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ORIGINAL RESEARCH ARTICLE

Temporal variation of tree diversity of main forest vegetation in Xishuangbanna

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ABSTRACT

In order to evaluate the temporal changes in tree diversity of forest vegetation in Xishuangbanna, Yunnan Province, the study collected tree diversity data from four main forest vegetation in the region through a quadrat survey including tropical rainforest (TRF), tropical coniferous forest (COF), tropical lower mountain evergreen broad-leaved forest (TEBF), tropical seasonal moist forest (TSMF). We extracted the distribution of four forest vegetation in the region in four periods of 1992, 2000, 2009, and 2016 in combination with remote sensing images, using simp son Shannon Wiener and scaling species diversity indexes compare to the differences of tree evenness of four forest vegetation and use the scaling ecological diversity index and grey correlation evaluation model to evaluate the temporal changes of forest tree diversity in the region in four periods. The results show that: (1) The proportion of forest area has a trend of decreasing first and then increasing, which is shown by the reduction from 65.5% in 1992 to 53.42% in 2000, to 52.49% in 2009, and then to 54.73% in 2016. However, the tropical rainforest shows a continuous decreasing trend. (2) There are obvious differences in the contributions of the four kinds of forest vegetation to tree diversity. The order of evenness is tropical rainforest > tropical mountain (low mountain) evergreen broad-leaved forest > warm coniferous forest > tropical seasonal humid forest, and the order of richness is tropical rainforest > tropical mountain (low mountain) evergreen broad-leaved forest > tropical seasonal humid forest > warm coniferous forest, The order of contribution to tree diversity in tropical rainforest > tropical mountain (low mountain) evergreen broad-leaved forest > tropical seasonal humid forest > warm tropical coniferous forest. (3) The tree diversity of tropical rainforests and tropical seasonal humid forests showed a continuous decreasing trend. The tree diversity of forest vegetation in Xishuangbanna in four periods was 1992 > 2009 > 2016 > 2000. The above results show that economic activities are an important factor affecting the biodivesity of Xishuangbanna, and the protection of tropical rainforest is of great significance to maintain the biodiversity of the region.

Keywords: Xishuangbanna; Tree Diversity; Forest Vegetation; Remote Sensing; Scaling Ecological Diversity Index; Grey Correlation Evaluation Model

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1. Introduction

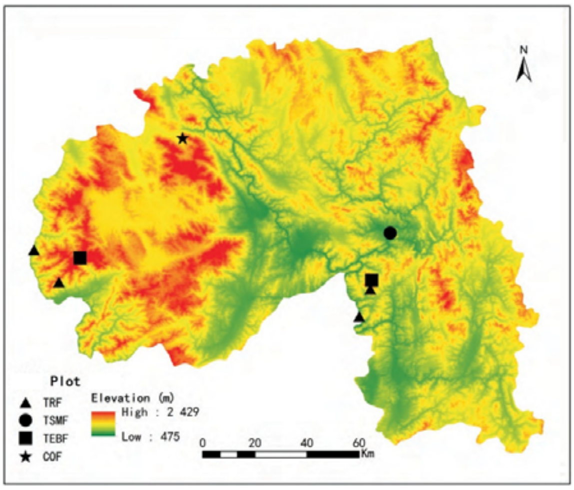
Biodiversity assessment can not only understand the current situation and change trends of regional biodiversity but also provide a scientific basis for the government's decision-making on regional biodiversity protection and sustainable development[1]. At present, the evaluation methods of regional biodiversity can be divided into the frequency analysis method and remote sensing inversion method. The frequency analysis method uses an expert consultation method to set weights by screening practical indicators, such as plant species, animal species, ecosystem types, and alien species, so as to compare the biodiversity of different regions. This method is not only highly subjective and lacks further scientific quantification, but also the regional biodiversity evaluation system and method are not unified, and the evaluation results of different regions are not well comparable[2]. Remote sensing technology has the characteristics of multi-space-time and multi-spectrum, which provides a new way for the monitoring and evaluation of regional biodiversity[3]. At present, remote sensing data can be used to map species or habitats, establish the relationship model between surface species diversity and the remote sensing spectrum, analyze the landscape index of the land use map interpreted by remote sensing, and evaluate and monitor regional biodiversity[4,5]. Although remote sensing can provide information such as area, structure, and species types for the evaluation of regional biodiversity, the evaluation of regional biodiversity also relies on geographic information technology and mathematical models[6]. Therefore, the scaling ecological diversity index[7] is proposed. The scaling ecological diversity index is composed of species' evenness and area. It is a comprehensive reflection of species evenness, species richness, and area in the region. The larger the index, the higher the ecological diversity[8].

