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Postprint: Research on Conservation Boundaries of Coastal Wetlands under Spatial Constraints

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Abstract

Wetland protection boundary delineation constitutes a fundamental prerequisite for sustaining wetland development and represents an essential pathway for coordinating wetland conservation with agricultural land utilization and urban development land allocation and spatial planning. This study approaches wetland protection boundaries from a "source-sink" ecological landscape interaction perspective, identifies wetland protection sources and their conservation priority levels, constructs a spatial constraint evaluation framework and ecological breakpoints to characterize the spatial hierarchical differentiation of sink landscapes, and employs a minimum cumulative resistance model to measure and classify wetland protection boundaries and their typologies. The research findings indicate: (1) Through multi-factor spatial constraint evaluation and the demarcation of wetland ecological breakpoints, the minimum resistance model effectively characterizes the constraints and differential impacts of integrated external factors on wetland protection, quantitatively delineating zones of minimum resistance for wetland conservation, thereby offering a novel methodological framework for wetland protection boundary demarcation. (2) Ecological breakpoints and regions with medium-to-high constraints within the southern Hangzhou Bay coastal area account for 52.69% of the study region, while unconstrained areas constitute merely 12.79%, establishing a fundamental pattern dominated by strong spatial constraints from comprehensive factors. Coupled with low-constraint regions occupying 34.53%, this demonstrates that the southern Hangzhou Bay coastal area predominantly exists in transitional stages between high and low spatial constraint regimes, thereby compressing the available space for wetland protection. (3) The study delineates wetland protection boundary extents and buffer zones at 49.11 km² and 24.07 km², respectively, with their combined area representing merely 5.47% of the southern Hangzhou Bay coastal region, indicating extremely limited capacity for wetland protection expansion and adaptive adjustment. Beyond ecological breakpoints providing natural boundaries for wetland protection, wetland protection boundaries are

manifested as three distinct types: conservation forest zones, agricultural land extension types, and water source protection categories.

Full Text

Preamble

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Mapping of Wetland Reserve Boundary in Coastal Zone Utilizing Spatial Constraints Assessment

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Abstract

The delineation of wetland reserve boundaries is fundamental not only for maintaining the functional sustainability of wetlands but also for coordinating land resource allocation and spatial distribution among wetland protection, farmland utilization, and urban development. This study analyzes wetland reserve boundaries from the perspective of source-sink landscape interaction theory, using the southern bank of Hangzhou Bay as a case study. The spatial differentiation of wetland protection sources and sink landscapes is examined through ecological boundaries and spatial constraints assessment. Wetland reserve boundaries and their types are delineated using the minimum cumulative resistance model. The research demonstrates the applicability of this approach for boundary delineation by integrating spatial constraints assessment and ecological zoning. Results show that ecological boundaries and high-to-medium constraint districts account for 52.69% of the study area, while only 12.79% comprises low or no-constraint districts, revealing an intensively constrained spatial pattern. The wetland reserve boundary and buffer zone cover 49.11 km^2 and 24.07 km^2 respectively, representing merely 5.47% of the southern Hangzhou Bay area, indicating extremely limited space for wetland protection expansion and adaptive adjustment. Beyond ecological boundaries, wetland reserve boundaries can be classified into three types: preserved forest areas, farmland expansion zones, and water source protection zones.

Keywords: wetland reserve boundary; source-sink landscape; spatial constraint assessment; ecological boundary; minimum cumulative resistance model; coastal zone

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Introduction

Wetlands, alongside forests and oceans, constitute Earth' s three major ecosystems, providing essential services including food and fertilizer production, pollutant degradation, water purification, and wildlife habitat. Despite their critical value, wetlands worldwide face severe threats from industrial and agricultural development, residential expansion, and pollution. China ranks fourth globally in wetland area, with vast ecological and economic value distributed across diverse types and scales. Effective wetland protection is essential for sustainable resource utilization and regional human-environment harmony.

