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SPECIES COMPOSITION AND DIVERSITY OF PLANTS AT DIFFERENT SUCCESSIONAL STAGES IN SMALL CATCHMENTS OF KARST AREAS

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Abstract

This study focused on the composition and species diversity of plants during different succession periods based on a field investigation in Houzhai Valley in Puding County, a karst area in Guizhou Province in Southwest China. The results showed that the vegetation in this area was mainly in four succession stages: grassland, shrub grassland, shrub forest and arbour forest. There were also some artificial fruit-bearing forests. In summary, 97 families, 230 genera and 382 species were investigated and recorded in the studied region. The predominant three families with the largest number of species were the Rosaceae, Compositae and Poaceae. The percentage of the life forms as arbour, shrub, herb and rattan accounted for 14.66%, 29.84%, 43.46% and 11.52% of the total species, respectively. The species richness index and Simpson's diversity index were as follows: arbour forest > shrub forest > shrub grassland > fruit-bearing forest > grassland. The species evenness and Shannon–Wiener index were as follows: arbour forest > shrub forest > shrub grassland > grass > fruit-bearing forest. In different stages of vegetation succession in the karst area, the measures taken for the restoration of vegetation and afforestation should be based on the specific species.

Key words: Diversity; Species composition; Different vegetation types; Small catchments; Karst areas.

Introduction

Karst rocky desertification refers to the evolutionary process occurring under the condition of the strongly developed natural environment of karst areas in the subtropics, in which damage caused by human activity has resulted in severe soil erosion, destruction of vegetation, extensive bare bedrock, a sharp drop in productivity and a visual desert landscape of the surface (Zhou *et al.*, 2010; Xie *et al.*, 2015). Rocky desertification has been one of the main obstacles to sustainable development of the south-western karst areas in our country. Vegetation recovery is at the heart of improving the ecosystem of karst areas (Zhang *et al.*, 2011). Given the high rate of bare rocks, thin and discontinuous soil, frequent alternation of rain and drought in habitats, vegetation recovery is extremely difficult in karst areas (Wang *et al.*, 2002). Sealing the mountains for afforestation has become the principal measure of recovering vegetation (Li *et al.*, 2009), and taking reasonable actions based on laws of vegetation succession is an important approach for accelerating vegetation recovery. In this respect, the first thing is to understand is the distribution characteristics of plant communities at different succession stages, as well as the laws of plant community succession (Matthews *et al.*, 2009). Species composition of plant communities and community structure are the foundations of studying plant community succession (Ashraf *et al.*, 2012). Therefore, it is one of the significant and fundamental jobs of governance of karst rocky desertification areas and vegetation recovery areas to study the species composition of plant communities at different succession stages to reveal the substitution processes of species and variation in community structure.

Species diversity and structural features of the ecosystem are one of the important ecological issues (Xu *et al.*, 2013). Species diversity is the foundation of ecosystem functions. A wide diversity of species in the ecosystem can not only enhance the ecosystem's ability to counter the unsavoury aspects of external uncertainty and recover from the impacts but also contribute to the sustainable use of nutrients and fertility within the ecosystem (Wang *et al.*, 2010; Davis *et al.*, 2004). Thus, productivity increases with species richness. In recent years, various measures have been taken in the Houzhai Catchment to restore the vegetation of the whole basin. Various types of community succession appeared in the Houzhai Catchment, from grassland, scrub grassland, shrub forest to arbour forest and artificial fruit forest, which constituted a representative series of succession. In this study, representative vegetation communities around the Houzhai Catchment were selected to study the species composition and structural features of communities at different vegetation succession stages; the final aim was to offer some valuable information for measures of vegetation recovery in karst areas as well as species selection and optimal distribution.

Materials and Methods

Study region: The study region (105°40′43″-105°48′2″E, 26°12′29″-26°17′15″N) is located in Puding County in the central part of Guizhou Province in south-western China. It covers an area of 75 km^2, including three towns, Chengguan (CG), Maguan (MG) and Baiyan (BY). The elevation ranged from 1223.4 m to 1567.4 m above sea level, and the air pressure was between 806.1 and 883.8 Pa. There are three major categories of soils in the studied region: Leptosols, Anthrosols and Ferralsols. The mean annual temperature and mean annual precipitation were approximately 15.1°C and 1378.2 mm, respectively (Huang *et al.*, 2018). The main ecosystem types in the study area included evergreen broad-leaved forest, coniferous and broad-leaved mixed forest, and montane elfin forest (Zhang *et al.*, 2017).

