Spatial Differentiation Characteristics of Biodiversity in the Bailong River Basin Based on the Comprehensive Index Method (Postprint)

Authors: Xie Yuchu, Gong Jie, Qi Shanshan, Hu Baoqing, Wang Kelin

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Abstract

Identification of spatial distribution patterns of biodiversity at macro- and meso-regional scales is a prerequisite for formulating and implementing regional biodiversity conservation plans, and constitutes one of the key issues urgently requiring resolution in research on prioritizing areas for biodiversity conservation. This study takes the Bailong River watershed in Gansu as a case study, integrating the InVEST model with remote sensing and GIS technologies, employing regional habitat quality, plant net primary productivity, and landscape status index as evaluation indicators, and applying normalization methods to construct a comprehensive assessment method for regional biodiversity spatial patterns, thereby conducting biodiversity evaluation and analysis of its spatial differentiation characteristics in the Bailong River watershed at the raster pixel scale. Results demonstrate that the Bailong River watershed possesses relatively rich biodiversity with pronounced spatial heterogeneity. Areas with higher biodiversity (Level I and Level II or above) account for approximately 39.80% of the total area, and are primarily concentrated in nature reserves and forestry management zones. Regions with lower biodiversity are mainly distributed along the Bailong River banks and areas to its north in Zhouqu-Wudu-Wenxian, along the Minjiang River in Dangchang County, as well as in alpine sparse vegetation zones and alpine snow-covered and bare rock areas.

Full Text

Assessment and Spatial Variation of Biodiversity in the Bailong River Watershed of Gansu Province

Authors: Xie Yuchu, Gong Jie, Qi Shanshan, Hu Baoqing, Wang Kelin
Affiliations: Key Laboratory of Environment Change and Resources Use in Beibu Gulf, Ministry of Education, Guangxi Teachers Education University;

Key Laboratory of Western China’ s Environmental Systems, Ministry of Education, College of Earth and Environmental Sciences, Lanzhou University; Key Laboratory of Agro-ecological Processes in Subtropical Region, Institute of Subtropical Agriculture, Chinese Academy of Sciences

Abstract

Biodiversity loss has become one of the major global environmental problems, urgently requiring strengthened conservation and protection efforts. Identifying and understanding spatial variation patterns of biodiversity at large and medium regional scales is a critical first step in formulating and implementing effective protection schemes, representing a key research priority in contemporary biodiversity assessment. This study takes the Bailong River Watershed of Gansu Province (BRWGP)—one of China’ s most biodiversity-rich regions located in the transitional ecotone among the Tibetan Plateau, Loess Plateau, and Qinba Mountains—as a case study. Using the InVEST model, remote sensing data, vegetation net primary productivity, and landscape state index as evaluation indicators, we applied normalization methods to construct a comprehensive regional biodiversity spatial pattern assessment framework. Biodiversity evaluation and spatial heterogeneity analysis were conducted at the grid cell scale. Results indicated that biodiversity in the BRWGP is relatively abundant with obvious spatial pattern variations. Areas with higher biodiversity account for 39.8% of the total watershed area, primarily distributed within national nature reserves and forest management zones. Regions with relatively poor biodiversity are mainly located in the valleys between Zhouqu-Wudu-Wenxian along the Bailong River, the Minjiang River valley in Tanchang County, alpine snow-covered mountain regions, and bare rock zones.

Keywords: biodiversity; assessment indicators; spatial variation; InVEST model; Bailong River Watershed of Gansu Province

1. Introduction

Biodiversity constitutes an indispensable material foundation for human survival and development, playing irreplaceable roles in climate regulation and maintaining natural balance. However, biodiversity loss is becoming increasingly severe, with the trend still not effectively curbed. According to the 2010 Global Biodiversity Outlook by UNEP, 15,000 species are disappearing, representing another serious global environmental threat following climate change. Strengthening biodiversity cognition, management, and policy formulation is not only crucial for achieving regional sustainable development but also extremely urgent.

