Ecological Impact Assessment of the Interaction between Tourism Development and Vegetation Landscape on Mount Wutai: Postprint

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Abstract

Investigating the impacts of tourism on vegetation holds significant practical implications for ecological management in scenic areas. An evaluation system encompassing four hierarchical levels and 27 specific indicators was constructed from six aspects: Landscape Importance Value (LIV), Species Diversity (SD), Plant Community Structure Ratio (PCS), Shade-tolerant Species Proportion (NSP), Anthropophilic Species Proportion (PS), and Tourism Impact Index (T), and an empirical analysis was conducted for the Wutai Mountain Scenic Area. The results indicate: (1) In different directions, as distance increases, tourism activities decrease progressively, and vegetation landscapes successively transition from residential areas, commercial areas, or artificial vegetation areas toward herbaceous areas, shrub-herb areas, and tree-shrub-herb areas. Correspondingly, LIV, SD, PCS, NSP, and Ecological Impact Value (EIV) increase progressively, while PS and T decrease progressively. (2) Different vegetation types exhibit distinct landscape characteristics. For the five characteristic values of LIV, SD, PCS, NSP, and EIV, herbaceous area < shrub-herb area < tree-shrub-herb area; whereas for PS and T , herbaceous area > shrub-herb area > tree-shrub-herb area. Different populations exhibit distinct bioecological characteristics under tourism disturbance, among which the Populus cathayana population is relatively unique. (3) For the entire Taihuai Town, the spatial pattern of tourism development intensity results from the combined effects of scenic spot distribution and topographic factors, and vegetation landscapes show clear ecological responses thereto. The number of sample plots in different directions serves as an indicator of tourism development intensity. Development intensity is strongest in the due south and northeast directions, followed by due north, southeast and southwest, and due east directions, and weakest in the northwest and due west directions. (4) Based on EIV, the entire region is classified into four categories: Category I areas comprise temple, residential, and commercial

zones; Category II areas are herbaceous zones; Category III areas are mixed tree, shrub, and herb zones; and Category IV areas are tree-shrub-herb zones.

Full Text

Preamble

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Evaluation of the Ecological Effect of Tourism Development on Vegetation Landscapes in Mount Wutai

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Abstract

Studying the impact of tourism on vegetation has important practical significance for the ecological management of scenic areas. This research constructed an evaluation system comprising six key indicators—Landscape Importance Value (LIV), Species Diversity (SD), Proportions in Community Structure (PCS), Negative Species Proportion (NSP), Proportion of Species in Close Proximity to Human Beings (PS), and Tourism Influencing Index (TII)—and applied it to Mount Wutai through empirical analysis. The system includes four layers and 27 specific indicators. The results demonstrate that: (1) With increasing distance from tourism centers in different directions, tourism activity decreases and vegetation landscapes succeed from residential, commercial, or artificial vegetation areas toward herbaceous areas, shrub-herb areas, and finally tree-shrub-herb areas. Accordingly, LIV, SD, PCS, NSP, and Ecological Effect Value (EIV) increase with distance, while PS and TII decrease. (2) Different vegetation types exhibit distinct landscape characteristics. For LIV, SD, PCS, NSP, and EIV, the ranking is: herb areas < shrub-herb areas < tree-shrub-herb areas. Conversely, for PS and TII, the ranking is: herb areas > shrub-herb areas > tree-shrub-herb areas. Different *Populus cathayana* populations demonstrate unique biological and ecological characteristics in response to tourism disturbance. (3) The spatial pattern of tourism development from Taihuai Town results from the interaction between scenic spot distribution and topographic factors, and vegetation landscapes show clear ecological responses. The number of sample plots in different directions indicates the degree of tourism development, which is strongest to the south and northeast, moderate to the north, southeast, southwest, and east, and weakest to the northwest and west. (4) The entire region can be divided into four areas based on EIV: Area I includes temple, residential, and commercial zones; Area II comprises

herbaceous zones; Area III is the mixed tree-shrub-herb zone; and Area IV represents the coexisting tree-shrub-herb zone.

Keywords: Mount Wutai; tourism development; vegetation landscapes; ecological effect evaluation

Introduction

As tourism development intensifies, ecological problems in destinations become increasingly severe. Mount Wutai, a typical religious tourist attraction and national key scenic area, has experienced tourism activities that seriously affect its local ecological environment. The region features a relatively high-cold natural environment, and its ecosystem is difficult to restore once subjected to excessive human disturbance. Monitoring and evaluating changes in the ecosystem is particularly important, especially for vegetation as the most sensitive ecological element. Analyzing tourism' s impact on vegetation best reflects the ecological effects of tourism activities.

