Postprint of Spatial Variation in Patch Stability of Xianghai Marsh Wetlands, 1985-2015

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Abstract

Wetland stability plays a crucial role in the structure and function of wetland ecosystems. To investigate the regional differentiation patterns and spatiotemporal dynamics of wetland patch stability, an expert scoring method was employed to construct a wetland patch stability model at the patch scale. Using remote sensing imagery as the data source, the spatiotemporal variation of marsh wetland patch stability in Xianghai Nature Reserve and its surrounding areas from 1985 to 2015 was examined. The results indicate that: the marsh wetland patch stability in both 1985 and 2015 exhibited characteristics of being strongest in the central region, weakest in the eastern region, and relatively strong in the western region; between 1985 and 2015, the marsh wetland patch stability in the study area generally shifted eastward, with enhanced spatial agglomeration; from 1985 to 2015, the marsh wetland patch stability in the study area showed an upward trend, with weakened spatial structure and increased degree of dispersion; in 1985, marsh wetland patch stability gradually decreased from the core zone outward, whereas in 2015, the marsh wetland patch stability in the experimental zone was greater than that in the buffer zone. The research findings provide rational recommendations for the planning and management of marsh wetlands in Xianghai Nature Reserve and its surrounding areas.

Full Text

Preamble

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Spatial Variation in the Patch Stability of Marshes in Xianghai Between 1985 and 2015

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Abstract

Wetland stability plays a vital role in the structure and functions of wetland ecosystems. In order to study the regional variation in wetland patch stability and the spatiotemporal dynamics of marshes, an expert evaluation method was used to construct a wetland patch stability model at the patch scale. Remote sensing image data were collected to investigate the spatiotemporal changes in marsh patch stability in the Xianghai National Nature Reserve and its surrounding area between 1985 and 2015. The results suggested that: (1) In 1985, marsh patch stability was strongest in central areas, weakest in the east, and relatively strong in the west; (2) Between 1985 and 2015, marsh patch stability shifted eastward and spatial clustering increased; (3) Overall marsh patch stability showed an upward trend, while spatial structure weakened and dispersion increased; (4) In 2015, marsh patch stability in the experimental zone was greater than in buffer zones; (5) Stability gradually decreased from the core area to the periphery since 1985. This study provides practical suggestions for planning and management of marshes in the Xianghai National Nature Reserve and its surrounding area.

Keywords: Xianghai National Nature Reserve; surrounding area; marshes; patch; stability

Wetlands are among the Earth' s most important ecosystems, forming unique natural complexes through water-land interactions that maintain biodiversity and provide resource utilization functions. With socio-economic development and population growth, wetland functions have been severely degraded and ecological benefits increasingly diminished, making wetland stability a research hotspot both domestically and internationally. Thermodynamics is considered the origin of stability concepts, and stability represents a crucial ecosystem characteristic that plays a vital role in ecosystem structure and function.

Landscape ecology clearly divides research scales into landscape, class, and patch scales. Previous studies on wetland landscape ecosystems have applied system stability theory, ecological and systematics principles, and landscape ecology theory to analyze and evaluate stability. Scholars have selected various indicators to investigate wetland landscape stability and its dynamics, including patch number and area change rates, patch density change rates, patch shape indices, distances to roads, and distances to settlements, all of which influence wetland landscape stability.

While numerous studies have significant implications for landscape conservation and management, particularly for wetlands, most have analyzed wetland stability at landscape or class scales in typical wetland regions, with relatively few investigations at the patch scale. Research at the patch scale can reveal regional differentiation patterns of wetland patch stability and is crucial for marsh conservation and planning. This study examines the Xianghai National Nature Reserve and its surrounding areas, selecting relevant indicators affecting marsh wetland patch stability to construct a wetland patch stability model and analyze spatiotemporal variation patterns from 1985–2015 using RS and GIS, providing theoretical basis and recommendations for management.

1. Study Area Overview

The Xianghai Nature Reserve extends approximately 20 km from center to edge. To compare with wetlands within the reserve, this study defines the research area as Xianghai National Nature Reserve and its surrounding region extending 20 km outward. Located in Tongyu County, western Jilin Province, and western Inner Mongolia, the area spans geographic coordinates of 121°49 –123°05 E, 44°40 –45°26 N, covering 5,680 km².