Research on biodiversity and its spatial differentiation characteristics at large and medium scales forms the basis for identifying priority conservation areas and ecological compensation zones, as well as for evaluating invasive species and human activity disturbances. It also provides a foundation for small-scale biodiversity assessment and conservation management planning. Scholars have conducted extensive work at large and medium regional scales. For instance, Zhu et al. constructed a comprehensive regional biodiversity evaluation index system to assess conservation importance in the upper Yangtze River. Li et al. examined spatial distribution patterns in the Chengdu-Chongqing Economic Zone at county-level units. Hou et al. applied the DPSIR framework to evaluate socioeconomic impacts on biodiversity. Luo et al. analyzed amphibian biodiversity patterns from perspectives of species richness, endemism, and threat factors. However, these studies mostly used administrative units as evaluation units or relied on biodiversity monitoring networks for field observation data, with few reports on grid cell-scale research in both spatial and temporal dimensions.

With the development of 3S technology and ecological models, regional biodiversity assessment has gradually become spatialized. The InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) model, developed by Stanford University, The Nature Conservancy, and WWF, can quantify multiple ecosystem services including biodiversity, carbon storage, soil retention, and water purification, presenting results as thematic maps. Studies by Yang et al., Xu et al., and Polasky et al. have demonstrated the feasibility of using InVEST and spatial analysis techniques to quantify biodiversity patterns.

The Bailong River Watershed in Gansu, located in the upper reaches of the Jialing River basin, constitutes an important component of the upper Yangtze River biodiversity conservation zone and is one of China’ s four major high-incidence areas for landslides and debris flows. With vegetation destruction and increasing human activities, ecological and natural disaster problems such as debris flows have become prominent, as exemplified by the catastrophic Zhouqu debris flow in 2010, seriously threatening sustainable socioeconomic development and biodiversity. Therefore, assessing spatial differentiation of biodiversity in this region is urgently needed. This study aims to construct a large-scale regional biodiversity spatial pattern assessment method based on an understanding of the watershed’ s biological, climatic, and geomorphological characteristics, using remote sensing and InVEST model support to quantitatively analyze biodiversity spatial differentiation characteristics at the grid cell scale, providing scientific basis for regional biodiversity conservation and planning management.

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2. Study Area Overview

The Bailong River Watershed of Gansu Province (32°36 –34°24 N, 103°00 – 105°30 E) is an important water source and ecological barrier in the upper Yangtze River. The watershed features complex terrain with significant vertical climate zonation and diverse climate types (precipitation 400–850 mm).

Located at the eastern edge of the Tibetan Plateau where the West Qinling and Min Mountains meet, the area has good vegetation cover. The climate is characterized by hot, rainy summers and cool, dry winters. The watershed source belongs to the Qinghai-Tibet Plateau alpine vegetation region, the middle and upper reaches are dominated by warm temperate deciduous broad-leaved forest, and the lower reaches feature subtropical evergreen broad-leaved forest.

The region hosts numerous rare and endangered plant species including Davidia involucrata, Metasequoia glyptostroboides, Emmenopterys henryi, Cercidiphyllaceae, Cathaya, Toona ciliata, Tetracentron sinense, and Taxus chinensis (national first-class protected plants), as well as second-class protected plants. It is home to the giant panda (Ailuropoda melanoleuca) and other protected wildlife, with nearly 200 species of medicinal plants including Angelica sinensis and Codonopsis pilosula.

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3. Research Methods

3.1 Habitat Quality Assessment

The InVEST model calculates habitat quality from land use/cover change perspectives by combining landscape type sensitivity and external threat intensity. Habitat quality is considered a continuous variable representing resources available for biological survival, reproduction, and development, with values indicating regional biodiversity richness. High habitat quality corresponds to high biodiversity, while low quality indicates low biodiversity.

The calculation process is as follows:

$$Q_{xj} = H_j \times \left(1 - \frac{D_{xj}}{D_{xj} + k_z}\right)$$

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \left(\frac{w_r}{\sum_{r=1}^{R} w_r}\right) r_y i_{ry} \beta_x S_{jr}$$

Where Q_{xj} is the habitat quality of grid cell x in land cover type j, H_j represents the habitat suitability of land cover type j, D_{xj} is the habitat degradation degree of grid cell x, k is the half-saturation coefficient, Z is a constant, R is the number of ecological threat factors, Y_r is the total number of grid cells for threat factor r, w_r is the weight of threat factor r, i_{ry} represents the number of threat factor r in grid cell y of land cover type y, and S_{jr} is the sensitivity of land cover type j to threat factor r (range [0,1]).