Xishuangbanna, located in the south of Yunnan Province, is a hot biodiversity distribution area[9]. On the land whose land area is only 0.2% of the national area, there are nearly 20% of China's mammals and birds, as well as more than 5000 kinds of plants[10]. However, since 1976, natural forests in Xishuangbanna have been decreasing, while rubber forests, tea gardens, and agricultural land have been increasing[13,14], of which rubber forests are the direct cause of the loss of biodiversity in the tropical rainforest in the region[11,13]. The fragmentation of tropical rainforests caused by land use change is more serious than that of other forest vegetation[14], resulting in changes in the composition and structure of tropical rainforest communities[15] and the loss of tree species diversity[16]. Although many scholars have proved the continuous loss of biodiversity in Xishuangbanna by various means, it is difficult to explain the differences between vegetation only by remote sensing[13,14]. Community survey[15-17] is difficult to reflect the biodiversity of the whole region. At present, there are few studies on the temporal changes of biodiversity in Xishuangbanna.

Taking Xishuangbanna as the study area, based on the quadrat survey of tree data of different forest vegetation, combined with Landsat TM and oli image interpretation of Xishuangbanna vegetation spatial distribution data in 1992, 2000, 2009, and 2016, using the scaling ecological diversity index[8], calculate the changes of tree diversity of different forest vegetation in four periods, The grey correlation evaluation model was used to evaluate the current situation and changes of forest vegetation arbor diversity in this area, so as to provide decision-making basis for biodiversity protection in Xishuangbanna.

2. Overview of the research site

Xishuangbanna (99°58'–102°00'E, 21°09'–22°30'N) is located in the south of Yunnan Province, connected with Pu'er City in the north and Myanmar and Laos in the South (**Figure 1**). The terrain is high in the East and West, and the Lancang River Valley in the middle is low above sea level. The West and East belong to the rest of the Nu mountain range and the Wuliang Mountain range. This area is deeply affected by the Indian Ocean monsoon, belonging to the tropical monsoon climate, with an annual average temperature of 18–21.7 °C; the seasonal variation of precipitation is obvious, with obvious dry and wet seasons, and the precipitation is 1,193–2,491 mm. Xishuangbanna has 32 typical formations, belonging to 7 main vegetation[18]. Under the influence of climate and vegetation, the tropical rain forest and seasonal rain forest at lower altitudes in Xishuangbanna are distributed with zonal latosol, while the monsoon evergreen broad-leaved forest is distributed with lateritic soil, and the limestone area is distributed with calcareous soil.



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

Figure 1. Locations of Xishuangbanna and sample plots.

3. Research methods

3.1 Sample plot setting and investigation methods

In order to compare the tree diversity of different vegetation and calculate the scaling ecological diversity index, according to the principles and basis of forest vegetation classification in Xishuangbanna[18], the well-developed forests that are less affected by human activities are selected in Xishuangbanna, and four tropical rainforests, one tropical seasonal humid forest, two tropical mountain (low mountain) evergreen broad-leaved forests, and An investigation sample plot of warm coniferous forest with four different forest vegetation (**Figure 1**), each sample plot has an area of 2,500 m^2. Identify and record all tree individuals with DBH ≥3 cm and height ≥3 m in the sample plot, and measure the DBH, height, coverage, and other information of tree individuals.

3.2 Vegetation distribution and area extraction

In order to obtain different vegetation areas in four periods and calculate the scaling ecological diversity index, this study uses Landsat TM and OLI images with a spatial resolution of 30 m in Xishuangbanna and Gdemv2 topographic data. With the support of Envi5.3 software, perform flash atmospheric correction on each image, select short wave infrared, near-infrared, red band, and green band data, and use Teillet module to perform terrain correction on the image, so as to weaken the impact of atmosphere and mountain shadow on vegetation extraction; then, the image is visually interpreted to extract broad-leaved forests, warm coniferous forests, and other vegetation (including bamboo forests, shrubs, grasses, cultivated and aquatic vegetation); finally, Arcgis10.3 software is used to superimpose the classified broad-leaved forest with altitude, extract the broad-leaved forest below 1,000 m as the distribution area of Tropical Rainforest[14], extract the limestone mountain distribution area[19] and superimpose the broad-leaved forest to obtain the distribution area of tropical seasonal humid forest. The kappa accuracy of 2016, 2009, 2000 and 1992 is 0.95, 0.92, 0.88 and 0.85, respectively.

