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RESEARCH ARTICLE

Study on successions sequence of evergreen broad-leaved forest in Gutian Mountain of Zhejiang, Eastern China: species diversity

Zhenghua HU (✉)[1], Mingjian YU[2]

1 College of Environmental Science and Engineer, Nanjing University of Information Science and Technology, Nanjing 210044, China
2 College of Life Science, Zhejiang University, Hangzhou 310028, China

Abstract Using the widely adopted scheme of space-for-time substitution for investigating 16 typical plots distributed as a pattern of contiguous grid quadrates within a sampling plot, the expressions of Shannon-Wiener index (H) for species diversity, Pielou index (J_{sw}, J_{SI}) for evenness and Simpson index (D) for ecological dominance are employed to investigate the species diversity (SD) of four evergreen broadleaved communities in the successions sequence within the Nature Reserve of the Gutian Mountains. Results showed that in the successions process from the coniferous to the mixed coniferous-broadleaved, then to *Schima superba* and finally to *Castanopsis eyrei* forest, the arbor layer SD showed the Shannon-Wiener index (H) as 1.9670, 2.4975, 2.6140 and 2.4356, respectively, characterized by their rise before drop and the shrub (herb) layer SD shows the maximum to be in the mixed coniferous-broadleaved (coniferous) forest (H arriving at 2.8625 (1.5334)). In the vertical structure, on the other hand, for the sequenced coniferous forest, coniferous-broad mixed forest and *Castnaopsis eyrei* forest, the number of SD ranges in a decreasing order from the shrub, arbor to herb layer in contrast to the SD in a decreasing order of *Schima superba* forest ranging from the arbor to shrub and then to herb layer, and during the succession, the herb layer exhibits the maximum range of SD change among these layers, with its variation coefficients of 0.1572, 0.0806, 0.0899 and 0.1884 for H, J_{SW}, J_{SI} and D, in order, in sharp contrast to the minimal SD range in the shrub layer, with the corresponding figures of 0.0482, 0.0385, 0.0142, and 0.1553.

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E-mail: huzhenghua@sohu.com

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1 Introduction

Biodiversity serves as a measure of the organizability of a community and its species diversity (SD) represents the multiplicity in its composition and structure as the basis for recognizing its organizability and functions, which is a crucial aspect of SD research. The study on SD of a community is focused on the ecosystem, which is of importance to the discovery of a relationship between the community and its environment (He et al., 1998a). Nowadays, the SD change in a succession is a heated issue of biodiversity research (Shi et al., 2002; Yang et al., 2002; Li and Shao, 2004). The Gutian Mountain Nature Reserve is located in the remote mountainous area of western Zhejiang, where an extensive region is available for the conservation of undamaged evergreen broadleaved forests, especially *Castanopsis eyrei* as the dominance species below 800 m MSL (mean sea level), the vegetation characteristics of which are typical and representative of such forests in the middle subtropical zone of East China. Previous studies mainly focus on flora, vegetation types and ecological features of the community there (Tian et al., 1999; Lou and Jin, 2000; Ding et al., 2001; Yu et al., 2001; Hu et al., 2002; 2003), with no reports regarding change in ecological properties in a succession sequence. This research aims at the SD in different succession phases of the involved community of forest under study in the mountain area, which is of certain significance to the comprehensive study of the dynamic mechanism for the ecosystem in its succession phases, thereby providing fundamental data for the conservation of evergreen broadleaved forests and their sustainable management in the central subtropical zone of eastern China.

2 Research region and techniques study

2.1 Natural background

The Nature Reserve under research (covering 8107hm^2, in 29º10′19.4″–29º17′41.4″N, 118º03′49.7″–118º11′12.2″E) is situated in the northwest of Kaihua County of Zhejiang Province and borders Wuyuan and Dexing Counties of Jiangxi Province, while the Gutian range is a part of the Huaiyu Mountains and a branch of the Nanling Mountain System, with its peak known as Qingjian rising up to 1258 m. Additionally, the Reserve consists of three ridges and two deep gullies orientated NW-SW, with its water running into Lake Poyang as a reservoir of the Yangtze.

The Gutian mountains are in the subtropical monsoon climate, marked by distinct seasonality, with an annual mean temperature of 15.3°C, and the accumulative temperature total of 5221.5°C in the period of plant growth, 250 days of frost-free period annually, the mean yearly precipitation (relative humidity) of 1963.7 mm (92.4%).

The study mountain consists of granite as the parent rock in the main, with the pH values ranging 5.5–6.5, which leads to the classification of the soil's acidity: 1) red earth below 500–700 m MSL; 2) yellow-reddish soil below 700–1000 m; 3) red-yellowish earth above 1000 m; and 4) meadow soil, in front of the Gutian Temple, as a local feature at 850 m MSL.

