Species Composition and Diversity Characteristics of Vegetation Communities at Different Degradation Levels in Northwestern Guangxi Karst Region (Postprint)

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Abstract

Worldwide, many natural ecosystems have been damaged to varying degrees. The degradation of fragile karst ecosystems is a complex process, and differences in vegetation community characteristics across varying degradation levels in karst regions require investigation. Using the quadrat method for a comprehensive survey, we studied the species composition, community structural characteristics, and species diversity of vegetation communities at five degradation levels in northwestern Guangxi karst regions. The results showed that: (1) Species composition and life-form composition varied significantly among communities at different degradation levels. The potential degradation community exhibited the highest family, genus, and species richness. Along the gradient of increasing degradation, tree species in the communities gradually decreased to disappearance, the proportion of shrubs showed a trend of initial increase followed by decrease, while the proportion of herbs gradually increased. (2) A total of 218 vascular plant species were recorded in this survey, belonging to 86 families and 168 genera; the flora was dominated by Euphorbiaceae, Meliaceae, Rosaceae, Verbenaceae, Poaceae, and Nephrolepidaceae. During the degradation process, the importance value of dominant species gradually decreased, their dominant status within the community gradually weakened, while the importance value of companion species gradually increased. (3) During the degradation process, community structure tended toward simplification, with the density, height, and cover of woody plants in the communities gradually decreasing. (4) Significant differences in species diversity existed among arbor, shrub, and herb layers of vegetation communities at different degradation levels. With increasing degradation, the overall vegetation species richness index, Shannon-Wiener diversity index, and Simpson dominance index of communities showed a general declining trend. During the degradation process, the species composition characteristics and diversity of vegetation communities underwent significant changes; studies on community change characteristics have important implications for research on degradation mechanisms and vegetation restoration in karst regions.

Full Text

Preamble

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Title: Changes in Species Composition and Diversity of Vegetation Communities Along Degradation Gradients in Karst Areas of Northwest Guangxi

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Abstract

Many natural ecosystems worldwide have suffered degradation to varying degrees. The degradation of fragile karst ecosystems is a complex process, yet differences in vegetation community characteristics across various degradation levels remain understudied. Using quadrat sampling methods, we investigated species composition, community structural characteristics, and species diversity across five vegetation communities at different degradation levels in northwest Guangxi karst areas. Results showed: (1) Significant differences existed in species composition and life-form composition among communities at different degradation levels. Potential degradation communities exhibited the highest family, genus, and species richness. Along increasing degradation gradients, arboreal species gradually decreased to complete disappearance, shrub proportions initially increased then decreased, while herbaceous proportions gradually increased. (2) We recorded 218 vascular plant species belonging to 86 families and 168 genera, dominated by Euphorbiaceae, Meliaceae, Rosaceae, Verbenaceae, Gramineae, and Nephrolepidaceae. During degradation, the importance values of dominant species gradually decreased, weakening their dominance within communities, while importance values of companion species gradually increased. (3) Community structure tended to simplify during degradation, with density, height, and coverage of woody plants gradually decreasing. (4) Significant differences in species diversity existed among tree, shrub, and herb layers across different degradation levels. Overall, total vegetation species richness index, Shannon-Wiener diversity index, and Simpson dominance index showed downward trends with increasing degradation. Vegetation community species composition characteristics and diversity changed significantly during degradation, and studying these community change characteristics is important for understanding degradation mechanisms and vegetation restoration in karst areas.

Keywords: vegetation community, lime soil, degradation, species composition, diversity

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Introduction

Plant communities form through long-term environmental adaptation and self-regulation, always tending toward maximum utilization of local environmental resources (Levine, 2000; Lomolion, 2001; Lortie et al, 2004). As the primary provider of ecosystem materials and energy, plant communities constitute the material foundation for maintaining ecosystem stability and sustainable productivity (Zhang et al., 2017). Community species composition, diversity, and structure both respond to ecological environments and represent comprehensive expressions of plant biological and ecological characteristics, which can characterize community stability and habitat differences (Jiang et al., 1997; Zhang, 1995). Soil, as one of the most important environmental conditions for plant survival, influences plant community structure and function. Studying plant community species composition, diversity, and structure can effectively evaluate community stability and soil characteristics.