The region has a temperate continental monsoon climate: dry and windy springs, hot and rainy summers, and cold, dry, long winters. The average annual temperature is 5.1°C, with 10°C accumulated temperature of 3011.7°C. Annual precipitation is 408.3 mm, while evaporation reaches 1,954 mm, concentrated in summer with frequent afternoon convective storms, causing large inter-annual and intra-annual precipitation variation.

Situated in the transition zone between the Inner Mongolia Plateau and eastern plains, the terrain gently slopes from west to east with minor relief, dominated by aeolian accumulation landforms. Soils are primarily saline-alkali soil, meadow soil, and chestnut soil. The area belongs to the western subsidence zone of the Songliao Depression. Three seasonal rivers—the Huolin River running east-west, the central Emutai River, and the northern Tao' er River diversion project—flow through the area. During flood seasons, river water spreads between sand dunes, forming extensive floodplain marshes and natural ponds such as Dudupao and Fulaowenpao.

2. Data Sources and Processing

This study uses land use data from 1985 and 2015 to analyze marsh wetland patch stability. Remote sensing images were obtained from the USGS (http://glovis.usgs.gov/) under clear, cloud-free conditions, all with consistent spatial resolution. Processing steps included: (1) Compositing bands 5, 4, 3 using ENVI 5.1; (2) Geometric correction with 1:50,000 topographic maps; (3) Image enhancement; (4) Visual interpretation to extract cultivated land, residential land, and major transportation routes, with a minimum marsh wetland patch area of 0.01 km²; (5) Accuracy verification using sampling statistics combined with high-resolution imagery and field validation points, achieving 91.9% interpretation accuracy.

3. Model Construction

This study examines marsh wetlands in the research area, referencing relevant literature [10,22-28] to select six indicators affecting patch stability: (1) Wetland patch area; (2) Patch shape index [17]; (3) Ratio of wetland area to buffer area within each 5,000 m buffer zone; (4) Distance from patch center to nearest road; (5) Distance to nearest settlement; (6) Ratio of farmland area to buffer area within each 5,000 m buffer zone.

To quantitatively analyze driving factors' impacts on marsh wetland stability, expert scoring was used to assess each indicator' s influence on stability, considering effects on spatial distribution, structure, and function. The model coefficients are 0.3, 0.3, 0.4, 0.3, 0.3, and 0.2 respectively.

The wetland patch stability index (PS) is calculated as: PS = 0.3×(patch area index) + 0.3×(patch shape index) + 0.4×(wetland ratio in buffer) + 0.3×(distance to road index) + 0.3×(distance to settlement index) + 0.2×(farmland ratio in buffer)

Using ArcGIS 10.2, the six indicator datasets were processed with maximum value standardization to normalize each index to a 0–1 range. Kriging interpolation was applied to stability values for marsh wetland patches in 1985 and 2015.

4. Results

4.1 Spatial Distribution of Marsh Wetland Patch Stability

Based on Kriging interpolation in ArcGIS 10.2, larger stability values indicate higher stability grades. In 1985, Wulanhua Town and Sijingzi Town in the southeastern study area had minimal marsh distribution, numerous residential areas, and strong human disturbance, resulting in the weakest patch stability. The central core area of Xianghai Nature Reserve exhibited the strongest stability. In 2015, eastern areas including Wulanhua Town, Sijingzi Town, and Xiangshilimengguzuxiang showed weakest stability due to extensive cultivated land and agricultural interference. Central reserve areas near Wobao and Jiandiwo maintained the strongest stability, while western Horqin Right Middle Banner showed relatively strong stability.

[Figure 2: see original paper] 1985–2015 Marsh Wetland Patch Spatial Distribution

4.2 Dynamic Changes in Marsh Wetland Patch Stability

Using ARCGIS 10.2 raster calculator, the 1985 stability index was subtracted from 2015 values. Positive values indicate enhanced stability, negative values indicate decreased stability, and zero indicates no change. Between 1985–2015, most marsh wetland patch stability decreased, particularly in Taonan and western Horqin Right Middle Banner where change amplitude was large. However, some areas showed increasing trends.