2.2 Methods

2.2.1 Investigation of the sampling plot

In a sense, utilization of the space-for time substitution has its own merits in the study of forest succession as a long-term natural replacement that makes it difficult to research the problem on a time basis. For the Nature Reserve, the successions sequence consists of the coniferous forest (i.e. *Pinus massoniana*)→coniferous-broad mixed forest (the dominance species being *Pinus massoniana* and co-dominance being *Schima superba)*→*Schima superba* forest→*Castanopsis eyrei* forest. The well-established "space-for time substitution" technique was adopted to investigate SD in the different successions phases and the survey was on the basis of the technique of ordered contiguous gradates, with the sampling plot measuring 20 m × 20 m divided into 5 m × 5 m squares (totaling in 16 plots). For the arbor layer records were the species names, trunk sizes, heights, canopy coverage etc.; for the shrub and herb layers, records were species names, stand number, height, coverage together with inter-layer plants. The total of 16 sampling pieces of land (arriving at 256 plots) covering 6400 m^2, along with the ecological conditions of the communities including elevation, slope orientation, inclination, community photopermeability, soil moisture, pH value and organic substances were investigated.

2.2.2 Statistics

(1) Calculation of related important values

The calculation was performed from the following expressions for the different layers.

For the arbor layer the expression takes the form

$$\text{Important value} = \tfrac{1}{3}\,(\text{relative density} + \text{relative frequency} + \text{relative prominence}),$$

and the expression for the shrub and herb layers is in the form

$$\text{Important value} = \tfrac{1}{3}\,(\text{relative density} + \text{relative frequency} + \text{relative coverage}).$$

(2) Measurement of species diversity index

The index of SD based on the number of stands would lead to errors and in contrast, the important value used to measure SD index includes frequency, coverage and biomass so that some scientists suggested that these expressions be employed (Ma et al., 1995; He et al., 1998a; 1998b). Based upon the expressions of important values, the SD index is generally measured using the methods as follows

$$\text{Shannon-Wiener index} \quad H = -\Sigma P_i \ln P_i$$
$$\text{Pielou index} \quad J_{SW} = (-\Sigma P_i \ln P_i)/\ln S$$
$$J_{SI} = (1 - \Sigma P_i^2)/(1 - 1/S)$$
$$\text{Simpson index} \quad D = \Sigma P_i^2$$

where P_i denotes the relatively important value and S denotes the total of species within the sampling plot.

3 Results and analysis

3.1 Comparison of layered SD indices at a range of successions phases of the different communities

The related SD indices are shown in Table 1 for comparison.

Table 1 Sub-layer SD of the four communities in succession

Type	Layer	H	J_{SW}	J_{SI}	D
Coniferous forest	Arbor	1.967 0	0.725 5	0.811 5	0.243 2
	Shrub	2.701 6	0.818 5	0.934 8	0.099 9
	Herb	1.533 4	0.751 9	0.756 7	0.343 2
Coniferous-broad mixed forest	Arbor	2.497 5	0.834 2	0.926 5	0.124 3
	Shrub	2.862 5	0.893 4	0.960 9	0.078 6
	Herb	1.371 5	0.812 9	0.845 7	0.331 0
Schima superba forest	Arbor	2.614 0	0.836 2	0.937 9	0.104 0
	Shrub	2.544 1	0.864 0	0.934 7	0.114 5
	Herb	1.245 1	0.832 7	0.853 5	0.339 0
Castanopsis eyrei forest	Arbor	2.435 6	0.803 2	0.894 3	0.149 9
	Shrub	2.687 1	0.883 7	0.954 2	0.092 5
	Herb	1.049 8	0.695 3	0.706 9	0.477 8

3.1.1 SD in the arbor layer

Table 1 shows that during the succession the *Schima superba* forest's Shannon-Wiener index and evenness are the greatest, next being the coniferous-broad mixed forest, with the smallest values of the coniferous trees that survived in such a severe environment that their SD was minimal. The environment became improved at the stage of coniferous–broad mixed forest that was responsible for great increase in SD, with the *Schima superba* forest SD higher than the others but the SD of *Castanopsis eyrei* forest as climax community declined because of the elimination of some heliophyte trees through competition. It was found from the successive process that the maximum SD occurred in the *Schima superba* forest and the SD of *Castanopsis eyrei* forest reduced, but with its stability higher, generally, with respect to that in the other communities, which illustrates that SD cannot completely replace the steadiness of the community (Li and Shao, 2004).