Survey of plant community: In June and August 2015, the sampling of a typical community was conducted by taking samples of the typical vegetation community in each succession stage. The investigation area was selected according to the representative minimum area of the community. A total of 28 sampling and investigation plots were designed at different vegetation succession stages (Fig. 1). The communities of the secondary arbour forest and the fruit-bearing forest were 20 m × 20 m, and the communities of shrub forest and shrub grassland were 10 m × 20 m. During the investigation, the original samples were divided into small 10 m × 10 m samples, which were further divided into six smaller 2 m × 2 m samples to investigate the herb layers and to record the plant names, height, crown width, diameter at breast height and basal diameter in detail (Mitsch *et al.*, 2004). The investigation of the herb layers included the plant names, height, abundance and coverage. The sampling area of grassland was 2 m × 2 m. In total, there were 28 samples (6 secondary arbour forests, 6 fruit-bearing forests, 5 shrub forests, 5 shrub grasslands and 6 grasslands).

Results and analysis

Species richness and life form components: The plant species and their life form in this area are shown in Figs. 2-3. A total of 97 families, 230 genera and 382 species of plants were recorded in this survey. Among them, there were 18 families, 26 genera and 38 species of ferns. Among the seed plants, there were 72 families, 176 genera and 288 species of dicotyledons; and 7 families, 28 genera and 56 species of monocotyledons. The three families with the largest number of species were Rosaceae (40 species), Compositae (38 species) and Poaceae (20 species). According to the life form, the species numbers of the four kinds of typical life forms, trees, shrubs, herbs and rattan, were 56, 114, 166, and 44, accounting for 14.66%, 29.84%, 43.46% and 11.52%, respectively, of the total species in the Houzhai Catchment.

Changes in community composition: Vegetation restoration is the ultimate goal of the improvement and restoration of the fragile ecologic function in karst areas, and the restoration and reconstruction of vegetation are the main ways to solve the problems of soil erosion and soil degradation in karst areas (Xu and Zhang, 2014). Vegetation in the Houzhai Catchment was restored to the shrub grassland stage, while the life form was mainly herbaceous plants with a few sparse shrubs; most of them were heliophyte herbs. In general, the species types were relatively small; until the shrub grassland stage was completely restored, the plant types of herbaceous and shrub increased significantly, as did sciophytes. In the end, the canopy density increased significantly, as did the arbour species. Finally, in the arbour stage, arbour trees became the main species, and the heliophytes were in the dominant position. In the process of self-restoration, the vegetation types of Houzhai Catchment alternated with each other. The difference between vegetation types, from pioneer species to transitionary species, was quite large, and the vegetation types increased significantly when they were restored to climax species.

