Spatiotemporal Dynamics of Ecological Disturbance Degree and Landscape Pattern Changes in the Ebinur Lake Wetland Nature Reserve over the Past 40 Years (Postprint)

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Abstract

Taking the Ebinur Lake wetland in Xinjiang as the study area, this research utilized Landsat remote sensing images from four periods (1972, 1998, 2007, and 2013) as data sources. Combined with the wetland' s land cover conditions and referencing the "National Land Use Classification," a classification system for ecological disturbance types in the Ebinur Lake wetland was established. Employing ecological disturbance indices, landscape pattern indices, and GIS spatial analysis methods, the spatiotemporal dynamics of ecological disturbance and landscape response mechanisms in the Ebinur Lake wetland were investigated. The results indicate: (1) From 1972 to 2013, the ecological disturbance degree in the study area exhibited a relatively stable trend overall, but its spatial distribution underwent changes. The transformation rate between ecological disturbance degree types showed an accelerating trend. (2) From 1972 to 2013, four landscape pattern indices—edge density index (ED), mean shape index (MSI), area-weighted mean patch fractal dimension index (AWMPFD), and landscape division index (DIVISION)—generally demonstrated an upward trend, while the regional landscape indices were relatively stable in 2013. (3) Landscape pattern indices exhibit close consistency with the degree of ecological disturbance. The magnitude of correlation between ecological disturbance degree and the spatial distribution of landscape pattern indices, in ascending order, is: edge density index (ED) < patch richness density (PRD) < Shannon diversity index (SHDI) < mean shape index (MSI) < area-weighted mean patch fractal dimension index (AWMPFD) < landscape division index (DIVISION). An objective and systematic understanding and evaluation of the ecosystem and environment of the Ebinur Lake wetland can provide practical reference for achieving natural environment protection in arid regions and coordinating the

relationship between land use and environmental protection.

Full Text

Preamble

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Analysis of the Temporal and Spatial Dynamics of Landscape Patterns and Hemeroby Index of the Ebinur Lake Wetland Nature Reserve, Xinjiang, Over the Last 40 Years

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Abstract

Wetlands constitute a critical component of ecological systems, providing essential habitats and resources for plants, animals, and humans while delivering substantial environmental benefits. In arid regions particularly, wetlands have attracted considerable scientific attention. The hemeroby index quantifies the

degree to which vegetation in an ecological environment deviates from its natural state due to human activities, offering valuable guidance for rational management that balances economic development with environmental protection. This study addresses a gap in understanding the sustainable development of wetland ecosystems in the Ebinur Lake Wetland Nature Reserve, Xinjiang, China.

We established a hemeroby-type classification system for the Ebinur Lake Wetland Reserve based on multiple datasets, including Landsat MSS/TM/ETM+/OLI imagery acquired in 1972, 1998, 2007, and 2013. Using hemeroby indices, landscape pattern metrics, spatial patch analysis, and GIS-based spatial analyses, we explored the spatiotemporal dynamics of hemeroby and the corresponding landscape pattern responses in the study area.

Our results reveal three key findings: (1) From 1972 to 2013, the ecological hemeroby degree of the Ebinur Lake wetland exhibited a relatively stable overall trend, though marked changes occurred in its spatial distribution. The distribution of partially disturbed wetland types changed significantly, indicating that the naturalness of wetland vegetation in this area is unstable and susceptible to human interference. Different hemeroby index (HI) types showed high conversion rates during this period, with dynamic changes likely attributable to combined natural, human, and policy-driven forces. Changes in natural factors (mean annual evaporation, temperature, and precipitation) and human factors (livestock, population, and GDP) altered vegetation distribution and lake area, thereby influencing ecosystem naturalness. (2) During 1972–2013, four landscape pattern indices showed significant increases: edge density (ED), mean shape index (MSI), area-weighted mean patch fractal dimension index (AWMPFD), and landscape division (DIVISION). However, in 2013, the regional landscape index became relatively stable. (3) High ED and AWMPFD values were recorded in areas with high HI, demonstrating that landscape patch fragmentation and complexity are greater in high-HI areas where naturalness is unstable. Conversely, low fragmentation and complexity values concentrated in low-HI areas. This indicates good consistency and correlation between landscape pattern indices and HI regarding spatial distribution. The HI was positively correlated with DIVISION, AWMPFD, MSI, Shannon' s diversity index, patch richness density, and ED, in decreasing order of influence.