For over a decade, scholars worldwide have conducted research from two perspectives: different tourism disturbance methods and various vegetation ecological responses. Studies comparing tourism with other disturbance types (such as global climate change and grazing) show that climate change has fundamental impacts, grazing is widespread, while tourism impacts are relatively localized. Research comparing different recreation modes, such as hiking, horse riding, and mountain biking, reveals varying ecological impacts on vegetation and soils. Long-term field plot observations have compared different ski piste management models and their effects on mountain vegetation. Studies from the vegetation ecology perspective have focused on sensitive plants, biodiversity, and interspecific relationships, revealing ecological responses to tourism disturbance.

However, most previous research has examined only single ecological characteristics such as species diversity or individual species traits. Systematic evaluation of tourism' s overall impact on scenic area vegetation remains limited. While some studies have constructed community landscape importance values to assess tourism impacts, they have not established a comprehensive evaluation system accounting for community structure and ecological characteristics of different vegetation layers. Different regions require different evaluation systems due to varying vegetation ecology. Previous vegetation ecology research on Mount Wutai has focused on flora, species diversity, and responses to climate change, but comprehensive evaluation of tourism impacts remains lacking.

This study addresses this gap by constructing a complete evaluation system for tourism impacts on vegetation, using Mount Wutai as a case study to support its ecological conservation and management.

1. Sampling Survey

Sampling survey details are provided in reference [16].

2. Indicator System and Measurement

The evaluation system comprises six indicators: Landscape Importance Value (LIV), Species Diversity (SD), Proportions in Community Structure (PCS), Negative Species Proportion (NSP), Proportion of Species in Close Proximity to Human Beings (PS), and Tourism Influencing Index (TII), encompassing 27 specific indicators across four layers.

2.1 Landscape Importance Value (LIV)

Considering ecological and aesthetic factors, LIV reflects both ecological and tourism values. In this study, LIV only reflects ecological value, calculated as the sum of tree importance value, shrub importance value, and herb importance value:

$$\text{LIV} = \text{Tree IV} + \text{Shrub IV} + \text{Herb IV}$$

Tree Importance Value = (Relative Dominance + Relative Height + Relative Density) / 300
Shrub Importance Value = (Relative Coverage + Relative Height) / 200
Herb Importance Value = Relative Coverage

Where: - Relative Coverage = (Coverage of a species / Sum of coverage of all species in the same transect) × 100 - Relative Height = (Average height of a species / Sum of average heights of all species) × 100 - Relative Density = (Density of a species / Sum of densities of all species) × 100 - Relative Dominance = (Average basal area × Number of individuals of a species / Sum of average basal area × Number of individuals of all species) × 100

2.2 Species Diversity (SD)

Species diversity includes richness, evenness, and diversity indices. To avoid zero or infinite diversity indices in single-dominant plots, different measurement methods are used for tree, shrub, and herb layers:

- Richness index: 采用 MATH_1
- Evenness index: 采用 MATH_2
- Species diversity index: 采用 MATH_3

Where MATH_4 represents the importance value of the *i*-th species, and *S* is the total number of species in the plot.

2.3 Proportions in Community Structure (PCS)

Plant community stratification depends on life forms. According to Raunkiaer' s classification, there are phanerophytes, chamaephytes, hemicryptophytes, cryptophytes, and annual plants. Phanerophytes are further divided by height into large, medium, small, and dwarf phanerophytes. PCS uses the importance of different life forms to characterize tourism impacts on community structure, with five specific indicators.

2.4 Negative Species Proportion (NSP)

NSP refers to the importance proportion of shade-tolerant plant species in a plot. Higher values indicate better ecological environments.

2.5 Proportion of Species in Close Proximity to Human Beings (PS)

PS refers to the importance proportion of companion plants in a plot. Stronger human influence leads to higher values. For residential, commercial, or temple areas, PS is recorded as 1.

2.6 Tourism Influencing Index (TII)

TII measures tourism disturbance intensity on vegetation landscapes, including impacts from garbage, trampling, and branch damage. Higher absolute values indicate stronger tourism destruction and poorer management quality. For residential, commercial, or temple areas, TII is recorded as 1.

Indicator Properties: LIV, SD, PCS, and NSP are positive indicators (higher values indicate better vegetation), while PS and TII are negative indicators (higher absolute values indicate worse conditions).

3. Analysis Methods

This study employs the Analytic Hierarchy Process (AHP) to determine indicator weights at each level. After weight determination, vegetation landscape characteristics can be quantitatively compared to identify the nature and magnitude of ecological effects, enabling classification of different ecological zones.