3.3 Diversity measurement method

In this paper, Simpson (HS), Shannon Wiener (H), and scaling species diversity index (d') are used to calculate the tree diversity of tropical rainforest, tropical seasonal moist forest, tropical mountain evergreen broad-leaved forest, and warm coniferous forest, and scaling ecological diversity index (d) is used to compare the changes of tree diversity of different forest vegetation in Xishuangbanna[7,8]. The calculation formula is as follows:

$$HS = 1 - \sum_{i=1}^{m} P_i^2 \tag{1}$$

$$H = -\sum_{i=1}^{m} P_i \ln P_i \tag{2}$$

$$D' = \ln\left(\sum_{i=1}^{m} P_i^{\frac{1}{2}}\right)^2 \tag{3}$$

$$D = -\frac{\ln\left(\sum_{i=1}^{m} P_i^{\frac{1}{2}}\right)^2}{\ln \varepsilon} \tag{4}$$

Where, P_i is the proportion of the i-th tree individual to all tree individuals in the sample plot; $\varepsilon = (e + A)^{-1}$, e = 2.71828, a represents the area of the survey object (hm^2).

3.4 Evaluation of forest tree diversity in Xishuangbanna

After calculating the scaling ecological diversity index of different vegetation in four periods, in order to compare the changes of biodiversity in Xishuangbanna in four periods, this study introduces the grey correlation evaluation model into the evaluation and comparison of tree diversity in Xishuangbanna between different periods. The grey correlation evaluation model infers the correlation of various indicators by reflecting the similarity between curves[20]. Its advantage is that it can infer the correlation with a small number of indicators with different dimensions, which is widely used in various fields. The steps of grey correlation degree are as follows[21,22].

First, set the reference sequence,

$$X_0 = \{x_0(1), x_0(2), \cdots, x_0(n)\}$$

and the compared sequence,

$$X_i = \{x_i(1), x_i(2), \cdots, x_i(n)\}$$

where X_0 takes the maximum value of scaling ecological diversity of each vegetation in four periods as the optimal state, and X_i represents the scaling ecological diversity index of each vegetation in the i year. Secondly, the scaling ecological diversity index of each vegetation is dimensionless by using the averaging method, and the expression is:

$$x_i'(k) = \frac{x_i(k)}{\overline{X_i}}$$

Where:

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

k represents different forest vegetation; then calculate the grey correlation index of ecological diversity of each vegetation, and the expression is:

$$\gamma_{0i}(k) = \frac{\min_i \min_k |x_0'(k) - x_i'(k)| + \varepsilon \max_i \max_k |x_0'(k) - x_i'(k)|}{|x_0'(k) - x_i'(k)| + \varepsilon \max_i \max_k |x_0'(k) - x_i'(k)|}$$

$\varepsilon = 0.5$. Finally, the grey correlation evaluation index of tree diversity in Xishuangbanna in each period is calculated, and the expression is:

$$\gamma_{0i} = \sum_{k=i}^{n} \omega(k)\gamma_{0i}(k)$$

where $\omega(k)$ represents the weight obtained from the scaling ecological diversity index of 4 plantations, and the calculation formula is as follows:

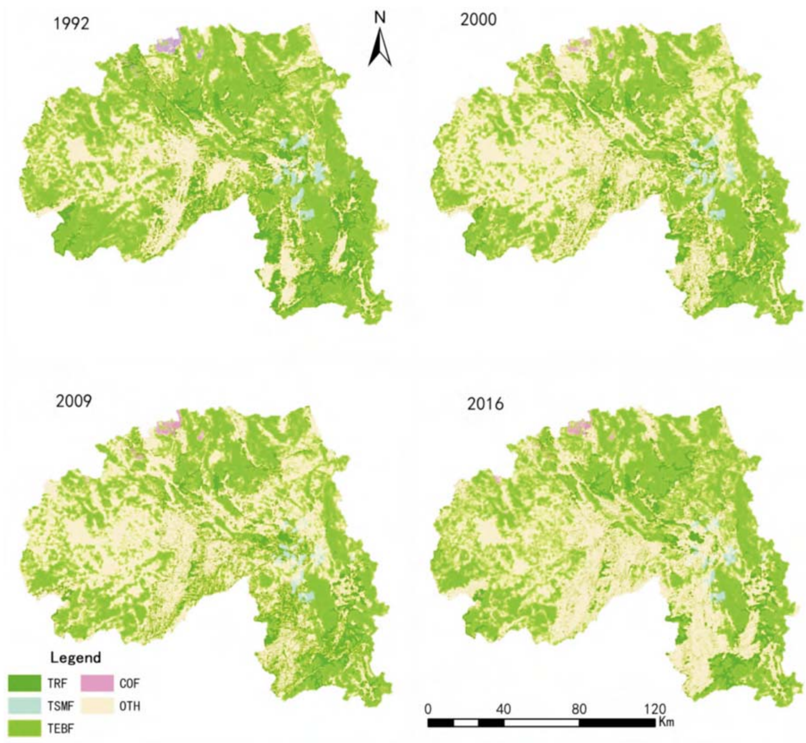
$$\omega(k) = \frac{\overline{x_k}}{\sum_{k=1}^{4} \overline{x_k}} \quad (5)$$

4. Results and analysis

4.1 Changes in forest vegetation area

According to the vegetation distribution in the four periods of remote sensing image interpretation (**Figure 2**), from 1992 to 2016, the forest area of Xishuangbanna generally showed a trend of decline first and then increase. The area of tropical rainforest decreased from 22.77% in 1992 to 15.1% in 2016; as the largest tropical mountain evergreen broad-leaved forest, it decreased from 41.6% in 1992 to 33.61% in 2000 and 33.35% in 2008, and increased to 38.4% in 2016; the distribution area of tropical seasonal moist forest and warm tropical coniferous forest in Xishuangbanna is small, both fluctuating below 1.2%; however, the area of other vegetation increased from 34.5% in 1992 to 45.27% in 2016.

It can also be seen from **Figure 2** that tropical rain forests are mainly distributed in the lower altitude areas in the middle and east of Xishuangbanna, tropical seasonal moist forests are distributed in the middle and East, and tropical mountain monsoon evergreen broad-leaved forests are distributed in Xishuangbanna, other vegetation is mainly distributed in the gentle terrain areas, and warm coniferous forests are distributed in the north of Pu'er City. From the comparison of time and space, the vegetation in Xishuangbanna has changed dramatically, especially the low-altitude tropical rainforest vegetation in Jinghong City and Mengla County has changed into other vegetation; the evergreen broad-leaved forest in tropical mountainous areas in the Midwest, northwest, and northeast of Xishuangbanna has been transformed into other vegetation; the low altitude tropical seasonal moist forest in the middle of Mengla County has been transformed into other vegetation.



Note: OTH. Other vegetations.

Figure 2. Map of main forest vegetation types in Xishuangbanna in 1992, 2000, 2009 and 2016.

4.2 Comparison of tree diversity of forest vegetation in the sample plot

From the number of arbor species in each sample area (**Table 1**), the average number of species in the tropical rainforest is 55, which is the vegetation with the largest number of arbor species; the second is 35 species of evergreen broad-leaved forests in tropical mountainous areas, higher than 29 species of tropical seasonal humid forests and 27 species of warm coniferous forests. In terms of the number of arbor plants, the number of trees in the tropical seasonal humid forest is 252, higher than that in tropical rainforest, 220, Simao Pine forest is 185, and the lowest number of trees in tropical mountain evergreen broad-leaved forest is 151. The evenness of the three species reflects that the evenness of different forest vegetation in Xishuangbanna is ranked as tropical rainforest > tropical mountain evergreen broad-leaved forest > warm coniferous forest > tropical seasonal humid forest.

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

Diversity index	TRF	TSMF	TEBF	COF
Area of each plot (m^2)	2,500	2,500	2,500	2,500
Plot number	4	1	2	1
Average species number	55 ± 11.34	29	35	27
Average plant number	220 ± 12.4	252	151	185
HS	0.95 ± 0.01	0.46	0.85	0.53
H	3.45 ± 0.28	1.35	2.70	1.54
D	3.72 ± 0.24	2.39	3.14	2.47

Note: Value = $\bar{x} \pm s$; TRF. Tropical rainforest; TSMF. Tropical seasonal moist forest; TEBF. Tropical lower montane evergreen broad-leaved forest; COF. Tropical coniferous forest. The same is below.