Evaluation of the Ebinur Lake region's ecological environment provides practical reference for natural environment and resource protection, and will prove beneficial for coordinated environmental management and sustainable development in arid regions.

Keywords: Ebinur Lake Wetland Nature Reserve; hemeroby; spatiotemporal dynamics; landscape pattern

Introduction

Wetlands represent one of Earth' s most productive ecosystems, playing irreplaceable roles in atmospheric regulation, runoff regulation, and environmental beautification. Consequently, wetland ecosystems are often called the "kidneys of the Earth."In ecologically fragile arid and semi-arid regions, lake wetlands not only reflect environmental quality but also maintain ecological and environmental balance. Human production activities and natural factors continuously alter landscapes, significantly impacting ecosystem processes and functions. Landscape pattern research has long been a hotspot in ecology, referring to the spatial distribution of landscape patches of varying sizes and shapes—outcomes of ecosystems subjected to different degrees of disturbance. The introduction of landscape ecology into wetland research has enabled objective scientific monitoring and evaluation of landscape changes, which helps slow ecosystem degradation and ensure sustainable natural resource development.

Arid zone ecosystems are both vulnerable and sensitive, with landscape pattern changes constrained by both natural conditions and human activities. Numerous studies have examined these dynamics: Yin Changping et al. analyzed landscape pattern characteristics of land use changes in the Baiyang River Basin, Xinjiang; Sun Qian et al. explored spatiotemporal changes in land use/cover and landscape patterns in the Weigan-Kuqa River Delta Oasis; Gong Jie et al. analyzed impacts on landscape patterns in the Jinta Oasis; and Feng Yixing et al. examined effects of land use changes on landscape patterns in the Manas River Basin. In these ecosystems, human interference is particularly pronounced, especially in wetland ecosystems and their landscape patterns.

The concept of hemeroby was first proposed by a Finnish botanist and later reinterpreted by German scholars as a method to evaluate vegetation naturalness. Li Maihe et al. introduced this concept to evaluate vegetation naturalness in China. Hemeroby can be understood as the degree to which naturalness of ecosystem components is disturbed. Several studies have quantified relationships between human disturbance and landscape patterns: Xiao Cui et al. analyzed the quantitative relationship between human disturbance and landscape patterns in Ximen Island Wetland using spatial analysis; Zhu Jiaojun et al. comprehensively analyzed relationships between secondary forests and hemeroby; and Sun Yongguang et al. used remote sensing to explore spatiotemporal dynamics of human disturbance and landscape pattern responses in the Dayang River Estuary Wetland. Studying landscape pattern succession mechanisms clarifies relationships between landscape change and hemeroby, which is crucial for wetland management, protection, and sustainable development since wetland energy cycles and biodiversity are closely related to landscape pattern changes.

The Ebinur Lake wetland, a typical arid zone lake wetland with a vulnerable and sensitive ecosystem, faces serious ecological problems amid socioeconomic development. The regional ecosystem has undergone reverse succession, with biodiversity facing severe threats, intensified landscape fragmentation and vul-

nerability, vegetation degradation, soil salinization, and accelerated desertification. These issues have attracted widespread social concern. Hemeroby reflects the degree of disturbance to landscape types within ecosystems. This study applies the hemeroby concept to analyze disturbance levels of different landscape types in the study area, building on domestic research discussing relationships between disturbance and landscape indices. From a landscape ecology perspective, we explore the hemeroby index of the study area and analyze relationships between landscape indices and hemeroby to provide theoretical basis for management, protection, and coordinated development of arid zone wetlands.

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1. Study Area Overview

The Ebinur Lake Wetland is located in Bortala Mongol Autonomous Prefecture, Xinjiang, with geographic coordinates of 44°30 –45°09 N, 82°36 –83°50 E. The wetland covers an area of 2670.85 km² at an elevation of 189 m, representing the lowest point of the Junggar Basin. Situated in the path of strong winds from the Alashankou Pass, the wetland plays important roles in windbreak and sand fixation, while serving as an indicator of ecological environmental changes in the Junggar Basin. The region features a typical continental climate characterized by dryness, low rainfall, and strong winds, with mean annual temperature of 10.5°C, annual precipitation of 1315 mm, and annual evaporation of 105.17 mm. Due to its special environmental and geographic location, the wetland has formed a unique ecological environment with rich biodiversity resources, making it typical and highly valuable for conservation.