Current research primarily focuses on deconstructing wetland utilization problems, protection measures, and sustainable development strategies. Studies have analyzed disturbance factors threatening wetlands and their external impacts, evaluated wetland protection utility and economic significance, identified protection gaps, and constructed optimized networks. However, wetland boundary research predominantly relies on vegetation, soil, and hydrological indicators to identify natural boundaries, with limited attention to human-driven boundary identification and guided protection.

Coastal zones represent China' s economic and population centers, where conflicts between economic development and ecological conservation constrain land use. As terrestrial resource limitations drive expansion toward sea and tidal flats, construction land encroachment causes gradual wetland retreat. For coastal zones serving as strategic pivots for maritime development, land resource allocation is critical. Maintaining wetland protection scope amid construction expansion and planning constraints to coordinate ecological and economic benefits is paramount for sustainable coastal land resources.

This study selects the southern bank of Hangzhou Bay as the research area to identify wetland protection sources and priority levels, constructing a spatial constraint assessment and ecological boundary framework to explore constrained spaces and protection limits for coastal wetland resources. Using an improved minimum cumulative resistance model that integrates ecological and natural factors, we simulate cumulative resistance that wetland protection must overcome, aiming to provide management strategy insights for coastal wetland protection patterns.

1. Study Area Overview

The southern bank of Hangzhou Bay forms an inverted U-shape across northern Ningbo, Zhejiang Province, extending from Yuyao City in the west to Zhenhai Cape in the east, bordering Hangzhou Bay estuarine tidal flats to the north and the Cuiping Mountain hilly area to the south. The region comprises mountainous foothills, lacustrine-alluvial plains, and coastal tidal flats, with abundant wetland resources including pond surfaces, river networks, and extensive tidal flats. The study area spans 120°–121°E longitude and 30°55 -30°27 N latitude.

As both Ningbo' s agricultural base and eastern Zhejiang' s industrial center, the region had per capita rural disposable income exceeding ¥13,337.83 in 2013. Cultivated land dominates land use (37.68%), followed by construction land (22.45%). The area features three core urban belts: Cixi, Hangzhou Bay New District, and Zhenhai. Planned reclamation reaches 108.67 km², with 77.26 km² already completed in the Cixi section alone. Under urban expansion and planning constraints, wetlands face increasingly severe threats from tidal flat reclamation, river infilling, and new district construction.

2. Data Sources

Land Use and Planning Data: Includes Second National Land Survey annual update data (2005–2020), 2020 land use planning data, Ningbo Urban Master Plan (2011–2020), and ecological protection redline zoning maps for Yuyao, Cixi, and Zhenhai districts.

Natural Background Data: 30m resolution Landsat 8 imagery from the Chinese Academy of Sciences'geospatial data cloud platform (path/row: 118/39). Geological hazard and subsidence data from Ningbo Municipal Bureau of Land and Resources.

Demographic and Transportation Data: Population data from 2013 statistical yearbooks of Yuyao, Cixi, and Zhenhai at township level. Transportation network data vectorized from Ningbo traffic route maps.

Environmental Protection Data: Heavy metal pollution source monitoring enterprises and wastewater treatment plants geolocated from Ningbo Environmental Protection Bureau monitoring lists. Marine water quality data digitized from 2013 Ningbo Marine Environment Bulletin pollution maps.

[Figure 1: see original paper] Location and wetland distribution of the study area

3. Wetland Protection: Source-Sink Landscape Framework

3.1 Wetland Protection Sources

Wetland protection is a process of resisting and compensating for human disturbance to maintain wetland functions sustainably. Protection sources are landscape patches that initiate and diffuse protection processes, serving as fundamental venues for environmental material exchange and ecological processes. Following the Ramsar Convention definition, wetlands include natural or artificial marshes, peatlands, or water bodies (fresh, brackish, or salt) with depth not exceeding 6m at low tide.

Based on Landsat 8 imagery and land use data, we extracted river surfaces, reservoirs, ponds, paddy fields, and tidal flats/marshes as wetland protection sources. Different landscape types contribute differently to ecological protection. We established protection priority levels based on distribution patterns, landscape fragmentation, and development characteristics—higher artificial influence corresponds to lower priority. The ranking coefficients are 0.95 for first rank, 0.90 for second rank, and 0.85 for third rank.