Ecosystem degradation is a complex process with intrinsic causes determined by its natural attributes, while external disturbances accelerate degradation (Tuyet, 2001; Zhang et al., 2001). Most research on degraded ecosystem plant communities has focused on alpine grasslands and wetlands (Zhou et al., 2012; Liu et al., 2008; Hou et al., 2009; Ma et al., 2016). Due to the special nature of carbonate rock substrates, excessive human disturbance in karst areas has caused vegetation reduction or disappearance, intensified soil erosion, soil degradation, and rocky desertification (Wang et al., 2008; Wang & Li, 2007). Karst habitats are extremely fragile with poor ecosystem stability and disturbance resistance, with most vegetation communities in degraded states and difficult to restore. Since entering the environmental protection stage in the mid-1980s, vegetation has begun natural recovery, but due to severe species diversity loss, lime soils remain at different degradation levels. In recent years, domestic scholars have preliminarily explored plant and soil characteristics of different forest types, successional sequences, and land use patterns in karst areas (Song et al., 2010, 2008; Peng et al., 2010; Zhang et al., 2008), providing important theoretical foundations for karst ecological restoration and reconstruction. However, research on lime soil degradation mechanisms requires further unification and improvement. Vegetation reduction is the trigger for karst ecosystem degradation, yet how species composition and diversity of karst vegetation communities change with increasing degradation degree remains unclear. Research on these questions is important for revealing karst lime soil degradation mechanisms and vegetation restoration.

Some studies have used remote sensing technology (Xiong et al., 2002) and rock exposure rate (Jiang et al., 2011) as classification criteria to divide karst rocky desertification into different grades. Some scholars argue that current rocky desertification classification is too simple, cannot reflect changes in ground material composition and vegetation landscape before and after rocky desertification, and is difficult to meet the needs of rocky desertification control planning and measure selection. They propose a superimposed classification of rocky desertification degree based on soil loss degree and ground material composition type (Zhang et al., 2007). However, these studies lack ground surveys and cannot truly reveal karst vegetation community degradation mechanisms. Based on the concept of soil degradation and following principles of intuitiveness, simplicity, operability, dominant factors, and comprehensive representativeness, this study uses rock exposure rate and vegetation coverage as basic criteria for soil degradation classification. Through soil and vegetation surveys, vegetation communities were divided into five degradation levels: no degradation, potential degradation, light degradation, moderate degradation, and severe degradation (Song et al., 2014). Using community ecology principles and the space-for-time substitution method (Barbouret et al., 1980), this study examines differences in vegetation community characteristics across degradation levels. By establishing plots at different degradation levels and conducting comprehensive vegetation surveys, we explored changes in plant community species composition, structural characteristics, and species diversity under different degradation levels in karst areas, providing important theoretical and practical foundations for revealing karst degradation mechanisms and developing vegetation restoration approaches for different degradation levels.

1 Study Area Overview

The study area was located in Dahua Yao Autonomous County, Guangxi (107°18 45 -108°03 45 E, 23°32 30 -24°22 30 N), situated on the slope of the transitional zone from the Yunnan-Guizhou Plateau to Guangxi hills. This represents one of Guangxi' s most typical "nine parts mountain, half part water, half part farmland" impoverished rocky mountain counties. The county covers a total area of 2,716 km^2, with total cultivated land of 162 km^2. The territory features dense peak clusters, with karst area totaling 2,059 km^2, accounting for 73% of the total county area, representing typical karst landforms. Soil parent material is primarily carbonate rock, with zonal red soil only distributed on soil mountains, while lime soil is common on rocky and semi-rocky mountains. The study area has a mild climate, belonging to the mid-subtropical monsoon climate with concurrent rainfall and heat. Annual average temperature is 18.12-21.17°C, and annual precipitation is 1,249-1,673 mm.