[Figure 1: see original paper] Geographical location of study area

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1. Data Sources and Processing Methods

This study utilized Landsat MSS/TM/ETM+/OLI remote sensing images from 1972 (80 m resolution), 1998, 2007, and 2013 (30 m resolution) as data sources. All images were acquired during peak vegetation growth periods. To ensure reliability and avoid resolution impacts on landscape indices, we uniformly resampled all images to 30 m resolution using nearest-neighbor interpolation. Ancillary data included vegetation distribution maps, master planning maps, and statistical data on mean annual evaporation, precipitation, livestock numbers, total population, and GDP for the Ebinur Lake Wetland Nature Reserve.

Using ENVI 5.1 software, we performed geometric correction, radiometric calibration, and atmospheric correction (FLAASH module) on all remote sensing images. Based on the master planning map and current land use/cover conditions, we employed maximum likelihood supervised classification to categorize the study area into six land types: Ebinur Lake water body, wetland, forest-grassland, salinized land, desert, and bare land. Field sampling validation con-

firmed classification accuracy above 85% for all land use/cover types, meeting research requirements.

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2. Landscape Classification Method

Based on previous hemeroby research and the national land use classification system, we established an ecological disturbance classification system considering regional vegetation distribution. We defined three disturbance types: slightly disturbed (HI<0.3), moderately disturbed (0.3 HI 0.60), and heavily disturbed (HI>0.60). The hemeroby index (HI) reflects the comprehensive impact and disturbance degree on ecosystems or landscapes, where higher values indicate greater disturbance intensity.

Given the study area' s unique environmental characteristics and reference to Chen Ailian et al. and Sun Yongguang et al., we assigned HI values to landscape types through expert evaluation and questionnaire surveys. The classification system (Table 1) categorizes landscape types based on their susceptibility to disturbance. Slightly disturbed types include natural ponds, naturally grown forests, and natural grasslands with high ecological service value. Moderately disturbed types include grasslands and other vegetation with moderate disturbance levels. Heavily disturbed types include salinized land, desert, bare land, and other landscape types highly susceptible to disturbance with significant environmental impacts.

Hierarchy of landscape type with respect to hemeroby index

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3. Landscape Pattern Indices

Ecological disturbance directly affects landscape structure, function, and ecosystem balance, influencing resistance to external interference. To explore landscape pattern responses to different hemeroby types, we selected indices reflecting fundamental landscape structure from three aspects:

(1) Fragmentation indices: Edge density (ED) measures the length of edges between heterogeneous landscape elements per unit area, characterizing landscape fragmentation.

(2) Shape indices: Mean shape index (MSI) and area-weighted mean patch fractal dimension index (AWMPFD) quantify landscape spatial complexity. AWMPFD ranges from 1 (simplest shape) to 2 (most complex perimeter), reflecting overall landscape pattern characteristics and human activity impacts.

(3) Aggregation indices: Landscape division (DIVISION) represents the probability of adjacent patches having different attributes, with lower values indicating greater landscape aggregation.

(4) Diversity indices: Patch richness density (PRD) and Shannon' s diversity index (SHDI) reflect landscape heterogeneity and composition. PRD is sensitive to non-equilibrium distribution of patch types, while SHDI positively correlates with species richness and habitat conditions.

Using Fragstats 3.4 and ArcGIS 10.0, we generated 3 km × 3 km grid-based spatial distributions of these indices for the study area across all four time periods.

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3. Results and Analysis

3.1 Spatiotemporal Dynamics of Hemeroby in Ebinur Lake Wetland

Overall, hemeroby in Ebinur Lake wetland showed a relatively stable trend from 1972 to 2013, though spatial distribution changed substantially. The area of heavily disturbed types remained large due to the arid environment, poor soil quality (mainly gray-brown desert soil), and extensive distribution of bare land and desert. Slightly disturbed types (Ebinur Lake water body and wetlands) showed decreasing lake area but increasing wetland area. Moderately disturbed types exhibited the most significant spatial distribution changes, primarily due to shifts in reed and forest-grassland distribution.