2. Results and Analysis

2.1 Weight Determination via AHP

AHP requires consistency testing, where CI is the consistency index ($CI = 0$ indicates perfect consistency) and CR is the random consistency ratio ($CR < 0.1$ indicates satisfactory consistency). In this study, all judgment matrices show $CR < 0.1$, indicating satisfactory consistency (Table 1).

Table 1 shows that at the first level, LIV has the highest weight (0.2465), followed by PCS (0.2208), SD (0.2100), TII (0.2040), with NSP (0.0610) and PS (0.0579) being smallest. At lower levels, tree importance value dominates LIV, while tree layer diversity is most important for SD. Among life forms, phanerophytes are most important, followed by annual plants. For TII, forest regeneration impact has the highest weight.

2.2 Directional Analysis of Tourism Development and Vegetation Response

Due to spatial differences in tourist attraction distribution, tourism development intensity varies by direction in Mount Wutai. Each direction shows different tourism attraction and disturbance intensity.

2.2.1 East Direction The east transect passes through Tayuan Temple, residential, and commercial areas (E1-E5) with strong human disturbance, where only scattered trees or herbs appear without forming complete communities. From E6 onward, vegetation transitions from pure herbaceous to tree-shrub-herb communities. E6-E9 represent herbaceous communities, E10-E11 are *Populus cathayana* communities, and E12 is a *Larix principis-rupprechtii* community.

With increasing distance, LIV, SD, PCS, and NSP show increasing trends while PS and TII decrease, indicating reduced tourism disturbance and improving vegetation quality. Herbaceous landscapes show lower characteristic values than tree landscapes. The *P. cathayana* community shows greater landscape characteristics than the *L. principis-rupprechtii* community under similar natural conditions and disturbance levels, suggesting unique biological characteristics of *P. cathayana*.

Ecological effect values (EIV) show negative effects at close distances (E1-E7) and positive effects at far distances (E8-E12). The transect shows increasing elevation and slope, with slopes becoming steeper, indicating that tourism development prefers gentle terrain.

2.2.2 Northeast Direction The northeast transect passes through temple and residential areas (NE1-NE7, NE9) with complex community types, followed by herbaceous areas (NE8, NE10-NE12). Communities include *Prunus armeniaca*, *Pinus tabulaeformis*, and *Picea wilsonii*. The northeast is the main entrance to Mount Wutai, affected by both attractions and transportation.

In tree landscapes, LIV, SD, PCS, and NSP increase with distance despite fluctuations among community types. *P. cathayana* communities show greater tourism disturbance than *P. tabulaeformis* and *L. principis-rupprechtii* communities, with smaller characteristic values. *P. armeniaca* communities near the center show small characteristic values due to high disturbance, while *P. tabulaeformis* and *L. principis-rupprechtii* communities far from the center show large values. This demonstrates different ecological habits among populations.

2.2.3 North Direction The north transect passes through temple areas (N1-N6) and tree landscapes (N7-N15). N7-N9 are *P. cathayana* communities on east-facing slopes, while N10-N15 are *L. principis-rupprechtii* communities on northeast slopes. With increasing distance, LIV, SD, PCS, and NSP increase while PS and TII decrease.

P. cathayana communities show greater tourism disturbance than *L. principis-rupprechtii* communities, with much smaller characteristic values, suggesting unique biological-ecological characteristics of *P. cathayana*. Moderate disturbance appears beneficial, as some mid-distance plots show relatively large characteristic values (e.g., N12).

2.2.4 Northwest Direction The northwest transect shows steep slopes and includes *Picea wilsonii* communities (NW1, NW3, NW4). With increasing distance, LIV, SD, PCS, and NSP increase while PS and TII decrease, showing succession from herbaceous to shrub-herb to tree-shrub-herb areas and a shift from negative to positive ecological effects.

Residential and herbaceous areas show negative effects, while shrub-herb and tree-shrub-herb areas show positive effects. Compared with *P. cathayana* communities, *P. wilsonii* communities receive less tourism disturbance but show smaller characteristic values, further demonstrating the unique biological-ecological properties of *P. cathayana*.

2.2.5 West Direction The west transect passes through herbaceous areas (W1-W4, W6), shrub-herb areas (W5), and tree-shrub-herb areas (W7-W9). W1-W5 are *Picea meyeri* communities on east-facing slopes, while W7-W9 are *L. principis-rupprechtii* communities.

With increasing distance, LIV, SD, PCS, and NSP increase while PS and TII decrease. Herbaceous areas show negative ecological effects. *P. meyeri* communities show larger characteristic values than *L. principis-rupprechtii* communities, indicating community-specific landscape features. Under tourism disturbance, herb layer constructive species have limited ecological roles compared with tree layer constructive species.