Human activities are the primary driver of stability changes. Population growth and farmland demand intensified disturbance. Central Chuangye Village and Xinglong Town Middle School areas experienced decreased stability due to water consumption for domestic and agricultural use. In contrast, central reserve areas near Wobao and Jiandiwo, located in the core zone with minimal agriculture, showed enhanced stability. The southeastern area, with few marshes and extensive farmland, exhibited decreased stability.

[Figure 3: see original paper] 1985-2015 Marsh Wetland Patch Stability Index Spatial Distribution

4.3 Standardized Ellipse Spatial Change Analysis

Standardized ellipse analysis reveals that between 1985-2015, the marsh wetland patch area centroid shifted eastward by 2.899 km. The short-to-long axis ratio of the standard deviation ellipse gradually decreased, with both axes shortening—particularly the short axis—indicating contraction in both east-west and north-south directions.

The stability centroid also shifted eastward by 2.283 km. The decreasing axis ratio and shortening axes demonstrate consistent contraction patterns. Both centroid shifts reflect the implementation of river-lake connectivity projects in western Jilin, which divert surplus water from the Huolin and Tao' er Rivers into large ponds in the reserve during flood seasons, increasing water volume and marsh area in central-eastern regions.

[Figure 4: see original paper] 1985-2015 Marsh Wetland Patch Stability Spatial Change

4.4 Zoning Dynamic Change Analysis

Using ARCGIS 10.2, the study area was divided into core area, buffer zone, experimental zone, and surrounding area. Area-weighted average stability values were calculated for each zone. Overall stability showed an upward trend from 1985-2015. The core area maintained the highest averages due to minimal human disturbance.

Marsh wetland areas in core, buffer, and experimental zones increased by 26 km^2, 5 km^2, and 70 km^2 respectively (24%, 20%, and 79% increases), directly related to farmland compensation policies and water conservancy projects.

Partition' s Marsh Wetland Patch Stability Area-Weighted Mean
Marsh and Cultivated Land Area in Study Area

4.5 Spatial Variation Analysis

Based on coefficient of variation (CV) classification (CV 0.1 = weak variation; 0.1<CV 1 = moderate; CV>1 = strong), marsh wetland patch stability showed strong variation in both 1985 and 2015. CV values increased from 1.101 to 1.611 between 1985-2015, indicating enhanced dispersion and weakened spatial structure, primarily due to increased farmland area and settlement numbers.

5. Discussion and Conclusion

5.1 Discussion

Zhao et al. used patch structure stability as an indicator in Sanjiangyuan wetland studies, where higher values indicate more stable patch mosaic structures. Our calculated patch structure stability values increased from 0.457 to 0.462 between 1985-2015, consistent with our area-weighted stability results and validating the model.

While our GIS- and RS-based model incorporates natural and human factors affecting patch stability, limitations include insufficient consideration of inter-patch mosaic structure stability indicators and limited validation methods compared to class- or landscape-scale studies.

Luo et al. classified oasis patches as natural or artificial, with stability dominated by human disturbance. Our results show core area marshes (natural stability) had highest stability, while buffer and experimental zones (human stability) had lower values. However, experimental zone stability increased from 1.877 in 1985 to 2.294 in 2015, approaching core area values (2.319), indicating transition from artificial to natural stability due to water projects and policies.

We recommend reclassifying marshes around Xianghaimengguzuxiang reservoir as core area. The southwestern surrounding area (stability index 2.346) and northeastern area (0.938) should be prioritized for protection.

Wetland landscape patterns exhibit significant spatiotemporal heterogeneity, closely related to climate and human activities. Precipitation variation affects water balance, while farmland reclamation changes wetland area and distribution. Our small study area did not incorporate meteorological factors like rainfall.

[Figure 6: see original paper] 1985-2015 Precipitation Change in Study Area

5.2 Conclusion

(1) In 1985, marsh patch stability was strongest in central areas, weakest in the east, and relatively strong in the west.

(2) Between 1985-2015, the stability centroid shifted eastward and spatial clustering increased.

(3) Overall stability showed an upward trend while spatial structure weakened.

(4) Core, buffer, experimental, and surrounding zones all exhibited increased stability.

(5) In 2015, experimental zone stability exceeded buffer zone and approached core zone values.

(6) We recommend reclassifying reservoir area marshes as core zone in future planning.

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Note: Figure translations are in progress. See original paper for figures.