2.1 Plot Setup and Survey

Based on rock exposure rate and vegetation coverage, vegetation communities were divided into five degradation levels (Song et al., 2014): no degradation (I), potential degradation (II), light degradation (III), moderate degradation (IV), and severe degradation (V). After comprehensive reconnaissance, typical vegetation communities representing the five degradation levels were selected for plot establishment in July 2016, with nine plots per degradation level, totaling 45 plots. Using typical community sampling survey methods, plot areas were set as 20 m × 20 m for no degradation, potential degradation, and light degradation communities. Each plot was divided into four 10 m × 10 m tree quadrats, with one 5 m × 5 m shrub quadrat and three 1 m × 1 m herb quadrats established within each tree quadrat. Moderate and severe degradation plots were 10 m × 10 m, divided into four 5 m × 5 m shrub quadrats, with three 1 m × 1 m herb quadrats in each quadrat. Surveys were conducted separately for tree layer (arboreal species with DBH $\geq$ 1 cm), shrub layer (including woody lianas, arboreal regeneration seedlings with DBH $<$ 1 cm, and arboreal species dwarfed into shrub form due to harsh habitats), and herb layer (including herbaceous lianas and ferns). For each quadrat, species, quantity, DBH, ground diameter, height, crown width, and coverage of trees, shrubs, and saplings were recorded; herbaceous plants were surveyed for species, quantity, average height, and coverage. Geographic location, topography, soil characteristics, human impact patterns and intensity, vegetation type, and total coverage were also recorded for each quadrat.

2.2 Community Structure and Diversity Measurement

Importance value comprehensively represents the relative importance of each plant species in a community. For woody plants including trees, shrubs, and woody lianas, importance value = (relative density + relative dominance + relative frequency)/3. For herbaceous plants, importance value = (relative abundance + relative coverage + relative frequency)/3. Relative density, relative dominance, relative frequency, relative abundance, and relative coverage were calculated following Dong et al. (1996), where relative dominance of trees was calculated by basal area at breast height, and relative dominance of shrubs by basal area. This study used richness index (S), Shannon-Wiener index (N1), Simpson dominance index (N2), and Pielou evenness index (J) to measure community species diversity. Calculation methods for community structure indices followed references (Ma et al., 1995). Importance values and diversity indices were calculated according to different degradation stages.

2.3 Data Processing

Community diversity index calculations were completed using R 3.3.1 software, while other data processing, analysis, and graphing were performed using Excel 2010.

3.1 Species Richness, Family/Genus/Species Composition, and Life-Form Characteristics

A total of 218 vascular plant species were recorded, belonging to 86 families and 168 genera. As shown in Figure 1 [Figure 1: see original paper], species richness decreased with increasing degradation level. No degradation communities contained 52 families, 78 genera, and 105 species. Potential degradation communities showed the highest species richness with 53 families, 80 genera, and 112 species. Species richness began to decrease from the onset of degradation, with a sharp declining trend; severe degradation communities had the lowest richness with 27 families, 51 genera, and 62 species. Life-form composition and proportions of different life-form species numbers varied significantly among plant communities at different degradation levels (Figure 2 [Figure 2: see original paper]). From potential to light degradation, arboreal species numbers sharply decreased from 28 to 9 species; moderate and severe degradation communities had no arboreal species. With increasing degradation, shrub species numbers gradually decreased, but the proportion of shrubs in light degradation communities increased due to the sharp reduction of arboreal species. Herbaceous species numbers increased with degradation level, reaching up to 79% of total species in severe degradation communities. Liana species showed little difference across degradation levels.

