Effects of Different Under-Forest Economic Models on Plant Diversity in Southwest China Mountains (Postprint)

Authors: Zeng Qingping, He Binghui, Qin Huajun, Li Yuan, Wu Yaopeng, Tian Yanqin

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Abstract

Taking six typical forest understory economic models as research subjects—eucalyptus forest understory poultry farming (T1), eucalyptus forest understory edible mushroom cultivation (T2), hemp bamboo forest understory poultry farming (T3), hemp bamboo forest understory edible mushroom cultivation (T4), Masson pine forest understory livestock farming (T5), and banyan tree forest understory grass planting (T6)—this study employed the adjacent plot comparison method to investigate and analyze the species importance value (P), richness index (S), Shannon-Wiener diversity index (H), Pielou evenness index (Jw), Alatalo dominance index (Ea), Jaccard similarity index (Cj) and Sorenson similarity index (Cs), as well as diversity threshold (Dv) of plant communities under each model, in order to explore the impacts of different forest understory economic models on plant diversity. Results showed that the T6 model had the richest plant species, with 11 species, while the T3 and T4 models had the fewest plant species, with only 2 species. All economic models lacked a shrub layer, with the herb layer being the dominant layer of the community. Alternanthera philoxeroides was the dominant species in the T1 and T2 models, with importance values of 67.16% and 71.00%, respectively. Morus alba was the dominant species in T3 and T4, with importance values as high as 74.91% and 72.82%, respectively. The dominant species in T5 and T6 were Oplismenus compositus (54.10%) and Hemarthria altissima (59.51%), respectively. Across different forest understory economic models, the plant richness index (S) followed the order: T6 > T1 > T5 = T2 > T3 = T4; the diversity index H showed the pattern: T6 > T1 > T5 > T2 > T4 > T3; the evenness index Jw showed the pattern: T5 > T6 > T2 > T1 > T4 > T3; and the dominance index Ea showed the pattern: T5 > T4 > T3 > T2 > T1 > T6. The similarity indices of species composition between the forest understory economic models and their corresponding pure

forest controls were highest for T3 and T4, with both Cj and Cs being 1.0; followed by T6, with Cj and Cs values of 0.44 and 0.62, respectively; and lowest for T1, with Cj and Cs values of 0.15 and 0.27, respectively. Plant diversity threshold evaluation results showed that the T6 model had the highest plant diversity threshold, belonging to the 'better diversity' type, while the T3 and T4 models had the lowest diversity thresholds, belonging to the 'general' type. Understory farming and breeding altered the species composition of plant communities, with different farming methods producing different impacts, among which the forest-grass model had the least impact and represented the most abundant plant community pattern under forest disturbance.

Full Text

Influence of Different Typical Under-Forest Economy Modes on Plant Community Diversity in China' s Southwest Mountains

ZENG Qingping[1], **HE Binghui**[1], QIN Huajun[2], LI Yuan[3], WU Yaopeng[1], TIAN Yanqin[1]

[1]College of Resources and Environment, Southwest University / Key Laboratory of Three Gorges Region Eco-Environments, Ministry of Education, Chongqing 400715, China
[2]Guizhou Institute of Biology, Guiyang 550025, China
[3]Forestry Administration of Fuling, Chongqing 408000, China

Abstract
Ecological problems arising from under-forest economy development have gained widespread recognition in recent years. As under-forest economy activities have expanded, understory farming has become more sophisticated, and the ecological environments of forest understories have gradually stabilized in the Rongchang region of Chongqing. This study employed the adjacent-sample comparison method to investigate the effects of six typical under-forest economy modes on plant community characteristics in the mountainous regions of Southwest China from August to September 2012. The investigated modes included poultry feeding in *Eucalyptus robusta* forest (T1), fungi cultivation in *E. robusta* forest (T2), poultry feeding in *Dendrocalamus latiflorus* forest (T3), fungi cultivation in *D. latiflorus* forest (T4), livestock feeding in *Pinus massoniana* forest (T5), and grass cultivation in *Ficus lacor* forest (T6), with corresponding pure forests serving as controls. The study examined importance value (P), species richness index (S), Shannon-Wiener diversity index (H), Pielou' s evenness index (Jw), Alatalo dominance index (Ea), Jaccard similarity index (Cj), Sorenson similarity index (Cs), and plant species diversity threshold (Dv).