Ecological threat factors include major human or natural factors impacting surface landscapes, such as urban areas, rural settlements, and transportation infrastructure. Land cover data were obtained through supervised classification of remote sensing imagery. Based on China' s land use classification standards and actual land resource utilization in the watershed, we identified high, medium, and low coverage grasslands as distinct categories.

3.2 Vegetation Net Primary Productivity

Vegetation Net Primary Productivity (NPP) represents plant community productivity under current natural conditions, reflecting regional terrestrial ecosystem status and resilience. Within certain ranges, higher NPP corresponds to higher biodiversity. At large and medium scales, NPP calculation is primarily based on the light use efficiency model (CASA), which considers photosynthetically active radiation and light use efficiency, with most parameters obtainable through remote sensing.

The calculation formula is:

$$NPP(x,t) = APAR(x,t) \times \varepsilon(x,t)$$

$$APAR(x,t) = SOL(x,t) \times FPAR(x,t)$$

$$FPAR(x,t) = \frac{NDVI(x,t) - NDVI_{i,min}}{NDVI_{i,max} - NDVI_{i,min}} \times (FPAR_{max} - FPAR_{min}) + FPAR_{min}$$

Where $NPP(x,t)$ is the vegetation net primary productivity of pixel x in month t, $APAR(x,t)$ is the absorbed photosynthetically active radiation, $\varepsilon(x,t)$ is the actual light use efficiency, $SOL(x,t)$ is total solar radiation, $FPAR(x,t)$ is the fraction of absorbed photosynthetically active radiation, $NDVI(x,t)$ is the normalized difference vegetation index, and $NDVI_{i,max}$ and $NDVI_{i,min}$ represent maximum and minimum values for vegetation type i.

We used the 2014 annual average to represent regional overall NPP status. Required data included MOD13Q1 remote sensing data and observations from 23 meteorological stations, processed using ENVI5.1 and ArcGIS10.2.

3.3 Landscape Structure Index

Landscape structure state indirectly reflects landscape diversity strength. More complex ecosystems with better landscape structure state and more balanced categories indicate greater landscape diversity. Landscape loss degree—representing potential loss after disturbance—can be characterized through weighted functions of landscape fragmentation, separation, and fractal dimension.

The landscape structure index is calculated as:

$$LS_i = aC_i + bN_i + cF_i$$

Where LS_i is the landscape state index, C_i, N_i, and F_i are landscape loss index, fragmentation index, separation index, and fractal dimension respectively, and a, b, and c are weights determined using the Analytic Hierarchy Process (AHP).

3.4 Biodiversity Comprehensive Index

The biodiversity comprehensive index (BI_x) is a weighted function of regional habitat quality, vegetation net primary productivity, and landscape structure index:

$$BI_x = Q_{xj} \times \beta_Q + NPP_x \times \beta_{NPP} + S_x \times \beta_S$$

Where BI_x is the biodiversity index of grid cell x, Q_{xj} is habitat quality, NPP_x is vegetation net primary productivity, S_x is landscape structure index, and β values are weights assigned as 0.5, 0.3, and 0.2 respectively based on AHP and study area characteristics. All indicators were standardized before calculation.

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4. Results

4.1 Single Indicator Analysis

The spatial distribution of habitat quality in the Bailong River Watershed shows clear patterns. Low habitat quality areas (<0.25) are mainly distributed in valley zones with frequent human activity along soil-rock mountain transition zones, including both sides of the Bailong River in the Wudu section, the Wenxian-Wudu border area, and northwestern Tanchang County. High habitat quality areas concentrate in mid-high mountain forest regions and nature reserves with weak human disturbance, with Diebu County showing the highest quality, followed by Wenxian County.

NPP values in 2014 ranged from 300–700 gC/m², with low-value areas (<500.59 gC/m²) mainly in agriculturally developed valley and hilly regions and alpine zones. The minimum occurred in Wudu District. High-value areas (>500 gC/m²) are distributed in southeastern and southern Wenxian, the Diebu-Axia forest region, and the upper reaches of the Boyu River Nature Reserve. Among vegetation types, evergreen broad-leaved forest showed the highest NPP (677.8 gC/m²), while alpine sparse vegetation showed the lowest (319.2 gC/m²).