3.2.1 Species Composition of No Degradation Communities

No degradation vegetation communities were rarely distributed in the survey area, retaining intact tree-shrub-herb layers. These communities were primarily evergreen-deciduous broadleaf mixed forests dominated by *Liquidambar formosana*, *Toona sinensis*, *Radermachera sinica*, *Cyclobalanopsis glauca*, *Zenia insignis*, and *Juglans regia*. In tree, shrub, and herb layers, species with importance values >10 comprised 3, 1, and 2 species respectively, accounting for 12.00%, 2.22%, and 7.41% of total species, and contributing 48.22%, 18.06%, and 40.83% of total importance values. Species with importance values of 1.00–10.0 numbered 12, 27, and 17 respectively, with all remaining species having importance values <1.00. Common arboreal species also included *Sterculia euosma*, *Ficus superba*, *Cinnamomum saxatile*, *Pterospermum heterophyllum*, *Albizia kalkora*, *Schima wallichii*, and *Machilus pingii*. Shrub layer dominants included *Alchornea trewioides*, *Embelia laeta*, *Rhus chinensis*, *Alchornea davidii*, *Vitex negundo*, and *Rubus alceaefolius*. Other common shrub species included *Ilex rotunda*, *Mallotus japonicus*, *Cinnamomum burmanni*, Euphorbiaceae, *Pyracantha fortuneana*, *Melastoma candidum*, and *Psychotria rubra*. Major herbaceous plants included *Nephrolepis auriculata*, *Microstegium vagans*, *Cyperus rotundus*, *Selaginella tamariscina*, *Cyclosorus parasiticus*, *Arthraxon hispidus*, *Eupatorium adenophora*, *Pteris semipinnata*, and *Cyclosorus parasiticus*. Lianas included *Dioscorea opposita*, *Lygodium japonicum*, and *Ampelopsis brevipedunculata*.

3.2.2 Species Composition of Potential Degradation Communities

Potential degradation vegetation communities are highly susceptible to degradation once disturbed. In these communities, species with importance values >10 in tree and shrub layers numbered 4, 1, and 2 respectively, accounting for 14.28%, 2.43%, and 8.70% of total species, and contributing 54.84%, 12.66%, and 66.14% of total importance values. Species with importance values of 1.00–10.0 numbered 12, 25, and 8 respectively, with all remaining species having importance values <1.00. Arboreal species included *Toona sinensis*, *Zenia insignis*, *Melia azedarach*, *Radermachera sinica*, *Lithocarpus thalassica*, *Cipadessa cinerascens*, *Rhus chinensis*, *Pterospermum heterophyllum*, and *Camptotheca acuminata*. Major shrub species included *Alchornea trewioides*, *Pyracantha fortuneana*, *Cipadessa cinerascens*, *Rubus alceaefolius*, *Embelia scandens*, *Callicarpa macrophylla*, *Embelia laeta*, *Boehmeria nivea*, *Mallotus barbatus*, Euphorbiaceae, and *Vitex negundo*. Herbaceous plants primarily included *Microstegium vagans*, *Nephrolepis auriculata*, *Cyclosorus parasiticus*, *Miscanthus floridulus*, *Cyperus rotundus*, *Pteris cretica*, *Pyrrosia lingua*, and *Mussaenda pubescens*. Lianas mainly included *Clematis* and *Zanthoxylum*.

