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Temporal Variation in Tree Diversity of Major Forest Vegetation Types in Xishuangbanna Region: A Postprint

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Abstract

Biodiversity assessment provides an important reference for regional sustainable development. To evaluate the temporal variation of tree diversity in forest vegetation in Xishuangbanna, Yunnan Province, tree diversity data for four major forest vegetation types (tropical rainforest, tropical seasonally moist forest, tropical montane evergreen broad-leaved forest, and warm-temperate coniferous forest) were collected through quadrat surveys; the distribution of these four forest vegetation types in the region during four periods (1992, 2000, 2009, and 2016) was extracted from remote sensing imagery; the Simpson, Shannon-Wiener, and Scaling species diversity indices were used to compare differences in tree evenness among the four forest vegetation types; and the Scaling ecological diversity index and grey relational evaluation model were employed to assess the temporal variation of forest tree diversity in the region across the four periods. The results indicate that: (1) The proportion of forest area exhibited a trend of initial decrease followed by increase, decreasing from 65.5% in 1992 to 53.42% in 2000, further decreasing to 52.49% in 2009, and then increasing to 54.73% in 2016, although tropical rainforest showed a continuous decreasing trend; (2) The four forest vegetation types exhibited significant differences in their contributions to tree diversity, with evenness ranking as tropical rainforest > tropical montane (low mountain) evergreen broad-leaved forest > warm-temperate coniferous forest > tropical seasonally moist forest, richness ranking as tropical rainforest > tropical montane (low mountain) evergreen broad-leaved forest > tropical seasonally moist forest > warm-temperate coniferous forest, and contribution to tree diversity ranking as tropical rainforest > tropical montane (low mountain) evergreen broad-leaved forest > tropical seasonally moist forest > warm-temperate coniferous forest; (3) Tree diversity in tropical rainforest and tropical seasonally moist forest showed a continuous decreasing trend, and the ranking of forest vegetation tree diversity in Xishuangbanna across the four periods was 1992 > 2009 > 2016 > 2000. The study demonstrates that economic activities constitute an important factor influencing biodiversity in Xishuangbanna, and that protecting tropical rainforests is of significant importance for maintaining biodiversity in the region.

Full Text

Preamble

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Title: Temporal Change in Tree Diversity of Main Forest Vegetation Types in Xishuangbanna, SW China

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Abstract

Biodiversity assessment provides critical reference for regional sustainable development. To evaluate temporal changes in tree diversity of forest vegetation in Xishuangbanna, Yunnan Province, we collected tree diversity data from four major forest vegetation types (tropical rainforest, tropical seasonal moist forest, tropical lower montane evergreen broad-leaved forest, and warm-temperate coniferous forest) through quadrat surveys. We extracted the spatial distribution of these four forest vegetation types for four periods (1992, 2000, 2009, and 2016) using remote sensing imagery. Simpson, Shannon-Wiener, and Scaling species diversity indices were employed to compare tree evenness differences among the four forest vegetation types. The Scaling ecological diversity index and grey correlational evaluation model were then used to assess temporal changes in forest tree diversity across the region.

The results show that: (1) The proportion of forest area initially decreased then increased, declining from 65.5% in 1992 to 53.42% in 2000 and 52.49% in 2009, before rising to 54.73% in 2016. However, tropical rainforest exhibited a continuous decreasing trend throughout the study period. (2) The four forest vegetation types contributed differently to tree diversity. Evenness ranked as: tropical rainforest > tropical lower montane evergreen broad-leaved forest > warm-temperate coniferous forest > tropical seasonal moist forest. Richness ranked as: tropical rainforest > tropical lower montane evergreen broad-leaved forest > tropical seasonal moist forest > warm-temperate coniferous forest. Overall contribution to tree diversity followed the order: tropical rainforest > tropical lower montane evergreen broad-leaved forest > tropical seasonal moist forest > warm-temperate coniferous forest. (3) Tree diversity in tropical rainforest and

tropical seasonal moist forest showed continuous declining trends. The ranking of overall forest vegetation tree diversity in Xishuangbanna across the four periods was: 1992 > 2009 > 2016 > 2000.

The study indicates that economic activities constitute a significant factor affecting biodiversity in Xishuangbanna, and that conserving tropical rainforest is crucial for maintaining regional biodiversity.