The landscape structure index spatial pattern correlates with habitat quality. Relatively stable landscape structures with high diversity concentrate in nature reserves and forest management zones, particularly in mid-mountain broad-leaved forest and subalpine coniferous-broadleaved mixed forest ecosystems. Low landscape diversity areas are mainly distributed in Majie Township of Wudu District, Tanchang County urban area to Chela Township, and Bali Township to Hadapu Town.

[Figure 2: see original paper] shows the spatial distribution of these biodiversity assessment indicators across the watershed.

4.2 Comprehensive Biodiversity Assessment

Comprehensive evaluation reveals that high biodiversity areas account for 26.53% of the watershed, mainly distributed in mid-high mountain forest regions at elevations of 1500-3000 m, including national nature reserves and forest management zones. These areas feature high species richness, high habitat quality, minimal human disturbance, and good vegetation cover, with nearly 100 animal and plant species listed in the CITES convention.

Medium-high biodiversity areas (37.89%) are primarily forest ecosystems with interspersed shrub-grassland, relatively rich species composition, good habitat quality, and locally high biodiversity. Medium biodiversity areas (13.3%) are mainly agricultural-forest or pastoral ecosystems with relatively poor species composition and general habitat quality. Low biodiversity areas (22.31%) are concentrated in agricultural production zones and urban-rural settlement areas with fragile ecological environments, frequent human disturbance, serious soil erosion, high landscape fragmentation, and poor habitat quality.

[Figure 3: see original paper] and present the comprehensive spatial distribution patterns and classification of biodiversity status in the watershed.

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5. Discussion

The spatiotemporal distribution characteristics of biodiversity in the Bailong River Watershed show clear regularity. Areas with low comprehensive biodiversity indices are mainly distributed in valley zones and gentle hill regions with frequent human activities and relatively developed agriculture and industry, particularly in urban-rural settlement areas and low-coverage grassland landscapes. High biodiversity areas—the key priority zones for conservation—are primarily distributed in nature reserves and forest management zones with minimal surface disturbance, accounting for 39.80% of the total area.

These findings align with previous research results and correspond with the objective fact that the BRWGP falls within China’s Minshan Mountain and northern Hengduan Mountains biodiversity conservation priority areas identified by the Ministry of Environmental Protection. Compared with previous administrative unit-based studies, this grid cell-scale approach compensates for potential discrepancies between administrative unit patterns and actual biodiversity distribution, facilitating more effective conservation planning and management.

This study attempted to improve the InVEST-biodiversity module' s assessment results by incorporating landscape geography perspectives, using habitat quality, NPP, and landscape structure indices to represent landscape richness and ecosystem diversity. Validation was conducted through field biodiversity surveys, nature reserve scientific expedition reports, and national wild flora and fauna inventories. Results demonstrate that the improved assessment can clearly and objectively reflect actual biodiversity spatial distribution patterns at regional scales.

However, due to the large study area and lack of standardized baseline monitoring data, with limited field survey plots and complex terrain-plant diversity relationships, future work should intensify biodiversity baseline surveys and long-term field observations, combined with macro-scale remote sensing monitoring, to develop more accurate quantitative assessment systems and address temporal and spatial scale limitations.

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6. Conclusion

Spatially, biodiversity-rich areas in the Gansu Bailong River Watershed are concentrated in national nature reserves including Baishuijiang, Daxia, Chaganliang, and Boyuhe, as well as in the Diebu County forest zones of Axia and Duo' er giant panda nature reserves and the Dala-Dieshan forest region. Low biodiversity areas are mainly distributed in the Zhouqu-Wudu-Wenxian valleys along the Bailong River, the Minjiang River banks in Tanchang County, and alpine regions above 3500 m in Diebu County.

Supported by remote sensing and InVEST model technology, this study constructed a regional biodiversity spatial pattern assessment method using habitat quality, NPP, and landscape structure indices, quantitatively analyzing biodiversity spatial distribution at the grid cell scale. Compared with InVEST alone or previous administrative unit-based approaches, this method provides more objective and realistic results for the mountainous, data-scarce Gansu Bailong River Watershed, better matching actual biodiversity distribution patterns.

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