3.2.3 Species Composition of Light Degradation Communities

Light degradation vegetation communities showed sharply reduced arboreal species, distributed only sporadically. Species with importance values >10 in tree and shrub layers numbered 3, 2, and 3 respectively, accounting for 33.33%, 4.88%, and 8.33% of total species, and contributing 72.43%, 23.00%, and 51.66% of total importance values. Species with importance values of 1.00–10.0 numbered 4, 26, and 11 respectively, while species with importance values <1.00 numbered 2, 13, and 22 respectively. Major arboreal species included *Camptotheca acuminata*, *Cratoxylum cochinchinense*, *Radermachera sinica*, *Maesa japonica*, *Albizia kalkora*, and *Cipadessa cinerascens*. The shrub layer was species-rich, with common shrubs including *Vitex negundo*, *Alchornea* *trewioides*, *Pyracantha fortuneana*, *Cudrania cochinchinensis*, *Toona sinensis*, *Pterolobium punctatum*, *Camptotheca acuminata*, *Sageretia thea*, *Desmos chinensis*, and *Paliurus ramosissimus*. Herbaceous plants mainly included *Miscanthus floridulus*, *Selaginella tamariscina*, *Microstegium vagans*, *Imperata cylindrica*, *Arthraxon hispidus*, *Nephrolepis auriculata*, *Cyclosorus parasiticus*, *Cyperus rotundus*, *Cyclosorus parasiticus*, *Cyrtococcum patens*, and *Bidens pilosa*. Lianas included *Bauhinia championii*, *Hedyotis hedyotidea*, and *Lygodium japonicum*.

3.2.4 Species Composition of Moderate Degradation Communities

Moderate degradation vegetation communities had no tree layer, only shrubs and herbs. In the shrub layer, species with importance values >10.00, 1.00–10.00, and <1.00 numbered 2, 13, and 10 respectively; in the herb layer, these numbered 4, 12, and 20 respectively. Shrub species decreased substantially compared with light degradation communities, mainly including *Vitex negundo*, *Phyllanthus emblica*, *Melastoma candidum*, *Rhus chinensis*, *Rubus cochinchinensis*, *Pyracantha fortuneana*, *Maesa japonica*, *Alchornea trewioides*, *Mallotus japonicus*, *Embelia ribes*, and *Mallotus barbatus*. Herbaceous plants mainly included *Microstegium vagans*, *Miscanthus floridulus*, *Heteropogon contortus*, *Arthraxon hispidus*, *Neottopteris nidus*, *Nephrolepis auriculata*, *Arundinella nepalensis*, and *Bidens pilosa*.

3.2.5 Species Composition of Severe Degradation Communities

Severe degradation vegetation communities were dominated by herb layers with relatively rich species. In the herb layer, only one species had importance value >10.00, accounting for just 2.04% of total species and 12.11% of total importance value. Species with importance values of 1.00–10.0 numbered 22, while 26 species had importance values <1.00. Dominant species were *Pogonatherum crinitum* and *Cyperus rotundus*, with common herbs including *Mentha haplocalyx*, *Ageratum conyzoides*, *Artemisia carvifolia*, *Cyrtococcum patens*, *Artemisia lavandulaefolia*, *Imperata cylindrica*, *Cymbopogon goeringii*, *Arthraxon hispidus*, and *Bidens pilosa*. Shrubs were sparse, with only scattered *Rubus alceaefolius*, *Melastoma candidum*, *Callicarpa macrophylla*, and *Embelia laeta*.

Table 4 Importance Values of Top 10 Species in Community Layers Under Different Degradation Levels

Layer	Species	Importance Value by Degradation Level (I-V)
Tree	*Liquidambar formosana*	19.67(1)
	Toona sinensis	16.30(2)