Keywords: Xishuangbanna, tree diversity, forest vegetation, remote sensing, Scaling diversity index, grey correlational evaluation model

1. Study Area Overview

Xishuangbanna (99°58 -102°00 E, 21°09 -22°30 N) is located in southern Yunnan Province, bordering Pu' er City to the north and Myanmar and Laos to the south [Figure 1: see original paper]. The terrain is characterized by higher elevations in the east and west, with the lower Lancang River valley in the central region. The western and eastern areas represent extensions of the Nushan and Wuliang mountain ranges. Strongly influenced by the Indian Ocean monsoon, the region has a tropical monsoon climate with mean annual temperatures of 18–21.7°C and distinct wet and dry seasons. Precipitation ranges from 1,193 to 2,491 mm. Xishuangbanna contains 32 typical community types belonging to seven major vegetation categories. Climate and vegetation strongly influence soil distribution: latosols occur in low-elevation tropical rainforests and monsoon forests, lateritic red soils in monsoon evergreen broad-leaved forests, and limestone soils in karst areas.

Note: TRF = Tropical rainforest; TSMF = Tropical seasonal moist forest; TEBF = Tropical lower montane evergreen broad-leaved forest; COF = Tropical coniferous forest. The same below.

2.1 Plot Setup and Survey Methods

To compare tree diversity among different vegetation types and calculate the Scaling ecological diversity index, we established survey plots in well-preserved forests with minimal human disturbance across Xishuangbanna, following regional forest vegetation classification principles. We set up eight plots covering four forest vegetation types: four tropical rainforest plots, one tropical seasonal moist forest plot, two tropical lower montane evergreen broad-leaved forest plots, and one warm-temperate coniferous forest plot [Figure 1: see original paper]. Each plot measured 2,500 m^2. We identified and recorded all tree individuals with diameter at breast height (DBH) \$ \$3 cm and height \$ \$3 m, measuring DBH, height, and crown cover for each individual.

2.2 Vegetation Distribution and Area Extraction

To obtain vegetation area data for four time periods for Scaling ecological diversity index calculations, we used Landsat TM and OLI imagery (30 m spatial resolution) and GDEMV2 topographic data for Xishuangbanna. In ENVI 5.3, we performed FLAASH atmospheric correction on each image, selected shortwave infrared, near-infrared, red, and green bands, and applied Teillet' s module for topographic correction to reduce atmospheric and topographic shadow effects. We then visually interpreted the images to extract broad-leaved forest, warm-temperate coniferous forest, and other vegetation types (including bamboo, shrubland, grassland, cultivated land, and aquatic vegetation). Using ArcGIS 10.3, we overlaid the classified broad-leaved forest with elevation data to extract broad-leaved forest below 1,000 m as tropical rainforest distribution areas. We also extracted limestone distribution areas and overlaid them with broad-leaved forest to identify tropical seasonal moist forest distribution. Kappa accuracies for 2016, 2009, 2000, and 1992 were 0.95, 0.92, 0.88, and 0.85, respectively.

2.3 Diversity Measurement Methods

We used Simpson (HS), Shannon-Wiener (H), and Scaling species diversity index (D) to measure tree diversity in tropical rainforest, tropical seasonal moist forest, tropical lower montane evergreen broad-leaved forest, and warm-temperate coniferous forest. The Scaling ecological diversity index (D) was used to compare temporal changes in tree diversity among different forest vegetation types. The formulas are as follows:

$$HS = \sum_{i=1}^{m} p_i^2$$

$$H = -\sum_{i=1}^{m} p_i \ln p_i$$

$$D' = \sum_{i=1}^{m} p_i^2 \ln(p_i^2)$$

$$D = \sum_{i=1}^{m} p_i^2 \ln(p_i^2) \cdot \frac{1}{\ln \varepsilon}$$

$$\varepsilon = e^{-1} + A$$

where p_i is the proportion of the ith tree individual relative to all tree individuals in the plot; $e = 2.71828$; and A represents the area of the study object (ha).

2.4 Evaluation of Forest Tree Diversity in Xishuangbanna

After calculating the Scaling ecological diversity indices for different vegetation types across four periods, we introduced the grey correlational evaluation model to compare biodiversity changes among periods. This model assesses correlation among indicators by reflecting curve similarity and is widely applied across fields due to its ability to infer relationships using few indicators with different dimensions. The procedure follows Zhang and Zhang (1996) and Zou et al. (2017):

First, we established a reference sequence $X_0 = \{x_0(1), x_0(2), \cdots, x_0(n)\}$ and comparison sequences $X_i = \{x_i(1), x_i(2), \cdots, x_i(n)\}$. The maximum value of each vegetation type' s Scaling ecological diversity index across four periods was taken as the optimal state, with X_i representing the Scaling ecological diversity index of each vegetation type in year i.

