

## Postprint of Landscape Naturalness Assessment of the Min River Estuary Wetland Nature Reserve and Its Surrounding Areas

**Authors:** Zhan Xin, Pan Wenbin, Zheng Peng, Ke Jinyan, Chen Qiliang

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### Abstract

The Minjiang River Estuary Wetland Nature Reserve represents a crucial component of Fujian Province's coastal wetland nature reserve network. Through interpretation of remote sensing imagery from two temporal phases (2003 and 2013), three indicators—natural landscape characteristics, ecological disturbance, and landscape fragmentation degree—were quantified utilizing RS and GIS spatial analysis techniques, upon which a two-tiered landscape naturalness evaluation index system was established. Concurrently, the Analytic Hierarchy Process was applied to compute the weight coefficients for each indicator stratum, enabling quantitative analysis of landscape naturalness dynamics in the study area during 2003–2013, and further investigating the impacts of concentric annular buffer zones at varying distances on landscape naturalness within the wetland reserve and its surrounding regions. The findings reveal that: from 2003 to 2013, landscape naturalness within the Minjiang River Estuary Wetland Nature Reserve declined by 9.17%, exhibiting a decreasing trend with increasing distance from the nature reserve boundary. Natural driving forces underlying landscape naturalness changes encompass climatic, hydrological, and vegetation succession processes, whereas anthropogenic driving forces consist of human development activities and policy orientation. Accordingly, three recommendations are proposed to enhance the effectiveness of naturalness conservation for both the reserve and its peripheral areas, thereby furnishing a scientific reference for the management of the Minjiang River Estuary Wetland Nature Reserve.

### Full Text

### Preamble

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## Landscape Naturalness Assessment of the Minjiang River Estuary Wetland Nature Reserve and Surrounding Areas

Zhan Xin<sup>1</sup>, Pan Wenbin<sup>1</sup>, Zheng Peng<sup>1</sup>, Ke Jinyan<sup>1</sup>, Chen Qiliang<sup>2</sup>

<sup>1</sup>College of Environment and Resources, Fuzhou University, Fuzhou 350116, China

<sup>2</sup>Fuzhou Environmental Monitoring Centre, Fuzhou 350011, China

Corresponding author. E-mail: wenbinpan@fzu.edu.cn

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### Abstract

The Minjiang River Estuary Wetland Nature Reserve represents a critical component of Fujian Province's coastal nature reserve network. This study interpreted remote sensing imagery from 2003 and 2013 to calculate indices of natural landscape features, ecological disturbance, and landscape fragmentation using GIS spatial analysis techniques. A multi-level landscape naturalness evaluation index system was constructed, and the Analytic Hierarchy Process (AHP) was employed to calculate the weight of each indicator layer, enabling quantitative analysis of landscape naturalness changes in the study area from 2003 to 2013. The influence of circular buffer zones at varying distances on the landscape naturalness of the wetland reserve and its surroundings was further examined. Results indicate that landscape naturalness within the Minjiang River Estuary Wetland Nature Reserve decreased by 9.17% during 2003-2013, with a clear trend of diminishing naturalness as distance from the reserve boundary increased. Natural driving forces included climate, hydrology, and vegetation succession, while anthropogenic drivers comprised development activities and policy orientation. Three recommendations are proposed to enhance protection effectiveness for the reserve and surrounding areas, providing a scientific basis for management of the Minjiang River Estuary Wetland Nature Reserve.

**Keywords:** wetland; nature reserves; analytic hierarchy processes; landscape naturalness

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### 1. Study Area Overview

The Fujian Minjiang River Estuary Wetland National Nature Reserve is located in Changle City and Langqi Economic Development Zone, Fuzhou City, with geographic coordinates of 119°35' 51.00" - 119°41' 12.00" E and 26°01' 07.05" - 26°04' 34.00" N. To investigate landscape naturalness changes in the reserve's periphery, the study area was defined as the reserve boundary plus a 6 km buffer zone outward. The reserve hosts a rich diversity of wildlife, including 131 species of wild vertebrates, among which 20 are under national key protection (5 Class I and 15 Class II). Aquatic biodiversity is abundant, with 131 species of benthic and intertidal organisms identified. The vascular flora comprises 109

species, predominantly warm-water varieties that form dominant and common populations. Based on species composition, physiognomic structure, and ecological distribution, the main vegetation types in the Minjiang River Estuary can be classified into mangroves, coastal psammophytic vegetation, and coastal salt marshes. Key species include *Spartina alterniflora*, *Phragmites communis*, *Cyperus malaccensis*, *Zoysia sinica*, *Clerodendrum inerme*, *Scirpus marqueter*, *Cynodon dactylon*, *Casuarina equisetifolia*, *Saccharum spontaneum*, *Acanthus ilicifolius*, and *Kandelia candel*.