Layer	Species	Importance Value by Degradation Level (I-V)
	Radermachera sinica	20.66(1)
	Cyclobalanopsis glauca	12.25(3)
	Zenia insignis	10.09(4)
	Juglans regia	18.65(2)
	Sterculia euosma	9.38(4)
	Ficus superba	2.03(8)
	Cinnamomum saxatile	8.16(5)
	Pterospermum heterophyllum	13.09(2)
	Melia azedarach	6.73(6)
	Lithocarpus thalassica	5.21(7)
	Cipadessa cinerascens	4.51(8)
	Rhus chinensis	3.46(9)
	Camptotheca acuminata	2.11(10)
	Cratoxylum cochinchinense	4.62(8)
	Maesa japonica	10.99(3)
	Albizia kalkora	1.81(9)
Shrub	*Alchornea trewioides*	18.06(1)
	Embelia laeta	12.66(1)
	Rhus chinensis	11.18(2)
	Alchornea davidii	2.51(9)
	Vitex negundo	6.04(2)
	Rubus alceaefolius	5.38(3)
	Ilex rotunda	4.74(4)
	Mallotus japonicus	4.48(5)
	Cinnamomum burmanni	4.5(4)
	Euphorbiaceae	11.81(1)
	Pyracantha fortuneana	38.16(1)
	Melastoma candidum	8.81(3)
	Psychotria rubra	4.25(6)
	Cipadessa cinerascens	3.03(7)
	Embelia scandens	5.64(3)
	Callicarpa macrophylla	18.36(2)
	Toona sinensis	9.07(3)
	Melia azedarach	6.82(5)
	Boehmeria nivea	3.82(6)
	Mallotus barbatus	3.56(7)
	Cudrania cochinchinensis	5.83(5)
	Pterolobium punctatum	3.54(8)
	Camptotheca acuminata	2.74(10)
	Sageretia thea	8.33(4)
	Desmos chinensis	6.5(4)
	Paliurus ramosissimus	4.45(6)
	Phyllanthus emblica	4.22(7)
	Maesa japonica	3.21(8)

Layer	Species	Importance Value by Degradation Level (I-V)
	Xylosma racemosum	3.21(9)
	Ficus pandurata	2.46(10)
	Broussonetia papyrifera	12.66(2)
Herb	*Nephrolepis auriculata*	4.13(7)
	Microstegium vagans	5.31(6)
	Cyperus rotundus	27.56(1)
	Selaginella tamariscina	24.46(2)
	Cyclosorus parasiticus	4.93(6)
	Arthraxon hispidus	2.78(6)
	Miscanthus floridulus	2.15(10)
	Eupatorium adenophora	13.26(2)
	Pteris semipinnata	38.86(1)
	Cyclosorus parasiticus	12.65(3)
	Cyperus rotundus	30.85(1)
	Pteris cretica	9.79(3)
	Pyrrosia lingua	1.12(10)
	Imperata cylindrica	9.58(4)
	Cyrtococcum patens	13.91(2)
	Bidens pilosa	5.92(5)
	Pogonatherum crinitum	9.93(3)
	Mentha haplocalyx	2.56(9)
	Ageratum conyzoides	3.89(6)
	Artemisia carvifolia	6.37(5)
	Artemisia lavandulaefolia	10.13(4)
	Cymbopogon goeringii	3.29(7)
	Artemisia argyi	3.68(4)
	Heteropogon contortus	25.74(1)
	Mussaenda pubescens	20.50(2)

Note: Numbers in parentheses indicate ranking within layer.

3.3 Community Structural Characteristics Across Degradation Levels

Forest community structure was measured using five indicators: density, average crown width, coverage, average DBH, and average height (Table 5). Structural characteristics varied significantly among vegetation communities at different degradation levels. No degradation communities showed significantly higher DBH, crown width, density, height, and coverage than other communities, with larger individuals, complete layers, and reasonable community structure. Potential degradation communities had significantly lower tree density than no degradation communities, with smaller individuals and relatively poor structural stability, showing higher sensitivity to disturbance. Degraded communities had incomplete structures: light degradation communities had sparse trees; moderate degradation communities were dominated by shrubs; severe degradation communities had only scattered shrubs, being dominated by herbs with low vegetation height and coverage.