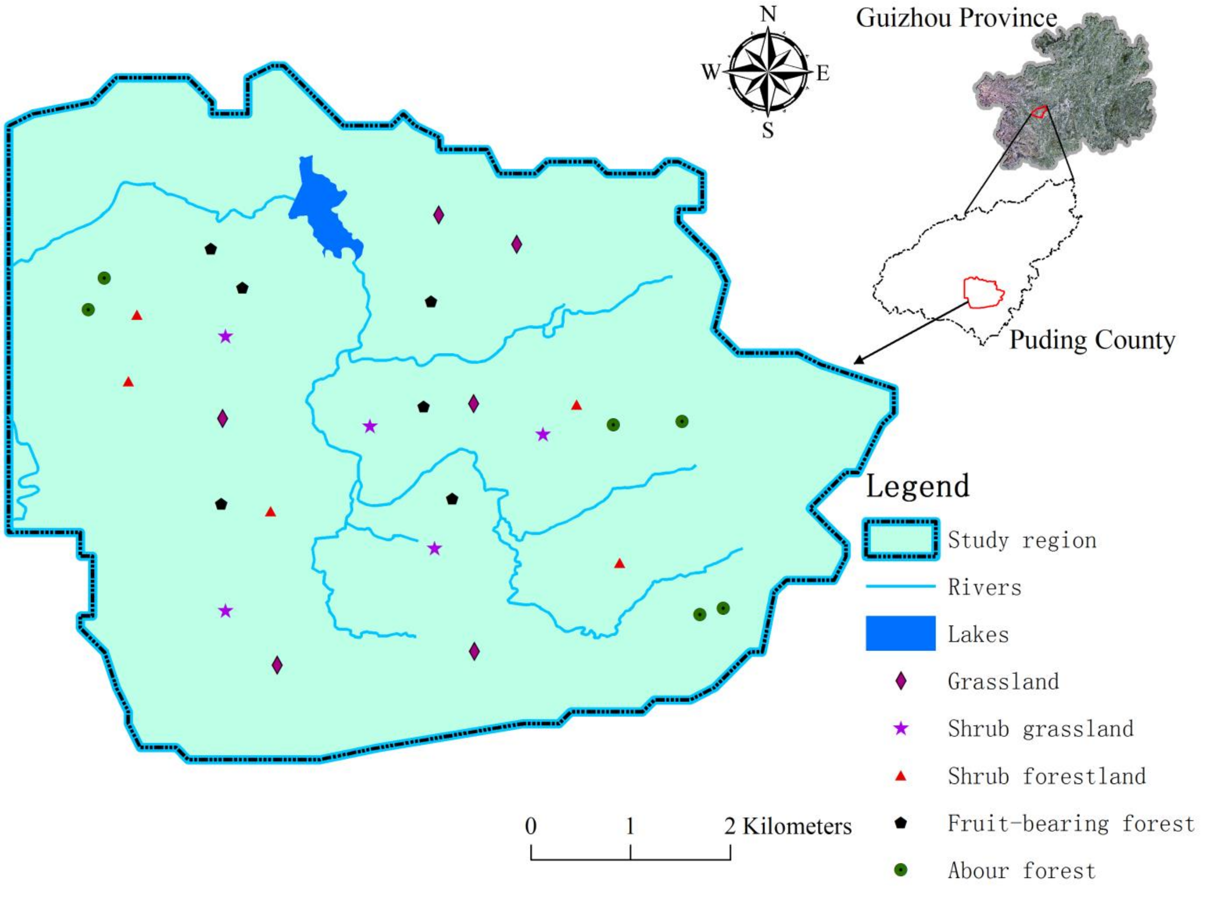

Fig. 1. Distribution of investigating sites.

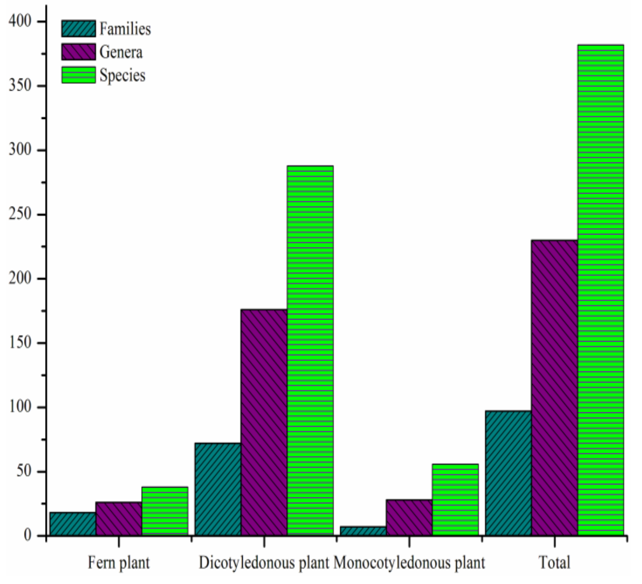

Fig. 2. Plant species composition in the Houzhai Catchment.

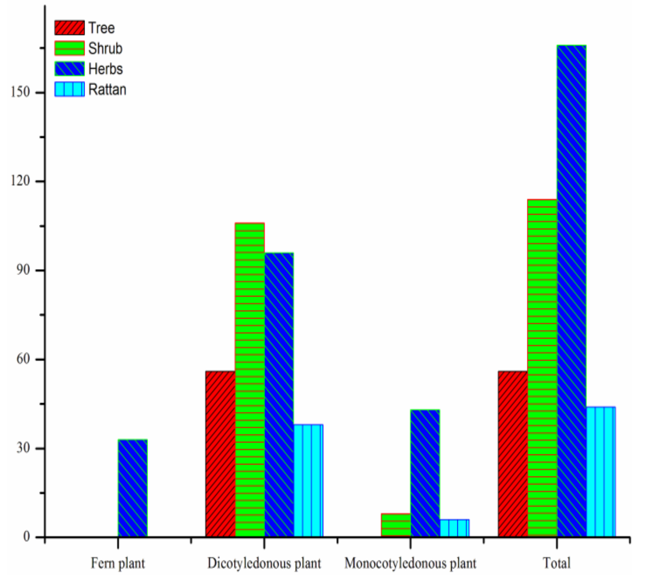

Fig. 3. Life form composition in the Houzhai Catchment.