4.3 changes in tree diversity of forest vegetation in the whole region

Based on the survey data of each vegetation sample plot and the vegetation data interpreted by remote sensing images, the changes in tree scaling ecological diversity of each vegetation in different periods in Xishuangbanna are calculated (**Table 2**).

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

Vegetation	Scaling diversity index				Ω (k)
	1992	2000	2008	2016	
TRF	48.31	47.53	47.41	46.78	0.36
TSMF	23.90	23.47	22.84	22.81	0.17
TEBF	40.86	40.26	40.24	40.66	0.30
COF	22.87	21.64	22.84	22.73	0.17

It can be seen from **Table 2** that the scaling ecological diversity index of tropical rainforest is above 46, which is the most important vegetation to maintain the forest tree diversity in Xishuangbanna. The second is tropical mountain evergreen broad-leaved forest and tropical seasonal moist forest, with the scaling ecological diversity index of 40–41 and 22–24, respectively. The scaling ecological diversity index of warm tropical coniferous forest with Pinus Simao as the dominant species is lower than 23. The contribution of tree diversity of Xishuangbanna vegetation to tree diversity is in the order of tropical rainforest > tropical mountain evergreen broad-leaved forest > tropical seasonal humid forest > warm coniferous forest.

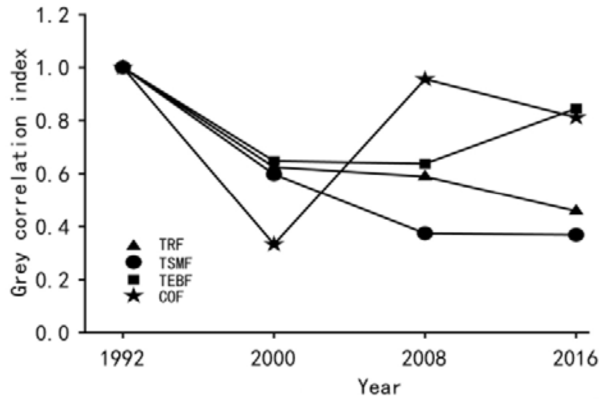


Figure 3. Change in the grey correlational index of tree diversity of main forest vegetation types in Xishuangbanna.

The grey correlation evaluation model was used to calculate the interannual changes of scaling ecological diversity of four forest vegetation trees in Xishuangbanna in four periods. From the changing trend of the grey correlation index (**Figure 3**), it is found that the tree diversity of tropical rainforest and tropical seasonal humid forest has a continuous decreasing trend during the study period, while the tree diversity of tropical mountainous evergreen broad-leaved forest shows a decreasing trend first and then increasing trend, and the warm coniferous forest shows an upward and downward fluctuation trend. The grey correlation evaluation indexes of forest tree diversity in Xishuangbanna in 1992, 2000, 2009, and 2016 were 1, 0.58, 0.63, and 0.62, respectively, so the order of forest tree diversity in Xishuangbanna in the four periods was 1992 > 2009 > 2016 > 2000.

5. Discussion

5.1 Cause analysis of tree diversity change

Economic activities are the main reason for the loss of biodiversity in Xishuangbanna. The results of this study show that the tree diversity of forest vegetation in Xishuangbanna has been losing continuously from 1992 to 2016, and the planting of economic crops such as rubber forests and tea gardens is the main reason for the loss of biodiversity[12,13]. Since the reform and opening up, with the increasing demand for rubber in production and life, a larger area of tropical rainforest has been destroyed to form rubber forests. Moreover, since 1992, the altitude of rubber forests has reached 1400 m[13], and some low-altitude evergreen broad-leaved forests in tropical mountains have also been destroyed to form rubber forests. Since the evergreen broad-leaved forest in the tropical mountains with higher altitudes in Xishuangbanna is not suitable for the planting of rubber forests, since 1990, the evergreen broad-leaved forest in the tropical mountains has been destroyed and formed tea gardens[12]. Xishuangbanna implemented the natural forest protection project[23] and the conversion of farmland to Forests Project[24] in 1998 and 2002, respectively. From 2000 to 2009, the biodiversity loss of tropical rain forests and tropical mountain evergreen broad-leaved forests in Xishuangbanna was not as severe as before, while the warm coniferous forests increased. However, after 2009, due to the impact of economic activities, the continuous rise of rubber prices led to the destruction of a large area of tropical rainforest in Xishuangbanna and the formation of rubber forests[12], which was contrary to the goal of tropical rainforest area restoration and development in the natural conservation project[25].