Table 5 Community Structure Characteristics Under Different Degradation Levels

<table>
<tr><th>Community</th><th>Average DBH (cm)</th><th>Average Crown Breadth (m)</th><th>Community Height (m)</th><th>Total Density (plant · hm^{-2})</th><th>Shrub Density (plant · hm^{-2})</th><th>Coverage (%)</th></tr>
<tr><td>I</td><td colspan="6">8.76$±4.54a|1.72±0.31a|6.68±1.05a|5, 988a|9.4±4.0a|82.36±9.82a||II|1.23±0.28b|3.02±0.89b|0.56±0.12
| – | –
|4, 091b|2.9±0.7c|60.86±6.45b||IV|–
| – | –
|2, 967c|1.0±0.4cd|48.32±5.31bc||V|–
|–|–|–
|0.3±0.1d|30.12±$4.20c</td></tr>
</table>

Note: Letters indicate significant differences among degradation levels (P < 0.05). Data are means ± standard deviation.

3.4 Species Diversity

Significant differences in species diversity existed among community layers across degradation levels (Figure 3 [Figure 3: see original paper]). For no degradation, potential degradation, and light degradation communities, species richness index (S) showed the pattern shrub layer > herb layer > tree layer, as shrub layers contained many saplings and seedlings of tree species, resulting in higher richness than tree layers. Along increasing degradation gradients, S in tree and shrub layers decreased; the herb layer of level V degradation communities showed the highest S because tree and shrub layers were incomplete in these severely degraded communities.

With increasing degradation, Shannon-Wiener diversity index (N1), Simpson dominance index (N2), and evenness index (J) gradually decreased across all community layers. Except for N1 and N2 in herb layers showing no significant differences, all other layers showed significant differences (P<0.05), following the pattern: no degradation > potential degradation > light degradation > moderate degradation > severe degradation. Across all degradation levels, herb layers had higher N1, N2, and J than shrub and tree layers. In no degradation communities, shrub layer N1 was higher than tree layer, while N2 and J were similar between these layers. In potential degradation communities, tree and shrub layers had similar N1 and N2, but tree layer J was higher than shrub layer. In light degradation communities, N1, N2, and J across layers showed the pattern herb layer > shrub layer > tree layer.

As shown in Figure 4 [Figure 4: see original paper], total community species richness index, Shannon-Wiener diversity index, and Simpson dominance index decreased with increasing degradation. The curves for Simpson dominance index and species richness index showed increased slope from level II onward, indicating that once degradation occurs, species richness and dominance indices change significantly, especially with sharp declines in species richness. The Shannon diversity index changed more gradually, decreasing at a relatively stable rate. The evenness index curve was gentle with small changes, indicating similar evenness across different degradation levels.

Note: Letters indicate significant differences in species diversity of the same vegetation life type across degradation levels ($P < 0.05$).

4.1 Species Composition Characteristics and Changes Across Degradation Levels

Plant communities are carriers of species, with different communities having different species compositions. Karst ecosystems are inherently fragile and highly sensitive, responding rapidly and intensely to disturbance. Slight disturbance causes species reduction, gradual vegetation disappearance, deterioration of land ecological factors, and easy ecosystem degradation (Zeng et al., 2007). After environmental degradation, vegetation undergoes further major degradation, with trees gradually replaced by small shrubs and herbs, vegetation service functions lost, and soil further degraded until rocky desertification occurs.

Through survey and analysis of vegetation communities at different degradation levels in karst areas, this study found significant changes in species life-form composition and structure. With increasing degradation, species richness increased in potential degradation communities but decreased sequentially from light degradation onward. No degradation and potential degradation communities had complete plant layers and relatively high species richness, with 105 and 112 species respectively recorded in nine plots totaling 0.36 hm^2. This is similar to species numbers reported by Du et al. (2013) for secondary forest (49 families, 84 genera, 101 species) and primary forest (50 families, 79 genera, 98 species) in karst peak-cluster depressions surveyed in six plots of 0.24 hm^2, but far lower than the 226 species in 0.4 hm^2 of natural secondary forest in southern red soil regions (Wang et al., 2013). This is related to the special soil environment of karst, where plants must have lithophytic, calciphilous, and drought-tolerant characteristics, along with well-developed and strong root systems, resulting in relatively fewer species. Along increasing degradation gradients, arboreal species in plant communities gradually decreased and even disappeared, while small shrubs and herbs became dominant, with further lime soil degradation, consistent with results from Zeng et al. (2007). Additionally, the proportion of evergreen species gradually decreased while deciduous species relatively increased, consistent with Song et al. (2010) who found that evergreen species proportions gradually increased along decreasing disturbance gradients (strong, moderate, weak) in different karst forest types.