[Figure 2: see original paper] The map of Hemeroby index (HI) at Ebinur Lake wetland

Quantitative analysis of classified remote sensing images revealed that the total area of slightly disturbed types decreased from 102,474.27 hm^2 in 1972 to 87,075.96 hm^2 in 2013, mainly due to lake area reduction. Moderately disturbed types showed an increasing trend with substantial area changes (12,913.86 hm^2 in 1972 to 40,901.71 hm^2 in 2013), resulting from exposed lake beds with high moisture and fertility facilitating vegetation growth. Heavily disturbed types remained relatively stable (184,213.46–189,900.64 hm^2), as desert and bare land are difficult to convert to other landscape types.

[Figure 3: see original paper] Area of different Hemeroby index (HI) types at Ebinur Lake wetland

3.2 Conversion Between Disturbance Types

Using ArcGIS 10.0 spatial overlay analysis, we quantified conversion directions and areas between disturbance grades from 1972 to 2013 (Table 2). Conversion rates accelerated between 2007–2013 compared to 1972–2007, with increasing area transitioning from low to high disturbance types. The total area transitioning from low to high disturbance types was 383.0436 hm^2, while high-to-low transitions totaled 228.9296 hm^2, indicating an overall increasing disturbance trend.

Transition of different Hemeroby index (HI) types from 1972 to 2013

3.3 Dynamic Degree of Hemeroby

Calculating dynamic degree of hemeroby using ArcGIS 10.0 revealed minimal change during 1972–1998, indicating stable naturalness of slightly disturbed types. However, 1998–2007 and 2007–2013 showed substantial changes concentrated in lake water bodies, deserts, and bare lands. The primary drivers were natural factors (climate change) and human activities (water diversion for agriculture). Since 2007, Ebinur Lake wetland has been designated as a national nature reserve, reducing direct human interference and allowing natural self-regulation and restoration.

[Figure 4: see original paper] Dynamic changes of Hemeroby index (HI) at different period

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2. Analysis of Driving Factors

2.1 Natural Factors

Natural factors significantly influence land use/cover changes, landscape patterns, and hemeroby, particularly in sensitive arid zone wetland ecosystems. Climate change affects hydrology, ecological processes, biotic communities, and entire ecosystems. We analyzed mean annual precipitation, temperature, and evaporation from 1972–2013 (Figure 5).

[Figure 5: see original paper] The change of annual evaporation, mean annual temperature and annual precipitation in 1972–2013

Evaporation showed fluctuating decline, while precipitation and temperature exhibited fluctuating increases. These climate variations directly affected lake area and vegetation distribution, altering hemeroby spatial patterns. The 1998–2013 period experienced relatively mild climate conditions with decreased evaporation and increased precipitation/temperature, beneficial for vegetation growth and reducing salinization. However, the 2007–2013 period saw increased evaporation and decreased precipitation, creating drier conditions that limited vegetation expansion despite the favorable temperature trend.

2.2 Human Factors

Human activities strongly influence hemeroby dynamics through land use policies and agricultural production. We analyzed livestock numbers, population, and GDP in Jinghe County (where the reserve is primarily located) from 1972–2013 (Figure 6).

[Figure 6: see original paper] The change of Livestock population and GDP at Ebinur Lake wetland in 1972–2013

Population and GDP growth increased water demand, with agricultural expansion being a major factor. Since 2008, livestock numbers have been controlled

and the wetland was designated as a national nature reserve, reducing direct human interference. However, indirect impacts persist through water diversion from inflow rivers for irrigation, causing lake area reduction and affecting landscape patterns of slightly disturbed water bodies and moderately disturbed forest-grasslands.

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3. Response of Landscape Pattern Indices to Hemeroby

3.1 Response to Disturbance Types

Changes in hemeroby types altered landscape pattern indices. Heavily disturbed areas showed high ED values, indicating complex patch edges and irregular shapes. From 1972–2013, ED in heavily disturbed areas decreased slightly, suggesting simplification of patch edges and stabilization of disturbance levels. MSI increased in moderately and heavily disturbed areas, indicating enhanced landscape complexity and heterogeneity. AWMPFD showed slight increases, reflecting human activity impacts. DIVISION remained stable in heavily disturbed areas but decreased in moderately disturbed areas, suggesting more aggregated landscapes.