First-rank sources (tidal flats/marshes, 386.92 km^2): Extensive contiguous distribution along Hangzhou Bay with strongest ecological function and risk resistance, highest protection priority.
Second-rank sources (reservoir/river surfaces, 40.26 km^2): Adjacent to urban belts but concentrated along the bay, limited human disturbance, moderate protection priority.
Third-rank sources (paddy fields/ponds, 172.12 km^2): Scattered distribution with high fragmentation due to agricultural activities, lowest protection priority.

The characteristic classification of wetland protect sources

3.2 Wetland Protection Sink Landscapes and Spatial Constraints

Sink landscapes negatively impact wetland protection processes, causing wetland degradation through varying constraint intensities. We categorized constraints into wetland protection resistance and ecological boundaries.

Wetland Protection Resistance: Includes urban expansion, pollution, and other 阻滞 factors forming the ecological resistance base surface through spatial constraint assessment.

Ecological Boundaries: Represent peak resistance zones where human activity completely excludes other organisms, causing functional loss. These are insurmountable artificial boundaries where ecological energy values undergo qualitative change, fundamentally differing from wetland characteristics.

3.3 Spatial Constraint Assessment System

We developed a 16-indicator assessment system encompassing natural environment, urbanization impacts, ecological significance, and planning measures, using AHP and Delphi methods for weighting.

Natural Environment (0.1636 total weight): Elevation and slope directly constrain development; ground subsidence indicates indirect constraints.
Urbanization Impact (0.2284 total weight): Population agglomeration index ($PGI_i = \frac{P_j}{n} \times \frac{D_{ij}}{A_i}$) and transportation accessibility ($A_i = \sum_{j=1}^{n} T_{ij}$) measure human disturbance intensity.
Ecological Significance (0.2197 total weight): Water function zoning, habitat sensitivity index ($S_i = l \times n \times m$), and vegetation cover (NDVI) reflect wetland importance.

Planning Measures (0.3883 total weight): Land use planning consistency, construction land control, ecological zone control, and tidal flat reclamation plans represent management constraints.

Evaluation system of wetland spatial constraints

4. Minimum Cumulative Resistance Model

We introduce an improved MCR model incorporating wetland protection priority coefficients:

$$MCR_i = f_{min} \sum_{j=1}^{n} (D_{ij} \times R_i \times K_j)$$

Where:
- MCR_i = minimum cumulative resistance for grid unit i
- f = unknown positive function showing positive correlation between resistance and spatial constraints
- D_{ij} = spatial distance from source j to unit i
- R_i = resistance coefficient of grid unit i
- K_j = protection priority coefficient of wetland source j

The model synthesizes resistance surfaces from different protection levels to reflect cumulative ecological resistance from multiple spatial constraint factors.

5. Wetland Protection Boundary Identification

5.1 Ecological Boundary Delineation

Ecological boundaries total 286.73 km² (21.43% of study area), comprising:
- **Urban construction land** (255.84 km²): Urban, rural, and independent industrial/mining areas
- **Transportation land** (30.89 km²): Railways, highways, rural roads, and port terminals

These represent the most active human activity zones with maximum constraint on wetland distribution.

5.2 Spatial Constraint Pattern Analysis

Based on natural breaks classification, the spatial constraint pattern shows a "two small ends, large middle" structure, with 68.74% of the area under high or medium constraints.

High-constraint zones (118.51 km², 22.40%): Centered on Xiaocao' e Coastal Industrial New District and Hangzhou Bay New District, interspersed with ecological boundaries, reflecting concentrated high-intensity production impacts.
Medium-constraint zones (299.63 km²): Surrounding high-constraint areas,

representing transitional zones where development avoids rising ecological resistance.
Low-constraint zones (461.91 km², 34.53%): Largest area, comprising major agricultural reclamation zones and tidal flats, though recent constraints may rapidly increase.
No-constraint zones (171.05 km², 12.79%): Located in Hangzhou Bay Wetland Park and southern Cuiping Mountain forest areas, representing ecological substrate that cannot be compromised.