3.1.2 SD in the shrub layer

The highest SD in the shrub layer happened in the coniferous–broad mixed forest, followed by the coniferous forest, *Castanopsis eyrei* forest and *Schima superba* forest, in order, with the highest evenness in the coniferous-broad mixed forest (Table 1). As for canopy density, the lower value belonged to the coniferous forest where sunlight was so abundant that the shrub layer was well-developed with plants distributed evenly, with higher species consisting mainly of heliophyte trees. For the coniferous-broad mixed forest, its ecological environment was greatly ameliorated, leading to rich species in the shrub layer with the inclusion of a variety of broadleaved trees, and hence to higher SD in comparison to the coniferous forest. In the *Schima superba* forest and *Castanopsis eyrei* forest their shrub-later SD was lower due to insufficient in-forest insolation. On the other hand, the *Castanopsis eyrei* forest grew in a stable environment and was distributed relatively homogeneously in the shrub layer, with the SD marginally higher compared with the *Schima superba* forest.

3.1.3 SD in the herb layer

The SD ranged in a decreasing order from the coniferous forest, coniferous-broad mixed forest, *Schima superba* forest to *Castanopsis eyrei* forest (see Table 1). The coniferous forest had lowest canopy density so that in-forest sunlight was so abundant that herbage grew exceedingly well, resulting in the highest SD. Almost the same happened in coniferous-broad mixed forest as regards the canopy density and SD. However, the *Schima superba* forest and *Castanopsis eyrei* forest as the type of evergreen broadleaved forest showed lower SD in the herb layer due to bigger canopy density and less insolation.

3.2 Layered SD comparison in the successions phases

The stratified SD indices of the coniferous forest, coniferous-broad mixed forest and *Castanopsis eyrei* forest ranged in a decreasing order from the shrub, arbor to shrub layer (Table 1), because, beside the shrub species in the shrub layer of coniferous forest, there were young trees and seedlings of arbor species, and a small number of intruding heliophyte broad-leaved trees there, so that the SD and number of stands were higher in the shrub than in the arbor layer. In coniferous-broad mixed forest with inclusion of those species as in the shrub layer of coniferous forest, there were in the shrub layer a small number of shade-resistant broadleaved young trees and seedlings so that the SD was more in the shrub than in the arbor layer. In *Castanopsis eyrei* forest the shrub layer showed the shrub species and arbor young trees and seedlings, leading to higher SD in the shrub than in the arbor layer. The stratified SD indexes in the *Schima superba* forest ranged in a decreasing order from the arbor, shrub to herb layer (cf. Table 1). *Schima superba* forest SD indices were higher in the arbor with respect to the shrub layer, which was ascribed to the fact that the former case also involved *Pinus massoniana* and other trees as the heliophyte coniferous species that were not growing well because in poor insolation their young trees and seedlings were eliminated. The *t*-tests (Table 2) indicate that there is no any remarkable difference in SD between the arbor and shrub layers of the four communities in succession. Apart from the coniferous forest, the SD of the others in succession was considerably lower in the herb than in the arbor and shrub layers.

Table 2 *t*-tests of stratified SD in the different successions phases

Type	Layer	*t* value			
		H	J_{SW}	J_{SI}	D
Coniferous	Arbor-shrub	–5.811	–2.027	–6.766	86.792**
forest	Arbor-herb	1.246	–0.149	0.353	–0.714
	Shrub-herb	2.462	–0.506	1.299	–1.758
Coniferous-	Arbor-shrub	–3.118	–7.386**	–4.985*	2.772
broad	Arbor-herb	5.119*	0.710	2.736	–4.001
mixed forest	Shrub-herb	5.279*	2.036	3.704	–4.208
Schima superba	Arbor-shrub	0.454	–40.262*	2.042	–1.776
forest	Arbor-herb	7.912**	0.072	2.316	–13.276*
	Shrub-herb	68.157**	0.655	2.133	–19.092*
Castanopsis	Arbor-shrub	–2.181	–2.375*	–2.216	2.230
eyrei	Arbor-herb	7.354**	1.364	2.324	–4.611**
forest	Shrub-herb	11.238**	3.036*	3.522**	–6.099**

* denotes that the figures pass the test at $p < 0.05$ and ** denotes at $p < 0.01$.

3.3 Variation coefficient of layered SD in the succession

In the succession observed in the Nature Reserve, the SD ranges are given in Table 3 for the three layers, with the herb-layer SD indices varying most conspicuously for the four communities under study, implying that as succession proceeded their canopy density was increasing gradually so as to step-by-step weaken sunlight in the community, thereby preventing greatly herb-layer plants from growth, with SD higher in the coniferous and coniferous-broad mixed forests and rather low in the *Castanopsis eyrei* forest phase. On the other hand, the SD variation coefficients were smallest in the shrub layer, indicating that the SD experienced smaller variation in the succession.

