26% classified as extremely important, 31.14% as very important, and 24.5% as moderately important. In contrast, unused land and water ecosystems had smaller proportions of extremely important areas, at 4.75% and 4.59%, respectively. Notably, construction land and arable land designated as extremely important for ecological conservation accounted for 13.1% and 5% of their respective ecosystem types.

Table 10. *Conservation priority stratification across ecosystem typologies reveals spatially heterogeneous protection urgencies*

Land use category	Entire area	Generally important		Relatively important		Moderately important		Very important		Extremely important	
	km²	km²	%	km²	%	km²	%	km²	%	km²	%
Arable land	18007.64	2504.22	13.9	6783.08	37	4879.93	27	2956.37	16.4	884.01	5
Woodland	3019.40	40.43	1.38	264.21	8.7	368.15	12.2	654.88	21.69	1691.73	56.03
Grassland	2627.84	94.68	3.6	670.19	25.5	643.82	24.5	818.35	31.14	400.8	15.26
Water body	1532.79	460.18	30.02	470.36	30.69	422.89	27.59	109.05	7.11	70.31	4.59
Construction land	5062.98	1240.72	24.5	1655.41	32.71	861.66	17.01	641.85	12.68	663.34	13.1
Unused land	35.53	14.48	40.75	12.48	35.13	4.03	11.34	2.85	8.03	1.69	4.75

Ecological patches with conservation importance levels of 7 and 9 were selected as ecological sources. To address management challenges associated with small patches, this study ultimately chose patches larger than 10 km² as ecological sources. These selected sources were then overlaid with the 19 nature reserves within the Jiaodong Peninsula (*Fig. 4c*). Spatially, the nature reserves largely overlapped with the conservation priority areas, affirming the reliability of the ecological importance evaluation. The spatial prioritization framework identified 96 priority conservation zones, covering an area of 4609.23 km², which constitutes 15.22% of the total study area (*Fig. 4b; Table 11*).

Table 11. *Area and percentage of each level of ecological conservation priority areas*

Level	Area/km²	Proportions/%
Generally important	5138.76	16.96
Relatively important	9663.53	31.9
Moderately important	7349.18	24.2
Very important	4829.86	15.94
Extremely important	3304.85	11

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DOI: http://dx.doi.org/10.15666/aeer/2304_72217236

Discussion and conclusion

This study selected six evaluation indicators based on the major ecological issues and typical ecosystem services of the Jiaodong Peninsula, including the importance of water conservation, soil conservation, habitat quality, carbon stock, alongside susceptibility to land degradation and soil erosion vulnerability. These spatially-explicit metrics establish an evidence-based framework for prioritizing conservation strategies and ecological rehabilitation. Geospatial prioritization analysis delineated critical conservation zones spanning 3304.85 km² (11% of the peninsula's total land area), corresponding to regions of exceptional ecological significance in the Jiaodong Peninsula. Spatial analysis reveals significant clustering of these zones within the northeastern littoral belt of the peninsula, the central region (including Yashan, Kunyushan, Dashan, and the Dagujia River), and the southern coastal region (including Laoshan and Wulian Mountain) of the Jiaodong Peninsula. Overall, the areas of extremely high ecological conservation importance are predominantly characterized by large mountain ranges and water systems. Patches with ecological conservation importance levels of 7 and 9 were selected as ecological sources, with those larger than 10 km² chosen as the final ecological sources. The spatial optimization protocol delineated 96 priority conservation nuclei encompassing 4609.23 km², representing 15.22% of the investigated territory's terrestrial surface. The 19 nature reserves within the Jiaodong Peninsula were overlaid with the ecological sources, revealing that the nature reserves largely overlap with the ecological source areas.

The ecological conservation importance exhibits significant variation across different land use types. Natural ecosystems, including woodlands and grasslands, clearly have the highest conservation priority value in ecological assessments, whereas artificial ecosystems, including construction land and arable land, show relatively low ecological conservation importance. Within the Jiaodong Peninsula, there are 19 nature reserves that play a critical role in biodiversity conservation. The area of extremely high importance for ecosystem services spans 4929 km², comprising 16.27% of the peninsula's aggregate surface, these ecologically vital zones exhibit significant clustering within the littoral belt of its northern periphery, the central region, and the southeastern coastal region of the peninsula, with Yantai City contributing a relatively large proportion. Furthermore, the area of extreme ecological vulnerability covers 3870.13 km², representing 13.2% of the peninsula's total area, predominantly clustered along the northern and southern littoral interfaces of the Jiaodong Peninsula.

Compared to other ecologically sensitive regions in China, such as the Loess Plateau, the Three Rivers Source Region, and the karst areas of Southwest China, the Jiaodong Peninsula exhibits unique ecological conservation characteristics and challenges. The Loess Plateau is well known for its severe soil erosion and long-term ecological restoration programs, such as the "Grain for Green" project, while the Three Rivers Source Region is a national-level ecological redline protection area critical for water source conservation. In contrast, the ecological significance of the Jiaodong Peninsula has often been overlooked due to the region's high urbanization and rapid economic development along the eastern coastline.

This study, however, reveals that the Jiaodong Peninsula harbors important ecosystem service hotspots, particularly in mountainous and coastal ecotones. These areas are facing considerable ecological vulnerability due to rapid land use changes, agricultural expansion, and urban sprawl. While these pressures are similar to those in regions like the Pearl River Delta, the manifestation of these challenges is distinct,

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shaped by the unique topographical, climatic, and biogeographical characteristics of the peninsula. The Jiaodong Peninsula requires a more integrated conservation approach, balancing ecological protection with socio-economic development. Its dense population, advanced infrastructure, and fragmented natural habitats necessitate detailed conservation planning that emphasizes green infrastructure, nature-based solutions, and adaptive landscape management.

In summary, as a transitional region between inland and coastal ecosystems, the Jiaodong Peninsula provides a valuable case for demonstrating how high-resolution spatial ecological assessments can guide regional conservation policies. By integrating ecosystem service provisioning and vulnerability patterns into a unified conservation priority index, this study offers a replicable methodological framework for other rapidly developing coastal regions in China and globally. To enhance the ecological conservation efforts in the Jiaodong Peninsula region, it is recommended that, on the one hand, important ecologically fragile areas should be targeted, disaster prevention and control measures should be taken, drastic human activities such as engineering and construction should be reduced, and serious natural disasters should be avoided, and in areas prone to soil erosion and land sanding, strategic implementation of terrestrial erosion control measures necessitates phased reforestation of marginal croplands through adaptive landscape management frameworks that prioritize ecological vulnerability gradations. On the other hand, it has strengthened the protection of core ecological sources such as nature reserves, water systems and mountain ranges, strictly prohibited the encroachment of land for construction and agricultural expansion, set up ecological protection zones, and constructed greenways to isolate external pollution of water bodies and improve the circulation of the ecosystem.

Future research should focus on integrating ecosystem service flow modeling, stakeholder decision analysis, and socio-ecological feedback mechanisms. Additionally, strengthening cross-regional cooperation, particularly with neighboring provinces such as Jiangsu and Liaoning, could enhance large-scale ecological connectivity and resilience across the coastal ecological corridor of eastern China.

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