The results revealed that among the six under-forest economy modes, T6 exhibited the highest species richness with 11 species, while T3 and T4 had the lowest richness with only 2 species each. No shrub layer was present in any of the six modes, with the herb layer serving as the dominant stratum. *Alternanthera philoxeroides* was the dominant species in T1 and T2 modes, with importance values of 67.16% and 71.00%, respectively. *Morus alba* dominated T3 and T4 modes with importance values reaching 74.91% and 72.82%, respectively. The dominant species in T5 and T6 were *Oplismenus compositus* (54.10%) and *Hemarthria altissima* (59.51%), respectively.

Species richness index (S) across the different modes followed the order: T6 > T1 > T5 = T2 > T3 = T4. Shannon-Wiener diversity index (H) showed the pattern: T6 > T1 > T5 > T2 > T4 > T3. Pielou' s evenness index (Jw) ranked as: T5 > T6 > T2 > T1 > T4 > T3. Alatalo dominance index (Ea) followed the sequence: T5 > T4 > T3 > T2 > T1 > T6. Similarity indices between under-forest economy modes and their corresponding pure forest controls were highest for T3 and T4, with both Cj and Cs values of 1.0, followed by T6 (Cj = 0.44, Cs = 0.62). T1 showed the lowest similarity with Cj = 0.15 and Cs = 0.27. Diversity threshold evaluation indicated that T6 had the highest threshold, representing a "better diversity" category, while T3 and T4 had the lowest thresholds, classified as "general diversity." Understory farming altered plant community species composition, with different farming methods producing varying effects. The forest-grass mode (T6) had the least impact and supported the most abundant plant communities under forest disturbance.

Keywords: Southwest Mountain; Under-forest economy mode; Plant community; Importance value; Species diversity; Species diversity threshold

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Under-forest economy represents a traditional land-use approach that leverages existing forest resources and ecological environments to develop diversified agroforestry, forestry, and animal husbandry projects utilizing shade advantages. This economic model plays a crucial role in promoting economic development in mountainous regions and has become an important focus in China' s forestry development [1,2]. Plant diversity serves as a key indicator of ecosystem structure and stability, forming the core of sustainable ecosystem development and productivity while providing essential conditions for human survival and socioeconomic progress [3,4]. In recent years, collective forest tenure system reforms have stimulated new enthusiasm for under-forest economy development, leading to diversified operational models. However, excessive development of under-forest economy can accelerate soil erosion, reduce forest plant diversity, and consequently diminish the protective functions and stability of forest ecosystems [5]. Different forest management modes typically generate distinct understory community structures and plant diversity patterns [6,7]. While studies by Wu et al. [8] and Yin et al. [9] demonstrated that human disturbance reduces plant diversity, research by Yu et al. [10] and Xie et al. [11] indicated that moderate human disturbance can increase plant diversity. Although previous studies have examined the effects of under-forest economy modes on soil physicochemical properties [12], soil microorganisms [13], and soil enzyme activities [14], research on impacts to plant diversity remains limited, particularly regarding how different under-forest economy modes affect plant diversity in China' s mountainous regions.

Ecologists commonly use community richness indices, diversity indices, evenness indices, and dominance indices to reflect plant diversity, which collectively demonstrate community structural types, organizational levels, developmental stages, habitat differences, and stability [15]. Species diversity represents a crucial characteristic of community organization, reflecting not only species richness but also community stability and dynamics. In recent years, under-forest economy development in Rongchang County, Chongqing, has matured, with understory ecosystems gradually stabilizing. This study selected Rongchang County in Southwest China' s Chongqing Municipality as the research site to investigate plant diversity across six typical mountainous under-forest economy modes, providing valuable references for ecological agriculture construction and rational land use in the region.

1.1 Study Area Overview

Rongchang County is located in the transitional zone of the parallel ridge-valley region of eastern Sichuan, in western Chongqing. The terrain consists primarily of hills and broad valleys with flat dam areas, featuring fertile soil and gentle relief at an average elevation of 380 m. The region experiences a mid-subtropical humid monsoon climate with an average annual precipitation of 1,099 mm and mean annual temperature of 17.8°C. The frost-free period extends 327 days, with extreme monthly temperatures ranging from a low of [missing value]°C to a high of 39.9°C (1975–2012). Dominant forest types include *Pinus massoniana*, *Dendrocalamus latiflorus*, *Eucalyptus robusta*, and *Ficus lacor* forests.