## 2. Data Sources and Processing

To analyze landscape naturalness dynamics in the Minjiang River Estuary Wetland Nature Reserve and surrounding areas, Landsat 7 and Landsat 8 remote sensing images from 2003 and 2013 were selected. All images were acquired during low tide periods and processed using standard false-color composite. A multi-step classification method was employed: first, a land classification system was established and spectral characteristics of each land type were compared; then, extracted land classes were masked to eliminate influence on other features; classification began with easily separable types, while less distinct types were interpreted through construction of new bands and supervised classification until all land cover information was obtained.

## 3. Research Methods

### 3.1 Landscape Classification of Study Area

Based on field survey data and relevant literature, the study area's land use was classified into 6 primary categories and 14 secondary categories. According to human disturbance intensity, these were grouped into natural landscapes (sea area, vegetation beach, grassland), semi-artificial landscapes (cultivated land, garden plots, bare land), and artificial landscapes (construction land, transportation land, and facility agricultural land). Facility agricultural land primarily comprises aquaculture areas and irrigation/drainage ditches. Classification accuracy assessment yielded overall accuracies of 90.31% and 93.77% for 2003 and 2013, respectively, with Kappa coefficients of 0.8774 and 0.9199, meeting minimum discrimination requirements.

### 3.2 Construction of Landscape Naturalness Evaluation Index System

Referencing domestic and international naturalness evaluation research and considering the reserve's ecological characteristics, an index system was developed following principles of international relevance, clear definition, and measurability. The target layer (A) was landscape naturalness assessment of the Minjiang River Estuary Wetland Nature Reserve. The criterion layer (B) comprised three components: natural landscape features (B1), ecological disturbance (B2), and landscape fragmentation (B3). The indicator layer (C) included ten metrics:

natural landscape dominance, natural landscape mean patch size, habitat quality index, artificial disturbance index, artificial landscape mean patch size, mean nearest neighbor index, area-weighted mean patch fractal dimension, fragmentation index, patch number, and interspersed-juxtaposition index.

Most indicator definitions follow established literature, with minor modifications. Natural landscape dominance, typically describing control by few landscape types, was represented here as the percentage of natural landscape area to total area. Natural landscape mean patch size indicates the average area of natural landscape patches—higher dominance signifies greater natural landscape composition. Artificial landscape mean patch size represents the average area of artificial landscape patches. The habitat quality index is the ratio of mean habitat suitability to expected habitat suitability, with suitability values for different land types derived from literature and expert consultation. The formula is:  $HI = \sum(H_i \times PLAND_i) / HMAX$ , where  $H_i$  is the habitat suitability value for landscape type  $i$ ,  $PLAND_i$  is the proportion of landscape type  $i$ , and  $HMAX$  is the maximum habitat suitability value.

### 3.3 Determination of Index Weights

Based on the established evaluation system, the Analytic Hierarchy Process (AHP) was used to determine index weights. Five wetland conservation experts were invited to judge the relative importance of factors at each level, all with backgrounds in nature reserves or ecology. Each expert constructed judgment matrices independently, which were then statistically analyzed. Inconsistent matrices were discussed in a round-table meeting to finalize a consensus matrix with satisfactory consistency, indicating reasonable construction. The resulting weights for criterion and indicator layers are shown in Table 1.

To evaluate landscape naturalness across the reserve and six buffer zones (1–6 km), all metrics were standardized using min-max normalization to eliminate dimensional effects and enable comparison, as original metrics had different units and varying directional effects (positive or negative) on naturalness. Positive indicators included natural landscape dominance, natural landscape mean patch size, habitat quality index, and area-weighted mean patch fractal dimension. Negative indicators comprised artificial disturbance index, artificial landscape mean patch size, mean nearest neighbor distance, fragmentation index, patch number, and interspersed-juxtaposition index. Final results were scaled to [0,1].