Table 1 The main tree species in the Karst forest.

Plant types	Families	Genera	Species
Pioneer plants	Rosaceae, Coriariaceae, Fabaceae, Euphorbiaceae, Anacardiaceae, Lauraceae, Moraceae, Guttiferae, Caesalpiniaceae	*Rubus*, *Coriaria*, *Indigofera*, *Mallotus*, *Rosa*, *Pyracantha*, *Rhus*, *Litsea*, *Broussonetia*, *Hypericum*, *Bauhinia*	*Rubus corchorifolius*, *Coriaria nepalensis*, *Indigofera amblyantha*, *Mallotus japonicus*, *Rosa laevigata*, *Pyracantha atalantioides*, *Rhus chinensis*, *Rosa cymosa*, *Litsea pungens*, *Broussonetia papyrifera*, *Hypericum monogynum*, *Bauhinia purpurea*
Transitional Plants	Berberidaceae, Verbenaceae, Lauraceae, Oleaceae, Hamamelidaceae, Euphorbiaceae, Gramineae, Rutaceae, Cornaceae, Anacardiaceae, Pittosporaceae, Juglandaceae, Fabaceae, Ebenaceae	*Nandina*, *Callicarpa*, *Lindera*, *Ligustrum*, *Liquidambar*, *Mallotus*, *Dendrocalamus*, *Clausena*, *Swida*, *Choerospondias*, *Pittosporum*, *Engelhardtia*, *Cladrastis*, *Diospyros*	*Nandina domestica*, *Callicarpa bodinieri*, *Lindera communis*, *Ligustrum quihoui*, *Liquidambar formosana*, *Mallotus repandus*, *Dendrocalamus tsiangii*, *Clausena dunniana*, *Dendrobenthamia hongkongensis*, *Choerospondias axillaris*, *Pittosporum glabratum*, *Mallotus philippensis*, *Engelhardtia roxburghiana*, *Cladrastis platycarpa*, *Diospyros kaki*
Top plants	Fagaceae, Ulmaceae, Juglandaceae, Betulaceae, Fagaceae, Olacaceae, Aceraceae, Aquifoliaceae, Lauraceae	*Cyclobalanopsis*, *Celtis*, *Platycarya*, *Carpinus*, *Cyclobalanopsis*, *Schoepfia*, *Acer*, *Zelkova*, *Ilex*, *Lindera*	*Cyclobalanopsis augustinii*, *Celtis sinensis*, *Platycarya strobilacea*, *Carpinus kweichowensis*, *Cyclobalanopsis glauca*, *Schoepfia fragrans*, *Cyclobalanopsis multinervis*, *Acer cinnamomifolium*, *Zelkova serrata*, *Ilex macrocarpa*, *Lindera communis*

The composition of representative species: In different stages of vegetation restoration, species replacement occurred to varying degrees. The main specie composition of different plant types and vegetation types were listed in Tables 1 and 2.

Diversity index of community: The restoration of karst vegetation was a developing process from the beginning stage to the advanced stage. The community in the forest was moving towards a more complicated and perfect structure. With the increase in species diversity in the community, the density of the community decreased. With the increase in the degree of community polarization, the number of species increased as well. Eventually, changes in the diversity index indicated changes in the structure and function of vegetation restoration in the Houzhai Catchment. According to Table 3, the species richness index and Simpson's diversity index were as follows: arbour forest > shrub forest > shrub grassland > fruit-bearing forest > grassland. The species evenness and Shannon–Wiener index were as follows: Arbour forest > shrub forest > shrub grassland > grassland > fruit-bearing forest. In general, during the restoration process from grassland to arbour forest in the Houzhai Catchment, the species of the whole community increased, and the diversity index and evenness index rose significantly, indicating that the ecological environment of the Houzhai Catchment was prominently improved by vegetation restoration.

Table 2 Species composition under different restoration modes.