[Figure 2: see original paper] The spatial constraint pattern of wetland

5.3 Boundary Delineation Using MCR Model

Ecological flow from source to sink landscapes accumulates resistance with distance. At critical threshold points, resistance values 突变, indicating sharply diminishing returns in wetland protection area and ecological value. Using 突变 points in the MCR-value vs. area curve (thresholds: 8,238 and 10,386), we delineated:

- **Wetland protection boundary**: 49.11 km²
- **Buffer zone**: 24.07 km²
- **Total**: 73.18 km² (5.47% of southern Hangzhou Bay)

Despite extensive wetland distribution, protection space is extremely limited.

6. Three Types of Wetland Protection Boundaries

Type 1: Preserved Forest Boundaries (34.51 km², 13.86 km² buffer): Located in southern Yuyao hills and Cuiping Mountain areas, connecting reservoir clusters (Duhu, Jiaohu) to northern Zhenhai. These provide water conservation functions, with buffers composed of low hills, scattered farmland, and rural roads forming integrated natural systems.

Type 2: Farmland Extension Boundaries (11.25 km² buffer): Connect paddy fields and ponds in clustered agricultural development zones, notably in northwest Cixi (Andong, Zhouxiang reclamation areas) and Guanhaiwei Town. These form block-shaped protection areas around transportation hubs, nurturing suburban agricultural belts.

Type 3: Water Source Protection Boundaries (5.75 km² total): Distributed in eastern Hangzhou Bay New District reservoir areas. Constrained by ecological boundaries in the west but extending eastward to connect reclamation zones, these maintain water supply for irrigation and agriculture through dam construction and field management.

[Figure 3: see original paper] The delineation of wetland reserve boundary

7. Conclusions and Discussion

From a landscape ecology perspective, this study analyzed wetland protection sources and assessed spatial constraints from sink landscapes, using an improved MCR model to simulate and identify protection boundaries for the southern Hangzhou Bay. Key findings include:

1. **Integrated Assessment Framework**: The minimum cumulative resistance model effectively characterizes how external factors constrain wetland protection with spatial differentiation, quantifying minimum-resistance zones and providing a novel approach for boundary delineation. Ecological boundaries and high-to-medium constraint zones dominate (52.69%), with only 12.79% unconstrained, indicating strong comprehensive spatial pressure.

2. **Limited Protection Space**: The delineated wetland protection boundary and buffer zone occupy just 5.47% of the area (49.11 km² and 24.07 km² respectively), revealing extremely limited expansion and adjustment space. The region sits largely in transition zones between high and low constraints, further compressing wetland protection margins.

3. **Boundary Typology**: Three boundary types were identified: preserved forest boundaries in southern Yuyao hills and Cuiping Mountain reservoir clusters; farmland extension boundaries in Cixi' s northwestern reclamation areas; and water source protection boundaries in Hangzhou Bay New District' s eastern reservoir zone.

Management Implications: Under rapid urbanization, wetland protection boundaries remain unresolved due to limited economic returns. Strategies should follow a landscape-matrix-function evolution logic:
- **Matrix perspective**: Strictly control degradation of ponds and reservoirs while managing the interface between ecological boundaries and protection sources to prevent urban sprawl.
- **Functional perspective**: Differentiate measures based on heterogeneous functions—ecological conservation, water retention, and agricultural/industrial water supply—creating corridor linkages between protection sources, boundaries, and buffers to form functional organic units.

Limitations: The study aggregated fragmented patches due to their limited overall impact, but future research should refine landscape patch selection thresholds and explore integrated multi-factor zoning methods to improve breakpoint identification in cumulative resistance analysis.