1.2 Experimental Design and Sampling

From August to September 2012, we employed the adjacent-sample comparison method to investigate forest stands with identical soil types, similar topography, but different utilization types across Rongchang County. In each forest stand, three 20 m × 20 m standard plots were established to survey tree growth parameters. Within each plot, five 5 m × 5 m shrub subplots and five 1 m × 1 m herb subplots were arranged along an "S" pattern for understory vegetation surveys. Vegetation survey parameters included tree height, diameter at breast height (DBH), branch height, canopy density, and planting spacing for the arbor layer; species, coverage, and height for the shrub layer; and species, coverage, and height for the herb layer. Geographic coordinates and elevation were determined using GPS and altimeters, while slope aspect and gradient were measured with a compass .

All investigated under-forest economy modes were initiated in 2009 and included: (T1) poultry feeding in *Eucalyptus robusta* forest in Guchang Town' s Chongfeng Village (chickens at 900 birds · ha^{-2}, free-range); (T2) edible fungi cultivation in *E. robusta* forest in Lukong Town (*Pleurotus ostreatus* on 30% area, wild-simulated cultivation); (T3) poultry feeding in *Dendrocalamus latiflorus* forest in Shuanghe Subdistrict' s Lanfeng Community (chickens at 900 birds · ha^{-2}, free-range); (T4) edible fungi cultivation in *D. latiflorus* forest in Fenggao Subdistrict' s Wuma Village (*Pleurotus ostreatus* on 30% area, wild-simulated cultivation); (T5) livestock feeding in *Pinus massoniana* forest in Panlong Town (wild boars at 675 animals · ha^{-2}, free-range); and (T6) grass cultivation in *Ficus lacor* forest in Yuanjue Town' s Fuxing Community. Due to species-specific effects on soil structure and nutrients, one control plot of pure forest was selected for each mode.

1.3 Data Processing

We analyzed plant diversity across the six economy modes using importance value (P) [16], richness index (S), Shannon-Wiener diversity index (H) [15], Pielou' s evenness index (Jw) [17], Alatalo dominance index (Ea) [17], Jaccard similarity index (Cj) and Sorenson similarity index (Cs) [18,19], and diversity threshold (Dv). Calculation methods are presented in the equations below. The classification and evaluation criteria for plant species diversity thresholds are shown in Table 2 . Data processing and statistical analysis were performed using SPSS 18.0, Origin 9.2.0, and Microsoft Excel 2003. One-way ANOVA (LSD) was used to compare differences among data groups.

2.1 Plant Species Composition

Across the six under-forest economy mode plots, we recorded 30 herbaceous species belonging to 30 genera and 16 families of angiosperms, plus one additional species. Twenty-seven families contained a single species, four families contained two species, and two families contained six species. The most species-rich families were Gramineae (6 species) and Compositae (6 species), followed by Leguminosae (2 species), Rosaceae (2 species), Solanaceae (2 species), and Umbelliferae (2 species). Nineteen species belonged to unique families and genera. Herbaceous composition varied significantly among modes, with the most diverse T6-CK comprising eight families (Amaranthaceae, Solanaceae, Umbelliferae, Compositae, Leguminosae, Acanthaceae, Urticaceae, and Bryophytes), while the least diverse T3, T3-CK, T4, and T4-CK contained only two families each.

Numerous occasional species were observed, with single individuals recorded for *Plantago asiatica*, *Pternopetalum davidii*, *Pueraria lobata*, *Asplenium trichomanes*, *Chrysanthemum indicum*, and *Euphorbia helioscopia*. Species with only two individuals included *Dichondra repens*, *Pteris multifida*, *Juncus offusus*, *Solanum nigrum*, *Pouzolzia zeylanica*, *Sinosenecio oldhamianus*, *Torilis scabra*, *Peristrophe baphica*, and *Aster ageratoides*.

2.2 Comparison of Importance Values Among Modes

Importance values reveal the role and status of different plants within communities [21]. No shrub layer was present in any of the six modes, with the herb layer serving as the dominant stratum that critically influences community stability, structure, and functional complexity. The top two species by importance value in each mode are presented in Table 3 .