Second, we applied mean normalization for dimensionless processing:

$$x_i'(k) = \frac{x_i(k)}{\frac{1}{n}\sum_{k=1}^{n} x_i(k)}$$

where k represents different forest vegetation types.

Third, we calculated the grey correlational coefficient for each vegetation type:

$$\gamma_i(k) = \frac{\min_i \min_k |x_0'(k) - x_i'(k)| + \varepsilon \max_i \max_k |x_0'(k) - x_i'(k)|}{|x_0'(k) - x_i'(k)| + \varepsilon \max_i \max_k |x_0'(k) - x_i'(k)|}$$

where $\varepsilon = 0.5$.

Finally, we calculated the grey correlational evaluation index for forest tree diversity in Xishuangbanna for each period:

$$\gamma_i = \sum_{k=1}^{n} \omega(k)\gamma_i(k)$$

where $\omega(k)$ represents the weight derived from the Scaling ecological diversity index of the four vegetation types, calculated as:

$$\omega(k) = \frac{x(k)}{\sum_{k=1}^{n} x(k)}$$

3.1 Changes in Forest Vegetation Area

Remote sensing interpretation revealed that total forest area in Xishuangbanna initially decreased then increased during 1992-2016 [Figure 2: see original paper]. Tropical rainforest area declined continuously from 22.77% in 1992 to 15.1% in 2016. Tropical lower montane evergreen broad-leaved forest, the largest vegetation type, decreased from 41.6% in 1992 to 33.61% in 2000 and 33.35% in 2008, then increased to 38.4% in 2016. Tropical seasonal moist forest and warm-temperate coniferous forest occupied relatively small areas, fluctuating below 1.2%. Other vegetation types increased from 34.5% in 1992 to 45.27% in 2016.

Spatial analysis shows tropical rainforest distributed primarily in low-elevation central and eastern areas, tropical seasonal moist forest in the central-east, tropical lower montane evergreen broad-leaved forest throughout the region, other vegetation in relatively flat terrain, and warm-temperate coniferous forest in the north bordering Pu' er City. Temporal comparison reveals dramatic vegetation changes, particularly conversion of low-elevation tropical rainforest to other vegetation in Jinghong City and Mengla County, conversion of tropical lower montane evergreen broad-leaved forest to other vegetation in central-western, northwestern, and northeastern areas, and conversion of low-elevation tropical seasonal moist forest to other vegetation in central Mengla County.

Note: OTH = Other vegetation.

3.2 Comparison of Tree Diversity in Sample Plots

Tropical rainforest exhibited the highest mean species richness at 55 species per plot, followed by tropical lower montane evergreen broad-leaved forest (35 species), tropical seasonal moist forest (29 species), and warm-temperate coniferous forest (27 species) . In terms of individual tree counts, tropical seasonal moist forest had the highest density (252 individuals), exceeding tropical rainforest (220 individuals), while warm-temperative coniferous forest had 185 individuals and tropical lower montane evergreen broad-leaved forest had the lowest density (151 individuals). All three evenness indices consistently ranked vegetation types as: tropical rainforest > tropical lower montane evergreen broad-leaved forest > warm-temperate coniferous forest > tropical seasonal moist forest.

Table 1 Tree diversity indices of main forest vegetation types in Xishuangbanna

Diversity index	TRF	TSMF	TEBF	COF
Plot number	4	1	2	1
Area of each plot (m^2)	2,500	2,500	2,500	2,500
Average species number	55±11.34	29	35±7.07	27
Average plant number	220±12.4	252	151±2.83	185
Wiener index (H)	3.45±0.28	2.33	2.90±0.14	2.68
Scaling index (D′)	3.72±0.24			

Note: Values = mean ± SD; TRF = Tropical rainforest; TSMF = Tropical seasonal moist forest; TEBF = Tropical lower montane evergreen broad-leaved forest; COF = Tropical coniferous forest. The same below.

3.3 Changes in Tree Diversity Across the Entire Region

Using plot survey data and remotely sensed vegetation distribution, we calculated temporal changes in Scaling ecological diversity indices for each vegetation type . Tropical rainforest maintained Scaling ecological diversity indices above 46, making it the most important vegetation for sustaining forest tree diversity in Xishuangbanna. Tropical lower montane evergreen broad-leaved forest and tropical seasonal moist forest followed, with indices of 40–41 and 22–24, respectively. Warm-temperate coniferous forest dominated by *Pinus kesiya* var. *langbianensis* had indices below 23. Consequently, the contribution ranking of vegetation types to regional tree diversity was: tropical rainforest > tropical lower montane evergreen broad-leaved forest > tropical seasonal moist forest > warm-temperate coniferous forest.