## 4. Landscape Naturalness Evaluation Results

### 4.1 Within the Minjiang River Estuary Wetland Nature Reserve

Evaluations were conducted for 2003 and 2013, treating all buffer zone data as a single dataset for standardization. Quantitative results after dimensionless processing show that the reserve's landscape naturalness value decreased from 0.84 to 0.76 during 2003–2013, a 9.17% decline. Natural patch mean area decreased

while artificial patch mean area increased substantially. Natural landscape area proportion declined, fragmentation index rose, and patch numbers increased, indicating intensified human disturbance and landscape fragmentation.

Field investigations revealed that primary human disturbances within the reserve were aquaculture encirclement by surrounding villagers, whose main economic activities include fishing, commerce, and migrant work. Large-scale aquaculture encroachment destroyed habitats for aquatic animals and birds, impeding foraging and reproduction. This expansion of facility agricultural land altered natural landscape structure, increased human disturbance, and drove conversion from natural to artificial landscapes. Biological invasion, particularly by *Spartina alterniflora*, also contributed significantly to naturalness decline. The indigenous species *Cyperus malaccensis* has been rapidly displaced by *Spartina alterniflora*, which now dominates most tidal flats, competing with native species for nutrients, causing aquatic organism mortality, impairing water exchange, and threatening local species. Its high salt content precludes use as animal feed, and its tall growth blocks waterways, requiring costly manual removal. The invasion-clearance cycle has converted vegetated beaches back to bare flats, while *Spartina* propagation solidifies substrate in formerly suitable aquaculture areas, degrading habitat quality and reducing naturalness.

#### 4.2 Peripheral Buffer Zones of the Reserve

Landscape naturalness values in buffer zones showed a decreasing trend with increasing distance from the reserve. From 2003 to 2013, the value changes from the reserve boundary outward were: -0.33, -0.11, -0.03, -0.03, -0.02, +0.01 in 2003 and -0.29, -0.10, -0.05, -0.05, -0.02, -0.01 in 2013. The decreasing magnitude diminished progressively outward, eventually stabilizing. This pattern reflects greater human activity impacts nearer to township built-up areas, with naturalness declining until reaching a stable lower threshold. Human disturbance exhibited clear spatial zonation: facility agricultural land dominated within the reserve, while construction land prevailed in inland buffer zones, shifting the disturbance center from inland to marine areas over time—a trend detrimental to ecological conservation.

In 2013, both the reserve and buffer zones showed lower naturalness values than 2003, indicating long-term, large-scale human impacts. All buffer zone values remained below the reserve's, demonstrating strong anthropogenic interference in surrounding areas. Road networks and construction land fragmented the landscape, while tourism development, production activities, and urbanization around the reserve drove naturalness declines.

#### 4.3 Surrounding Circular Zones of the Reserve

To further examine buffer zone degradation and its influence, the original buffers were segmented into six circular ring zones at 1 km, 2 km, 3 km, 4 km, 5 km, and 6 km distances from the reserve boundary, numbered by proximity.

Evaluation results (Figure 4) show overall declining naturalness in all rings during 2003–2013, though the 1 km ring exhibited a 5.34% increase, suggesting local governance measures have achieved initial success.

[Figure 4: see original paper]

The 4 km ring showed the lowest naturalness values, primarily because this zone lies at a moderate distance from the reserve where ecological supervision weakens, and it traverses Langqi Town where recent development has been intensive. The analysis reveals that ecological protection has only achieved preliminary results, requiring sustained investment of resources for long-term management.

## 5. Driving Forces of Landscape Naturalness Change

### 5.1 Natural Driving Forces

Climate change has significantly impacted the Minjiang River Estuary Wetland. The region experiences a mid-subtropical maritime monsoon climate. Analysis of Fuzhou climate data shows rising average temperatures (19.7°C in 1981–1990, 20.3°C in 1991–2000, 20.6°C in 2001–2014) and increasing precipitation (1369.9 mm, 1387.8 mm, 1437.3 mm, respectively). While warm, humid conditions benefit wetland development, increased evaporation and altered precipitation patterns reduce water supply, causing wetland area reduction. The reserve experiences frequent typhoons (2–3 annually), which suspend sediments, erode beaches, and create irregular coastlines, intensifying landscape fragmentation.

Hydrological dynamics also drive change. The estuary experiences regular semidiurnal tides influenced by topography and runoff. The Meihua Water Channel significantly affects tidal flat landscapes. River flow scours and deposits sediments, developing new sandbars and pushing shorelines seaward, which expands tidal flats. This sediment movement, as an intrinsic driver of environmental evolution, controls wetland formation and transformation. While tidal flat expansion increases patch boundary complexity, it also reduces original sea area habitat quality.