Table 3 Variation in layered SD in the different successions phases

Layer		H	J_{SW}	J_{SI}	D
Arbor	M[a)]	2.378 5	0.799 8	0.892 6	0.155 3
	CV[b)]	0.119 4	0.064 7	0.064 0	0.396 0
Shrub	M[a)]	2.698 8	0.864 9	0.946 2	0.096 4
	CV[b)]	0.048 2	0.038 5	0.014 2	0.155 3
Herb	M[a)]	1.300 0	0.773 2	0.790 7	0.372 8
	CV[b)]	0.157 2	0.080 6	0.089 9	0.188 4

[a)] M denotes the mean over the community concerned; [b)] CV denotes the variation coefficient (= standard deviation divided by M).

4 Discussion and conclusions

4.1 SD in the arbor layer

The SD of a community is determined by multiple factors including the community *per se* and its ecological environment (Chapin, 1992; Grime, 1997). The SD of the community varied with differing successions phases. In the successions stages of the evergreen broadleaved forest in the Nature Reserve the coniferous trees grew in a harsh condition which makes it difficult for broadleaved species to survive, leading to the lowest SD in the arbor layer, with Shannon-Wiener index attaining just 1.9670. As the succession went on, the ecological environment became gradually bettered, with moistening felt inside the community that led to the appearance of broadleaved species to form a coniferous-broad mixed forest, causing a great increase in SD, with the index arriving at 2.4975. Ahead of the formation of *Castanopsis eyrei* forest as the climax community the *Schima superba* community consisted of both heliophyte and neutral species, leading to Shannon-Wiener index reaching 2.6140. When the *Castanopsis eyrei* forest emerged, it had to rule out part of other species to expand its own niche before the species *per se* dominated in the community, during which the SD number declined instead when some heliophyte seedlings were eliminated in view of insufficient insolation they received.

4.2 SD in the shrub layer

Coniferous forest of low canopy density permitted the shrub layer to develop well because of rich insolation in the community, resulting in more species and stands as well as an even distribution so that Shannon-Wiener index attained 2.7016, except that the species were mostly heliophyte trees. For the coniferous-broad mixed forest its soil nutrients and moisture were high inside, thus ameliorating the ecological environment enough for abundance in species (including coniferous and broadleaved species) in the shrub layer compared with the coniferous forest, with Shannon-Wiener index of 2.8625. For *Schima superba* forest and *Castanopsis eyrei* forest, their canopy density was big enough to reduce the number of stands and SD in the shrub layer due to poor insolation, with the respective Shannon-Wiener indices arriving at 2.5441 and 2.6871. The slightly higher Shannon-Wiener index in the *Castanopsis eyrei* forest was ascribed to its more stable ecological environment and relatively homogeneous distribution for higher evenness.

4.3 SD in the herb layer

In the succession, within the coniferous forest the canopy density was lowest, allowing abundant sunlight to fall onto the herb layer, thereby causing herb plants to grow well so that the SD was highest compared with the other layers and Shannon-Wiener index reached 1.5334. The canopy density was relatively low in the shrub layer of the coniferous-broad mixed forest such that the herb layer received sufficient insolation for species to be in greater abundance. In contrast, the *Schima superba* and *Castanopsis eyrei* communities showed lower SD in the herb layer due to higher canopy density. And particularly in the *Castanopsis eyrei* forest where light was dim, moisture high and a small number of herb species and stands distributed surprisingly unevenly inside, just with more at the edges and gaps. As a result, its herb-layer SD and evenness were minimal.

4.4 Comparison of sub-layer SD of the four communities in succession

In the succession, the stratified SD varied quite greatly inside the communities, with the stratified SD ranging in a decreasing order from the shrub, arbor to herb layer for the coniferous, coniferous-broad mixed and *Castanopsis eyrei* forest and the shrub-layer SD higher than the arbor layer was attributed to the existence of young trees and seedlings of arbor type in addition to the species of shrubs. For the *Schima superba* forest the layered SD ranged in such a decreasing order from the arbor, shrub to herb layer and lower SD in the shrub layer was in view of the fact that a small part of heliophyte *Pinus massoniana* trees were removed out of the shrub layer because shade wetness leads to poor development of seedlings inside.

In the succession, the SD varying range in herb layer (shrub layer) was the greatest (smallest) among the three layers, which was owing to the enough light inside the coniferous forest and coniferous-broad mixed forest for the highest SD in the herb layer and the fact that *Castanopsis eyrei* had high canopy density leading to shade wetness for poor development of SD in the herb layer. As a result, the herb-layer SD varying range became larger.

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