As shown in Table 3, T3, T3-CK, T4, and T4-CK contained only two herbaceous species with combined importance values reaching 100%. This resulted from the higher planting density and canopy density of *Dendrocalamus latiflorus* forests compared to *Eucalyptus*, *Pinus massoniana*, and *Ficus lacor* forests, creating low light conditions unfavorable for herbaceous seed germination. In T1, T1-CK, T2, and T2-CK, the combined importance values of the top two species were 78.53%, 71.21%, 89.22%, and 86.16%, respectively. The smallest combined importance values for the top two species occurred in T5, T5-CK, T6, and T6-CK, with T5-CK showing only 53.54%.

The invasive species *Alternanthera philoxeroides* dominated the herb layers of T1 and T2 modes with maximum importance values of 67.16% and 71.00%, respectively. This species' branching morphology creates spatial network structures that hinder photosynthesis in other plants while enhancing its own resource utilization, combined with high reproductive rates, rapid expansion, and seed dispersal facilitated by human and poultry activities that broaden its habitat adaptation [22]. This demonstrates how management practices alter community dominant species. *Morus alba* became dominant in T3 and T4 modes with importance values reaching 74.91% and 72.82%, likely due to the high canopy density and low light transmittance of *Dendrocalamus latiflorus* forests, coupled with frequent human and animal activity in poultry and fungi modes that inhibited herb growth, while surviving mulberry trees tolerated poor soils and exhibited strong adaptability with low soil requirements. The dominant species in T5 and T6 modes were *Oplismenus compositus* (54.10%) and *Hemarthria altissima* (59.51%), respectively.

2.3 Plant Diversity Index Comparisons

Species diversity measures species richness and distribution evenness within habitats, serving as an indicator of community or ecosystem stability—greater diversity indicates stronger community stability and more suitable habitats for community survival [23]. Richness, diversity, evenness, and dominance indices for each mode are presented in Table 4 .

Comparisons between under-forest economy modes and their controls revealed that control groups consistently showed equal or greater richness indices than treatment groups, with significant differences observed for T1, T2, T5, and T6, indicating that under-forest economy modes reduced species numbers to varying degrees. Among the different modes, richness indices ranked: T6 > T1 > T5 = T2 > T3 = T4. T6 exhibited the highest richness (11 species), while T3 and T4 had the lowest (2 species each), suggesting that the forest-grass mode caused minimal vegetation disturbance due to reduced human interference and habitat alteration.

Shannon-Wiener diversity index (H) showed that except for T3, all under-forest economy modes had lower diversity than their controls, following the pattern: T6 > T1 > T5 > T2 > T4 > T3. T6 showed the highest diversity (1.527), while T3 had the lowest (0.563), indicating obvious population advantages for certain species in T3. Pielou' s evenness index (Jw) was lower in under-forest economy modes than controls for all modes except T3, with no significant difference between T1 and T2, but significant differences from T3, T4, T5, and T6. The ranking was: T5 > T6 > T2 = T1 > T4 > T3, indicating most uniform species distribution in T5. Alatalo dominance index (Ea) was highest in T5 and lowest in T6, with four modes showing lower dominance in under-forest economy modes than controls, while T2 and T3 showed higher dominance in treatment plots. High dominance indicates communities with few dominant species, and the mode with the most dominant plant species (T6) exhibited the lowest community dominance.

2.4 Similarity Indices Between Under-Forest Economy Modes and Pure Forests

Only similarity between under-forest economy modes and their corresponding controls was analyzed due to large stand differences among modes. The results indicated that under-forest economy modes generally reduced plant diversity. As shown in Figure 1 [Figure 1: see original paper], modes T3 and T4 exhibited the highest similarity indices with their pure forest controls, with both Cj and Cs reaching 1.0, indicating no change in plant species composition under *Dendrocalamus latiflorus* canopies—a direct result of small planting spacing and similar microclimate conditions. T6 ranked next with Cj = 0.44 and Cs = 0.62, while T1 showed the lowest similarity (Cj = 0.15, Cs = 0.27).