3.2 Spatiotemporal Relationship with Hemeroby

Spatial analysis of ED and AWMPFD (Figure 7) revealed that low ED values concentrated in low-HI areas (lake water body), while high ED values appeared in high-HI areas (wetlands near the lake, deserts, and bare lands). This demonstrates good consistency and correlation between ED spatial distribution and hemeroby. AWMPFD high-value areas were concentrated in low-HI regions in 1972 and 1998, but distribution decreased over time, primarily appearing in heavily disturbed landscape types by 2013.

[Figure 7: see original paper] Stats of different disturbed degree of Hemeroby index (HI) at different years

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4. Spatial Correlation Between Hemeroby and Landscape Pattern Indices

We analyzed correlations between HI and six landscape indices (ED, MSI, AWMPFD, DIVISION, PRD, SHDI) (Table 3). Results show significant positive correlations between HI and ED, MSI, AWMPFD, and DIVISION, with MSI showing the highest correlation. This indicates that greater hemeroby leads to increased landscape fragmentation and complexity. Correlations between HI and PRD/SHDI were lower, suggesting complex relationships between hemeroby and landscape component diversity.

Correlation matrix of Hemeroby index with landscape pattern index

The correlation magnitude follows this order: ED < PRD < SHDI < MSI < AWMPFD < DIVISION. The decreasing correlation trend over time suggests weakening ecological disturbance, likely due to protective policies implemented since 2007.

[Figure 8: see original paper] Spatial distribution of landscape pattern index in 1972–2013 at Ebinur Lake wetland

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1. Discussion

Hemeroby has been widely applied in landscape monitoring and evaluation to describe disturbance levels in forest and wetland ecosystems. Previous studies by Chen Ailian et al. and Li Jihong & Hu Qinglei systematically evaluated hemeroby dynamics in the Shuangtai River Estuary Wetland and Baoqing County Wetland, respectively. Our study extends this approach to Ebinur Lake Wetland, exploring spatiotemporal differentiation characteristics and landscape pattern responses.

This research has several limitations: (1) The four periods of remote sensing images were not acquired on the same date, and varying natural factors (precipitation, temperature) between years affected vegetation growth and lake area, influencing hemeroby dynamics. (2) The hemeroby classification system was constructed based on limited literature without comprehensive standardization, a common issue in similar studies. (3) Landscape index selection relied heavily on literature review and subjective understanding, potentially missing indices that better reflect hemeroby responses. (4) Driving factor analysis referenced existing literature without considering more comprehensive variables, requiring further investigation.

Despite these limitations, hemeroby effectively reflects ecosystem vulnerability and environmental conditions. Our analysis of Ebinur Lake Wetland provides decision support for environmental management in developing arid regions, particularly highlighting the need for enhanced protection in high-hemeroby areas.

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2. Conclusions

Based on comprehensive consideration of national land use classification and regional vegetation distribution, this study applied remote sensing technology to analyze hemeroby spatiotemporal changes in Ebinur Lake Wetland and explored landscape response mechanisms using landscape ecology principles. Key conclusions are:

(1) From 1972–2013, overall hemeroby remained relatively stable, but spatial distribution changed significantly, indicating unstable naturalness of wetland vegetation susceptible to interference. Conversion rates between disturbance types accelerated, with 383.0436 hm^2 transitioning from low to high disturbance versus 228.9296 hm^2 transitioning from high to low disturbance, showing an overall increasing disturbance trend.

(2) Natural factors (increasing temperature, fluctuating precipitation, high evaporation) and human factors (population growth, economic development, agricultural water diversion) drove changes in vegetation distribution and lake area, directly affecting ecosystem naturalness. Climate warming and water resource competition caused lake shrinkage and landscape type conversions.

(3) Four landscape indices (ED, MSI, AWMPFD, DIVISION) showed overall increasing trends, while PRD and SHDI generally decreased, indicating increased disturbance to ecosystem naturalness. Hemeroby correlated positively with ED, MSI, AWMPFD, and DIVISION, with correlation magnitude following: ED < PRD < SHDI < MSI < AWMPFD < DIVISION. The high correlation with MSI suggests substantial hemeroby impacts on landscape fragmentation and complexity.

(4) Spatial distribution of landscape indices showed good consistency with hemeroby, with ED and AWMPFD high-value zones concentrating in high-HI areas. This relationship provides practical reference for coordinating land use and environmental protection, and for achieving sustainable development in arid zone wetlands.

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