Vegetation types	Families	Genera	Species
Arbour forest	Caesalpiniaceae, Rosaceae, Juglandaceae, Fagaceae, Grossulariaceae, Lauraceae, Pittosporaceae, Ulmaceae, Araliaceae, Rhamnaceae, Betulaceae, Anacardiaceae, Moraceae, Meliaceae	*Bauhinia*, *Pyracantha*, *Platycarya*, *Lithocarpus*, *Itea*, *Machilus Nees*, *Quercus*, *Pittosporum Banks ex Soland*, *Celtis*, *Kalopanax*, *Rhamnella*, *Carpinus*, *Lindera*, *Prunus*, *Rhus*, *Allaeanthus*, *Toona*	*Bauhinia purpurea*, *Pyracantha atalantioides*, *Platycarya longipes*, *Lithocarpus confinis*, *Itea yunnanensis*, *Machilus cavaleriei*, *Quercus aliena*, *Pittosporum brevicalyx*, *Celtis bungeana*, *Celtis sinensis*, *Kalopanax septemlobus*, *Rhamnella martini*, *Carpinus pubescens*, *Quercus acutissima*, *Lindera hemsleyana*, *Prunus salicina*, *Rhus chinensis*, *Broussonetia papyrifera*, *Toona sinensis*
Shrub forest	Euphorbiaceae, Rosaceae, Coriariaceae, Stachyuraceae, Rutaceae, Thymelaeaceae, Aquifoliaceae, Lauraceae, Myrsinaceae, Smilacaceae, Fabaceae, Betulaceae, Rubiaceae, Rhamnaceae, Caprifoliaceae, Labiatae, Guttiferae, Scrophulariaceae	*Mallotus*, *Rose*, *Indigofera*, *Rhamnus*, *Stachyurus*, *Zanthoxylum*, *Daphne*, *Ilex*, *Lindera*, *Myrsine*, *Campylotropis*, *Smilax*, *Sageretia*, *Corylus*, *Pyracantha*, *Elsholtzia*, *Serissa*, *Berchemia*, *Viburnum*, *Spiraea*, *Rubus*, *Hypericum*, *Coriaria*, *Litsea*, *Brandisia*, *Cotoneaster*	*Mallotus japonicus*, *Rosa cymosa*, *Rosa laevigata*, *Indigofera amblyantha*, *Coriaria nepalensis*, *Rhamnus heterophylla*, *Stachyurus obovatus*, *Zanthoxylum ovalifolium*, *Rhamnus leptophylla*, *Smilax microphylla*, *Zanthoxylum esquirolii*, *Daphne odora*, *Ilex coralline*, *Lindera communis*, *Myrsine africana*, *Smilax glaucochina*, *Campylotropis macrocarpa*, *Myrsine semiserrata*, *Sageretia thea*, *Corylus heterophylla*, *Myrsine verruculosa*, *Pyracantha fortuneana*, *Elsholtzia rugulosa*, *Zanthoxylum armatum*, *Serissa japonica*, *Berchemia polyphylla*, *Indigofera pseudotinctoria*, *Viburnum foetidum*, *Elsholtzia ciliate*, *Spiraea chinensis*, *Rubus xanthoneurus*, *Hypericum patulum*, *Coriaria nepalensis*, *Litsea rubescens*, *Brandisia hancei*, *Rosa henryi*, *Cotoneaster adpressus*, *Rosa rubus*
Grass	Cyperaceae, Compositae, Gramineae, Liliaceae, Polypodiaceae, Sinopteridaceae, Dryopteridaceae, Berberidaceae, Rubiaceae, Pteridaceae Ranunculaceae, Araceae, Urticaceae, Cannabaceae, Gramineae, Violaceae	*Carex*, *Senecio*, *Oplismenus*, *Ophiopogon*, *Pyrrosia Mirbel*, *Onychium*, *Aster*, *Polystichum*, *Epimedium*, *Rubia*, *Pteris*, *Spodiopogon*, *Thalictrum*, *Arisaema*, *Lemmaphyllum*, *Miscanthus*, *Pilea*, *Humulus*, *Themeda*, *Arthraxon*, *Capillipedium*, *Bothriochloa*, *Artemisia*, *Viola*, *Taraxacum*, *Heteropogon*	