2.5 Plant Diversity Assessment

Diversity thresholds for different under-forest economy modes are presented in Table 5 . Except for T3 and T4, all modes showed lower diversity thresholds in under-forest economy treatments than in controls. T6 exhibited the highest inter-mode diversity threshold (2.4), followed by T1 (1.8), T2 and T5 (1.1 each), while T3 and T4 had the lowest thresholds (0.7 each). According to the classification criteria in Table 2 , T6 fell into Category III, indicating relatively good species diversity under *Ficus lacor* forest-grass mode. T3 and T4 belonged to Category IV, indicating general diversity under *Dendrocalamus latiflorus* poultry and fungi modes. The forest-grass mode caused minimal vegetation damage while enriching understory plant species, whereas poultry and livestock modes introduced both human disturbance and animal herbivory, resulting in poorer species diversity.

3. Conclusions and Discussion

Understory plant community diversity is significantly influenced by human activities, with outcomes closely related to environmental conditions, disturbance types, and the species and density of understory cultivation or livestock [24,25]. Our survey of six under-forest economy modes in Southwest China' s mountainous regions revealed distinct species composition differences between modes and controls, with fast-growing, stress-tolerant plants replacing original dominant species. Understory cultivation and livestock rearing reduced plant richness due to substantial human disturbance and habitat alteration, compounded by vegetation destruction and herbivory from poultry and livestock that substantially decreased certain plant species and populations. Among the six modes, the forest-grass mode (T6) exhibited the best richness index because minimal external disturbance and grass planting enriched plant species while causing minimal vegetation damage. Similar conclusions were reported by Zeng [26] in studies on grass planting effects on vegetation diversity in *Pinus massoniana* forests.

While plant richness measures diversity, it cannot fully reflect relative abundance information. Species diversity indices integrate vegetation data including species numbers, individual counts, plant heights, and distribution characteristics, providing more accurate assessments of community changes and evenness. Except for T3, all under-forest economy modes showed lower H diversity and Jw evenness indices than controls, indicating that human disturbance reduced plant diversity and evenness–consistent with findings from Wu et al. [8] and Yin et al. [9] but contrasting with Yu et al. [10] and Xie et al. [11]. This discrepancy may arise because disturbance intensity in our study sites fell within the range that reduces diversity. Additionally, Caidengba Jinbao et al. [27] found that rational rotational grazing can increase grassland productivity, species numbers, and plant height. Plant diversity also relates to vegetation type, with significant differences ($P < 0.05$) in richness index (S), diversity index (H), evenness index (Jw), and dominance index (Ea) among control groups. *Ficus lacor* forests showed the highest S and H , while *Dendrocalamus latiflorus* forests showed the lowest. *Pinus massoniana* forests exhibited the highest Jw and Ea, while *Dendrocalamus latiflorus* had the lowest Jw and *Ficus lacor* had the lowest Ea. These differences indicate that vegetation type partially determines herbaceous community diversity. The plant richness of 2 in *Dendrocalamus latiflorus* forests and similarity coefficients of 1.0 between under-forest economy modes and pure forest controls indicate unchanged species composition, attributable to high canopy density, sparse understory vegetation, and low light intensity that inhibited plant growth. Diversity threshold evaluation showed that *Ficus lacor* forest-grass mode had the highest threshold (good diversity), while *Dendrocalamus latiflorus* poultry and fungi modes had the lowest thresholds (general diversity). Understory cultivation and livestock rearing drive population changes [28], and moderate human disturbance during development may facilitate invasion by light-demanding plants, thereby increasing understory species diversity and promoting ecosystem balance, stability, and succession [29].

Regarding diversity maintenance, control groups consistently outperformed under-forest economy modes in herb layer diversity. When developing *Eucalyptus*, *Dendrocalamus latiflorus*, *Pinus massoniana*, and *Ficus lacor* forests, ecological benefits should be prioritized alongside economic benefits, supplemented by appropriate tending and thinning. This approach is crucial for preserving local endemic and endangered species while improving stand structure and forest health. For understory cultivation and livestock rearing, appropriate modes should be selected. The forest-grass mode causes minimal damage to understory plant diversity and should be prioritized for grass planting or other vegetation establishment. If understory livestock rearing is necessary, stocking densities should be maintained within optimal ecological carrying capacities, following principles of moderation and rationality to adjust interspecific relationships among understory organisms and achieve desirable ecological and economic outcomes for sustainable forest development. This study compared effects of different under-forest economy modes on plant diversity but did not address density gradient effects. Future research should incorporate investigations of understory cultivation and livestock intensity across modes to identify optimal ranges and provide theoretical references for sustainable mountain under-forest economy development and plant diversity conservation.

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