Table 2 Tree Scaling diversity index change and weight [ω(k)] of main forest vegetation types from 1992 to 2016

Vegetation	1992	2000	2009	2016	ω(k)
TRF	46.82	42.31	39.54	38.21	0.33
TSMF	24.15	23.08	22.31	22.00	0.17
TEBF	41.23	40.15	40.77	40.92	0.29
COF	22.31	23.08	22.62	22.77	0.21

Application of the grey correlational evaluation model to interannual changes in Scaling ecological diversity indices revealed continuous declines in tree diversity for tropical rainforest and tropical seasonal moist forest, an initial decrease followed by increase for tropical lower montane evergreen broad-leaved forest, and fluctuating patterns for warm-temperate coniferous forest [Figure 3: see original paper]. Grey correlational evaluation indices for Xishuangbanna forest tree diversity were 1.00, 0.58, 0.63, and 0.62 for 1992, 2000, 2009, and 2016, respectively, yielding the ranking: 1992 > 2009 > 2016 > 2000.

4.1 Analysis of Causes for Tree Diversity Changes

Economic activities represent the primary driver of biodiversity loss in Xishuangbanna. Our results demonstrate continuous biodiversity decline from 1992–2016, with rubber and tea plantations being the main culprits. Since economic reforms, increased rubber demand has driven large-scale tropical rainforest conversion to rubber plantations, with cultivation extending to 1,400 m elevation since 1992. Some low-elevation tropical lower montane evergreen broad-leaved forests have also been converted to rubber plantations, while higher-elevation areas unsuitable for rubber have been transformed into tea plantations. Although the Natural Forest Protection Program (1998) and Sloping Land Conversion Program (2002) slowed biodiversity loss in tropical rainforest and tropical lower montane evergreen broad-leaved forest during 2000–2009, increasing rubber prices after 2009 triggered renewed large-scale tropical rainforest conversion, contradicting program objectives.

4.2 Significance of Tropical Rainforest in Maintaining Regional Biodiversity

Tropical rainforest is the most critical vegetation for maintaining forest tree diversity in Xishuangbanna. It ranked first in contribution to regional tree diversity across all four periods, being the second-largest forest type by area after tropical lower montane evergreen broad-leaved forest. Tropical rainforest exhibited substantially higher tree evenness and richness per unit area than other vegetation types, meaning its loss incurs greater biodiversity impacts. Furthermore, as a key ecosystem service indicator, tropical rainforest provides biodiversity maintenance value of US$41 ha^{-1} yr^{-1} compared to US4*ha*^{-1}$ yr^{-1} for other forests, underscoring the severe consequences of its loss for regional biodiversity maintenance functions.

Loss of rare species drives forest biodiversity decline, particularly in tropical rainforest and tropical lower montane evergreen broad-leaved forest. In warm-temperate coniferous forest dominated by *Pinus kesiya* var. *langbianensis* and tropical seasonal moist forest dominated by *Cleistanthus sumatranus*, other tree species constitute a relatively small proportion of community composition, so their reduction does not significantly affect evenness. However, in tropical rainforest where dominant species are less pronounced, rare species comprise a high proportion of community composition, and their loss substantially impacts overall biodiversity. Similarly, although tropical lower montane evergreen broad-leaved forest is dominated by Fagaceae and Lauraceae species, rare species also represent a significant proportion.

4.3 Applicability Analysis of the Scaling Ecological Diversity Index

The Scaling ecological diversity index combined with remote sensing can be applied to regional biodiversity assessment. Like Simpson and Shannon-Wiener indices, Scaling measures community evenness, but uniquely incorporates area to measure species richness across study areas. Ground surveys combined with remote sensing can also extract ecosystem types and monitor vegetation integrity. The Scaling index aligns with high-weight indicators in traditional regional biodiversity studies—species richness, ecosystem type, and vegetation integrity—demonstrating its applicability.

However, standardization challenges exist. Different plot sizes and sampling criteria compromise comparability, necessitating uniform sampling standards across vegetation types. Although studies show the Scaling index is resolution-independent within 30–150 m scales and species-area relationships facilitate scaling, upscaling from community to regional level is complicated by sampling effects and habitat heterogeneity, with difficulty increasing with study area size. The index' s reliability in large or highly heterogeneous regions requires further investigation, as does its application for comparing different vegetation types across regions. The grey correlational evaluation model also has limitations, including lack of order-preserving effects in dimensionless processing and unsatisfied normalization of correlational degrees, necessitating development of improved mathematical models.

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