2.2.6 Southwest Direction The southwest transect passes through street areas and tree-shrub-herb areas (SW1, SW13), with abandoned farmland of varying ages. With increasing distance, vegetation succeeds toward herbaceous, shrub-herb, and tree-shrub-herb areas, though some characteristic values fluctuate due to interspersed landscape types.

The transect end (SW9) is a *P. cathayana* community with large characteristic values due to minimal disturbance, again demonstrating the uniqueness of *P. cathayana*.

2.2.7 South Direction The south transect passes through parking lots, residential and commercial service areas, and tree-shrub-herb areas. S1-S28 are *P. cathayana* communities near transportation routes, while S31-S41 are *Pinus tabulaeformis* and *Betula platyphylla* communities.

Tourism development is intense, with original vegetation replaced by artificial landscapes. Characteristic values increase with distance, showing succession from artificial to herbaceous to shrub-herb to tree-shrub-herb areas. Most artificial and herbaceous areas show negative ecological effects, while shrub-herb and tree-shrub-herb areas show positive effects. *P. cathayana* communities show larger values than *B. platyphylla* communities but have simpler structure with underdeveloped shrub layers.

2.2.8 Southeast Direction The southeast transect passes through temple areas (SE1), residential and commercial areas (SE2-SE4), and tree-shrub-herb areas (SE5-SE8, SE9-SE11). With increasing distance, LIV, SD, PCS, and NSP increase while PS and TII decrease. Tree-shrub-herb areas show greater characteristic values than herbaceous areas. The end of the transect (SE12-SE14) is a *P. cathayana* community with large values due to minimal disturbance.

2.3 Overall Spatial Pattern

In the east, south, and southeast directions, sample numbers reflect tourism development intensity: more samples indicate stronger tourism activity. Tourism development is strongest in the south and northeast, moderate in the north, southeast, southwest, and east, and weakest in the northwest and west. This pattern results from the interaction between scenic spot distribution and topography.

Temples, the main attractions, vary in historical significance and importance, creating different influence levels. The northeast and north have many temples, while the northwest and west have few. Topography constrains human activities –gentle terrain favors residential and commercial development (as in Taihuai Town), while steep slopes limit activities and support better vegetation growth. Some sites like Dailuo Ding become attractions precisely due to their prominent topography.

With increasing distance from the central White Pagoda, vegetation succeeds from residential/commercial/artificial areas to herbaceous, shrub-herb, and tree-shrub-herb areas. LIV, SD, PCS, and NSP increase while PS and TII decrease. EIV > 0.25 indicates minimal tourism disturbance.

Based on EIV, the entire Mount Wutai area can be classified into four vegetation landscape zones: - **Area I (EIV = -0.2646)**: Temple, residential, and commercial areas with strongest tourism development and only scattered plants - **Area II (-0.2646 < EIV 0)**: Herbaceous areas near the center with strong tourism destruction and degraded original vegetation - **Area III (0 < EIV 0.25)**: Complex vegetation types including shrub-herb areas, quality herbaceous areas, and poor tree-shrub-herb areas with moderate human activity - **Area IV (EIV > 0.25)**: Tree-shrub-herb areas far from the center with minimal tourism disturbance

3. Conclusion and Discussion

This study constructed a comprehensive evaluation system with 27 indicators to assess tourism impacts on vegetation landscapes, using Mount Wutai as a case study. Key findings include:

1. With increasing distance in all directions, vegetation succeeds from residential/commercial/artificial areas to herbaceous, shrub-herb, and tree-shrub-herb areas. LIV, SD, PCS, and NSP increase while PS and TII decrease.

2. Different vegetation types show distinct landscape characteristics. Tree-shrub-herb areas > shrub-herb areas > herbaceous areas for positive indicators, with the reverse for negative indicators. Different populations, particularly *P. cathayana*, show unique biological-ecological characteristics under tourism disturbance.

3. The spatial pattern of tourism development results from the interaction between scenic spot distribution and topography. Sample numbers in different directions indicate development intensity: strongest in south and northeast, moderate in north, southeast, southwest, and east, weakest in northwest and west.

4. The entire region can be divided into four areas based on EIV, representing different tourism disturbance levels and vegetation responses.

Future research should address: (1) Incorporating tourism value indicators (visual, aesthetic aspects) that are not currently included in the ecologically-focused system; (2) Investigating the ecological mechanisms of tourism disturbance responses in detail; and (3) Examining soil as an intermediate factor in tourism impacts on vegetation.

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