Species composition differed among plant communities at different degradation levels. During retrogressive succession of karst vegetation communities, importance values of dominant species gradually decreased, weakening their dominance within communities, while importance values of companion species gradually increased. Vegetation community degradation began with reduction of arboreal species and changes in dominant species, with arboreal species sharply decreasing from potential to light degradation, primarily due to human disturbance (logging, cultivation, fuelwood collection, grazing). Sustained human disturbance led to vegetation reduction and land degradation, further intensifying community degradation and ultimately causing disappearance of arboreal species, forming moderate degradation shrub communities that further deteriorated into severe degradation herb communities. Therefore, reducing human disturbance is one of the key factors for karst vegetation restoration.

4.2 Community Structural Characteristics and Diversity Changes Across Degradation Levels

Degradation of karst ecosystems not only changes community species composition but also alters structural characteristics and species diversity, which decrease with intensifying degradation. Plant community species diversity can directly or indirectly reflect community structure types, stability levels, and habitat differences, serving as an indicator for judging community structural changes and ecosystem stability (Meng et al., 2015; Bhim & John, 2014). The relationship between plant diversity and community stability is more complex in karst peak-cluster depressions, where plant diversity alone cannot fully represent community stability. Community stability requires not only rich plant diversity but also reasonable community structure (Zeng et al., 2007). Reduced species diversity and damaged community structure are main factors of plant community degradation, with obvious changes in community structure and species diversity during karst vegetation community degradation.

Potential degradation communities had slightly higher species richness and diversity indices than no degradation communities, but were dominated by small trees and large shrubs, while no degradation communities had the highest coverage, larger arboreal individuals, and relatively reasonable structure, making them more disturbance-resistant and stable than potential degradation communities. No degradation communities in karst areas have thick, continuous soil layers, high vegetation coverage, and good community stability, suitable for agriculture, forestry, and animal husbandry, but rarely exist in fragile karst lime soil habitats. Potential degradation communities have high species richness and diversity indices, continuous soil layers, and are suitable for forestry and animal husbandry, but have certain rock exposure rates and weak disturbance resistance. Once subjected to external disturbance, they easily degrade. Vegetation reduction causes soil degradation, which inevitably leads to further vegetation degradation, with both being mutually causal. Therefore, for this community type, land management and utilization should ensure vegetation coverage and species diversity are maintained.

Light degradation lime soil communities have sparse trees, are shrub-dominated, have unreasonable structure, poor stability, and discontinuous soil cover, suitable for forestry and animal husbandry but with 50% rock exposure rate. They should focus on forestry to increase vegetation coverage for ecological restoration. This community type is the main vegetation type in karst areas. Moderate degradation communities are widely distributed in karst areas, dominated by shrubs and herbs, with low vegetation coverage, thin and discontinuous soil layers, high rock exposure rates, and poor disturbance resistance and stability. For this community type, human disturbance should be eliminated to allow natural vegetation recovery. Severe degradation communities are distributed in highly rocky desertified areas with high rock exposure rates, low vegetation coverage, sporadic soil distribution, and sparse herbaceous vegetation only, making land utilization difficult and requiring long-term natural recovery to restore vegetation and improve community environment. The exact time required remains to be further explored.

This study established a degradation series of karst vegetation communities using the space-for-time substitution method to analyze changes in community composition, structure, and species diversity during degradation, which helps reveal and deepen understanding of karst community degradation ecological processes and provides a basis for karst community restoration, having practical significance. Long-term permanent plot studies would yield more satisfactory results.

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