5.2 Significance of tropical rainforest in maintaining regional biodiversity

Tropical rainforest is the most important vegetation to maintain the forest tree diversity in Xishuangbanna. This study shows that the contribution of tropical rainforest to forest tree diversity in Xishuangbanna has always been the first in four periods. Because the area of tropical rainforest is second only to the evergreen broad-leaved forest in tropical mountains, and it is the second largest forest vegetation in Xishuangbanna. At the same time, in the same area quadrat, the evenness and richness of trees in the tropical rainforest are much higher than that of other forest vegetation, and the abundance is also maintained at a high level, so the loss caused by tropical rainforest per unit area is higher than that of other forest vegetation[26]. In addition, as an important indicator of ecosystem services, the value of biodiversity maintenance (biological regulation and genetic support) created by tropical rainforests per hectare per year is $41, while that of other forests is $4[27]. Therefore, from the perspective of biodiversity value assessment, the loss of tropical rainforests has a more serious impact on the maintenance function of regional biodiversity.

The loss of rare species in forests will lead to the loss of forest biodiversity[27], especially in tropical rain forests and tropical mountain evergreen broad-leaved forests. In the warm and hot coniferous forest and tropical seasonal humid forest with Simao Pine and closed flower trees as the dominant species, the number of other tree species does not account for a high proportion of the number of species in the whole community, so the reduction of the number of other tree species does not significantly reduce the evenness of this vegetation. However, in the tropical rainforest where the dominant species are not significant, the proportion of rare species in the number of community species is high, and the reduction of rare species will affect the loss of biodiversity of the whole community[28]. Although Fagaceae and Lauraceae trees are the dominant species in the evergreen broad-leaved forest in the tropical mountains, rare species also account for a high proportion. In conclusion, the loss of rare species in the forest has a greater impact on the tropical rainforest and tropical mountain evergreen broad-leaved forest.

5.3 Applicability analysis of scaling ecological diversity index

Scaling ecological diversity index combined with remote sensing technology can be applied to regional biodiversity assessment. Scaling, Simpson and Shannon Wiener indexes can measure community evenness. As the number of species increases with the increase of area, the scaling ecological diversity index also uses area index to measure species richness in the study area[8]. In addition, the combination of ground survey and remote sensing technology can also extract ecosystem types and monitor the integrity of vegetation. The traditional regional biodiversity research and the scaling ecological diversity index in this study combined with remote sensing technology coincide with the indicators with higher weight in species richness, ecosystem type and vegetation integrity[29,30], indicating that the scaling ecological diversity measurement indicators combined with remote sensing technology can be applied to the evaluation of regional biodiversity. However, different areas and different sampling standards will lead to no contrast in the calculation results of diversity. In order to make the calculation results of diversity among different vegetation comparative, it is necessary to unify the sampling standards of different vegetation sample plots in community investigation.

The scaling ecological diversity index also has problems in regional biodiversity assessment. Although scholars have concluded that the scaling ecological diversity index is not affected by the resolution within the spatial scale range of 30 m to 150 m resolution[31], at the same time, the species-area relationship can be applied to the scale transformation of biodiversity[32]. However, species diversity is retrieved from the community scale to the regional scale. The difficulty of scale conversion is affected by the sampling effect and habitat heterogeneity[32] The difficulty of scale conversion also increases with the increase of the area of the study area. Therefore, in the study area with a large area or high heterogeneity, the reliability of scaling ecological diversity index needs further research. In addition, how to apply the index to the comparison of different vegetation in different regions also needs more in-depth research. The grey correlation evaluation model has some problems, such as the lack of order-preserving effect in dimensionless processing, and the dissatisfaction with the standardization of correlation degree[20]. In future work, it is also necessary to develop or use the corresponding mathematical model to improve the evaluation system of forest vegetation arbor diversity in the study area.

Conflict of interest

The authors declare that they have no conflict of interest.

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