Vegetation succession represents another key natural driver. Major vegetation types include mangroves, *Casuarina equisetifolia*, and reeds. *Spartina alterniflora*, a salt-tolerant perennial, acts as both pioneer and dominant species, accelerating sediment deposition and tidal flat expansion. However, under frequent typhoons and tidal scouring, erosion can reverse succession, converting vegetated areas back to bare flats. Human activities, particularly tidal flat reclamation and *Spartina* introduction, have altered natural succession processes by destroying original vegetation and accelerating geomorphological changes that drive faster vegetation type transitions.

### 5.2 Anthropogenic Driving Forces

Human development activities have profoundly impacted the reserve. From 2003–2013, Changle City's GDP grew from 11.321 to 48.507 billion RMB (328%

increase). Population growth and expanded industrial/agricultural production caused severe sewage discharge, degrading water quality and destroying suitable vegetation habitats. Multiple red tide events occurred in the Minjiang Estuary, reducing habitat suitability for species.

Since the Minjiang River Estuary Wetland Park's establishment in 2008, human interference has intensified. Most beaches near Langqi Town have been developed into resorts, with extensive tidal flat reclamation for aquaculture. Frequent human activity has markedly reduced bird and fish populations, including declining overwintering migratory birds. Rapid expansion of facility agricultural land within the reserve has encroached on original tidal flats and vegetated beaches, destroying habitats and threatening biodiversity, thereby reducing landscape naturalness.

Policy factors also play a role. Since the reserve's establishment in 2003, the Fujian Provincial Government, Fuzhou Municipal Government, and Changle Municipal Government have implemented various protection measures. In 2008, a management agency was established as a county-level public institution. The 2010 "Changle Minjiang River Estuary Wetland Nature Reserve Management Measures" marked a shift toward procedural and legal management. While these policies have reduced poaching and improved management, the overall landscape naturalness continues declining, indicating that macro planning must further adjust human production and lifestyle patterns to reduce landscape disturbance.

## 6. Protection Measures for the Minjiang River Estuary Wetland Nature Reserve and Surrounding Areas

As a typical wetland ecosystem, the reserve's primary conservation targets are estuarine waterfowl. Protecting and restoring this wetland ecosystem is fundamental for species survival and sustainable development. Based on evaluation results, three recommendations are proposed:

- (1) **Control ecological invasion.** The reserve's native vegetation faces severe threat from *Spartina alterniflora* invasion, which cannot self-recover. Manual removal should be implemented with artificial promotion of natural restoration. Mangrove species should be planted in suitable plots to restore natural vegetation and provide appropriate habitats for waterfowl.
- (2) **Protect rare bird resources.** The reserve is a critical wintering habitat for endangered species including the Chinese crested tern (*Thalasseus bernsteini*), black-faced spoonbill (*Platalea minor*), and scaly-sided merganser (*Mergus squamatus*). Bird monitoring stations should be established with improved early warning systems for avian diseases. Contaminants on wetland water surfaces must be cleaned to reduce waterfowl mortality from marine pollution.
- (3) **Implement scientific planning and reasonable development.** Wetlands are fragile ecosystems that should prioritize protection over devel-

opment. The Minjiang River Estuary Wetland Park should focus on environmental education and strictly follow planning guidelines. Unreasonable development and habitat utilization must be reduced through effective environmental planning that strictly controls construction land indices in surrounding areas, addressing pollution from tourism development.

## 7. Conclusions and Discussion

This study integrated landscape pattern indices with naturalness assessment, using AHP to establish a comprehensive evaluation system that quantifies landscape naturalness in the Minjiang River Estuary Wetland Nature Reserve and surroundings. The system demonstrates good applicability, revealing a 9.17% naturalness decline within the reserve during 2003–2013 and a decreasing gradient from reserve to buffer zones. While management efforts have achieved some success, with slight naturalness recovery in peripheral areas, the overall declining trend indicates that long-term governance is needed.

Human disturbance has expanded from inland to estuarine areas over time, converting natural landscapes to artificial/semi-artificial ones. The driving mechanism involves interactions between natural forces (climate, hydrology, vegetation succession) and anthropogenic forces (development activities and policy orientation). This study examined landscape naturalness exclusively; however, comprehensive naturalness also includes biological composition, sediments, and underwater topography. Future work should incorporate these factors to construct a more scientific evaluation model, potentially leveraging advanced technologies like drones to obtain extensive data for wetland conservation.

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