*Carex lanceolata, Senecio scandens, Oplismenus undulatifolius, Liriope platyphylla, Pyrrosia lingua, Carex cruciata, Onychium japonicum, Aster ageratoides, Polystichum tsus-simense, Epimedium sagittatum, Rubia cordifolia, Pteris cretica var. intermedia, Spodiopogon ramosus, Thalictrum minus, Arisaema penicillatum, Lepidogrammitis drymoglossoides, Miscanthus floridulus, Pilea cavaleriei, Hemiboea subcapitata, Carex ligulata, Themeda japonica, Arthraxon lanceolatus, Capillipedium assimile, Bothriochloa bladhii, Gerbera anandria, Artemisia japonica, Viola verecunda, Taraxacum mongolicum, Heteropogon contortus, Capillipedium parviflorum*
Shrub grass	Gramineae Bignoniaceae, Labiatae, Blechnaceae, Cyperaceae, Fabaceae, Rosaceae, Rhamnaceae, Anacardiaceae, Betulaceae, Ericaceae, Moraceae, Compositae, Convolvulaceae, Asclepiadaceae, Apocynaceae, Vitaceae, Ranunculaceae	*Cymbopogon*, *Oplismenus*, *Geum*, *Heteropogon*, *Setaria*, *Eremochloa*, *Themeda*, *Capillipedium*, *Incarvillea*, *Micromeria*, *Clinopodium*, *Miscanthus*, *Woodwardia*, *Imperata*, *Lespedeza*, *Rubus*, *Pyracantha*, *Indigofera*, *Rhamnus*, *Rhus*, *Betula*, *Rhododendron*, *Sophora*, *Cotoneaster*, *Helianthus*, *Ipomoea*, *Millettia*, *Periploca*, *Parthenocissus*, *Dalbergia*, *Trachelospermum*, *Clematis*, *Ficus*	*Cymbopogon goeringii*, *Aneilema malabaricum*, *Juncus effuses*, *Heteropogon contortus*, *Setaria viridis*, *Eremochloa ophiuroides*, *Capillipedium parviflorum*, *Incarvillea arguta*, *Micromeria biflora*, *Clinopodium megalanthum*, *Miscanthus floridulus*, *Woodwardia japonica*, *Imperata cylindrical*, *Carex bristachya*, *Lespedeza virgata*, *Rubus corchorifolius*, *Pyracantha fortuneana*, *Indigofera tinctoria*, *Rhamnus calcicolu*, *Rhus chinensis*, *Betula luminifera*, *Rhododendron simsii*, *Sophora tonkinensis*, *Ficus tikoua*, *Cotoneaster hjelmqvistii*, *Helianthus annuus*, *Ipomoea batatas*, *Millettia dielsiana*, *Periploca calophylla*, *Parthenocissus heterophylla*, *Dalbergia hancei*, *Trachelospermum axillare*, *Clematis uncinata*, *Ficus tikoua*
Fruit forest	Cupressaceae, Taxodiaceae, Rosaceae, Eucommiaceae, Juglandaceae, Fabaceae, Salicaceae, Ginkgoaceae, Bignoniaceae, Rutaceae, Lauraceae, Meliaceae	*Cunninghamia*, *Cunninghamia*, *Prunus*, *Eucommia*, *Juglans*, *Pyrus*, *Cladrastis*, *Populus*, *Ginkgo*, *Catalpa Scop*, *Catalpa*, *Cinnamomum*, *Cupressus*, *Toona*	*Cupressus funebris*, *Cunninghamia lanceolata*, *Cerasus pseudocerasus*, *Prunus* spp., *Eucommia ulmoides*, *Juglans regia*, *Pyrus* spp., *Cladrastis platycarpa*, *Populus* spp., *Ginkgo biloba*, *Catalpa bungei*, *Citrus reticulate*, *Cinnamomum bodinieri*, *Cupressus funebris*, *Populus adenopoda*, *Toona sinensis*, *Pyrus pyrifolia*