References

[1] 湿地科学研究进展及研究方向. 中国科学院院刊, 2002, 17(3): 170-172.
[2] Turner R K, Bateman I J, Georgiou S, Jones A, Langford I H, Matias N G N, Subramanian L. An ecological economics approach to the management of a multi-purpose coastal wetland. Regional Environmental Change, 2004, 4(2/3):

86-99.
[3] Turner K. Economics and wetland management. Ambio, 1991, 20(2): 59-63.
[4] 中国湿地资源及其保护研究, 1999, 21(6): 34-37.
[5] 黄河流域湿地格局特征、控制因素与保护, 2012, 31(10): 1764-1774.
[6] 江苏省湿地资源现状及其可持续利用研究, 2004, 24(1): 81-84.
[7] 向海国家级自然保护区湿地资源保护与可持续利用探析, 2000, 20(2): 193-196.
[8] 环杭州湾城市规划及产业发展对湿地保护的影响, 2008, 63(10): 1055-1063.
[9] 陕西渭河下游湿地环境风险因素分析, 2007, 27(3): 371-375.
[10] 扎龙保护区湿地扰动因子及其影响研究, 2003, 23(6): 692-698.
[11] 覆被变化对洪河保护区湿地景观的影响, 2007, 62(11): 1215-1222.
[12] Zheng Y M, Zhang H Y, Niu Z G, Gong P. Protection efficacy of national wetland reserves in China. Chinese Science Bulletin, 2012, 57(10): 1116-1134.
[13] 湿地资源保护经济学分析—以北京野鸭湖湿地为例, 2012, 32(17): 5337-5344.
[14] 长江中游生态区湿地保护空缺分析及其保护网络构建, 2007, 27(12): 4979-4989.
[15] 黄淮海地区湿地系统生物多样性保护格局构建, 2010, 30(15): 3953-3965.
[16] 青岛市湿地保护红线划定研究, 2016, 14(1): 129-136.
[17] Segal D S, Latham P J, Best G R. Delineating a wetland boundary using vegetative, soil and hydrologic characteristics: a Florida cypress dome example. Wetlands, 1987, 7(1): 51-58.
[18] Adams D A, Buford M A, Dumond D M. In search of the wetland boundary. Wetlands, 1987, 7(1): 59-70.
[19] Tiner R W. The primary indicators method—a practical approach to wetland recognition and delineation in the United States. Wetlands, 1993, 13(1): 50-64.
[20] 湿地边界确定研究进展, 地理科学进展, 2006, 25(4): 41-48.
[21] 湿地边界确定的理论、方法与案例, 东北林业大学学报, 2006, 34(5): 66-69.
[22] Pearsel G, Mulamoottil G. Wetland boundary and land-use planning in southern Ontario, Canada. Environmental Management, 1994, 18(6): 865-870.
[23] 海岸带土地发展潜力评价—以杭州湾南岸为例, 海洋学研究, 2016, 34(1): 27-34.
[24] 基于区域土地利用规划的黄河口湿地退缩风险分析, 自然资源学报, 2011, 26(10): 1670-1679.
[25] 景观理论及其生态学意义, 2006, 26(5): 1444-1449.
[26] 基于 GIS 的农村住区生态重要性空间评价及其分区管制—以兴国县长冈乡为例, 2011, 31(1): 230-238.
[27] Hansen W G. How accessibility shapes land use. Journal of the American Institute of Planners, 1959, 25(2): 73-76.
[28] 一个基于专家知识的生态系统服务价值化方法, 自然资源学报, 2008, 23(5): 911-919.
[29] 基于 GIS 的区域关键性生态用地空间结构识别方法探讨, 2011, 33(1): 112-119.
[30] 基于 GIS 技术的图们江流域湿地生态安全评价与预警研究, 生态学报, 2014, 34(6): 1379-1390.
[31] 洞庭湖区湿地生态系统健康综合评价, 2009, 28(6): 1665-1672.
[32] Ye Y Y, Su Y X, Zhang H O, Liu K, Wu Q T. Construction of an ecological resistance surface model and its application in urban expansion simulations. Journal of Geographical Sciences, 2015, 25(2): 211-224.
[33] 平顶山新区生态用地的识别与安全格局构建, 2015, 35(6): 2003-2012.
[34] 基于最小阻力模型的土地整治中生态连通性变化及其优化研究, 2014, 34(6): 733-739.

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