Table 3 Plant diversity index under different restoration modes.

Vegetation types	Species richness index	Simpson's diversity index	Shannon–Wiener index	Species evenness
Arbour forest	69	2.71	10 .93	6.64
Shrub forest	43	1.92	7.28	5.27
Grassland	23	0.92	3.82	1.11
Shrub grassland	31	1.63	5.16	3.67
Fruit-bearing forest	25	1.03	3.06	0.93

Discussion

After researching and analysing communities at different vegetation succession stages of grassland, shrub grassland, shrub forest, forest and fruit forest, a wider diversity of species in the karst area of Puding was found. Superior humidity and temperature, rich flora and geographical elements, distinctiveness of the habitat, diversity and complexity of the structure, and high heterology of the small habitats make it easy for species with various habits to grow (Koulouri *et al.*, 2007; Ying *et al.*, 2012). Species richness increased successively with vegetation succession and peaked at the forest stage, similar to other studies (Gruchy *et al.*, 2001). At different succession stages, species substitution existed, and the composition of life forms varied. For different vegetation succession stages, different methods were adopted for vegetation recovery, and different species were selected for afforestation (Yan *et al.*, 2007). Communities' ecological environment and species composition varied at different vegetation recovery stages, where community structure also differed. Grassland was a community in which the soil circumstance had been badly affected and was no longer meant for tillage, but from which a few trees and shrubs that were not completely destroyed sprouted from the roots (Harwell *et al.*, 2003). However, this community was distinctive. In contrast to the thin grassland community, the essential soil nutrients remained, and the rocky desertification was not as severe (Hobbs and Norton, 1996). Moreover, large propagules and living shrub roots were preserved in the soil, which meant that most broken woody plants could sprout and grow rapidly after a period, making a full recovery without further damage (Zhu *et al.*, 2013; Du *et al.*, 2011). For this community, sealing measures should be taken as soon as possible to avoid damage by human activity. The shrub grassland community was in the initial stage of vegetation recovery from severe damage (Wan *et al.*, 2001). The simple community structure mainly consisted of drought-tolerant and infertility-tolerant plants, with advantaged species of *Themeda japonica*, *Carex lanceolata* and *Heteropogon contortus*. Dwarf shrubs or subshrubs with good drought tolerance, such as *Campylotropis macrocarpa*, *Hypericum patulum*, *Indigofera pseudotinctoria* and *Elsholtzia rugulosa*, were also common. Due to the rough habitat conditions by severe erosion of water and soil, grazing and other causes, it was difficult for vegetation to recover, and there were few naturally growing dwarf shrubs. For this community, the first thing is to implement is prohibition of grazing to protect it and avoid further degradation. Then, some forest shrubs with good drought tolerance can be planted to recover the community (Zhang *et al.*, 2014).

After extreme degradation from forest to shrub, the community was dotted with a few trees, which had been degraded to shrubs or small trees. Vine shrubs such as *Rosa cymosa*, *Pyracantha fortuneana*, *Rhamnus heterophylla*, and *Zanthoxylum armatum* reigned supreme, and herbaceous plants flourished between the shrubs. If the ecological environment remained good with little effect from human activity, the karst shrubs would be in a succession towards karst forest vegetation; otherwise, they would be in a reverse succession towards thin shrub grasslands (Kinsey, 2013). For vegetation at this stage, management should be improved to prevent damage from human activity (Luzuriaga *et al.*, 2005). Drought-tolerant trees can be planted simultaneously to contribute to the process of forward succession. The forest-shrubbery transition was mostly a stage where the extremely degraded communities were in a gradual succession towards secondary forest, and the quantity of forest species increased largely compared to those of the previous stages (Zedler & Callaway, 1999). For vegetation at the forest-shrubbery transition and secondary forest stages, sealing the mountains for preservation may be the key effort. These forest and shrub species have individual requirements of physical geography boundaries and soil texture; thus, contrasting selection of the geographical factors and optional species of the restoration area should be made for vegetation recovery.

Conclusion

Based on field investigation, there were 97 families, 230 genera and 382 species of plants recorded in Houzhai Catchment. Species composition varied among different succession stages. Along the process of succession, the plant diversity increased, and the species richness index and Simpson's diversity index were as follows: arbour forest > shrub forest > shrub grassland > fruit-bearing forest > grassland. The species evenness and Shannon–Wiener index were as follows: arbour forest > shrub forest > shrub grassland > grass > fruit-bearing forest. In different stages of vegetation succession in the karst area, the measures taken for the restoration of vegetation and afforestation should be based on the specific species. In summary, promoting the succession of vegetation is good for increasing species diversity in the Houzhai catchment, and special attention should be paid to the cultivation of fruit-bearing forests due to low species diversity, which is of great importance to the health and stability of forest ecosystems.

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