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Vegetation Community Characteristics Under Different Vegetation Eco-restoration Techniques at Xiangjiaba Hydropower Station

B.Q. Zhao*(**), R.Z. Gao*(**), D. Xia, L. Xia*(**), W.Q. Zhu*(**) and W.N. Xu *(**)†**

*Key Laboratory of Disaster Prevention and Mitigation, China Three Gorges University, Yichang, Hubei 443002, China

**Engineering Research Center of Eco-environment in Three Gorges Reservoir Region, Ministry of Education, China Three Gorges University, Yichang, Hubei 443002, China

†Corresponding author: Wennian Xu; xwn@ctgu.edu.cn

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ABSTRACT

The objective of this study is to understand the characteristics of vegetation communities under different vegetation eco-restoration models (vegetation concrete eco-restoration technique, frame beam filling soil technique, thick layer base material spraying technique, and external soil spray seeding technique). Vegetation coverage, dominant species, species composition, and species diversity of vegetation community under different vegetation eco-restoration modes were analyzed by field survey. The vegetation community of the abandoned slag slope was unstable due to the simple vegetation community structure. The species and number of the thick layer base material spraying slope were low and fail to form a healthy multilayer community structure due to invade of *Leucaena leucocephala* (Lam.) de Wit. Studying the allelopathy of *Leucaena leucocephala* (Lam.) de Wit and seeking the best species composition that can coexist with it is significant to promote the positive succession of the vegetation community. The frame beam filling soil technique, external-soil spray seeding technique, and vegetation concrete eco-restoration technique can effectively promote the succession process of the vegetation community and have well water and soil conservation capacity. These findings suggest that artificial vegetation eco-restoration measures can effectively promote vegetation eco-restoration and the positive succession of vegetation community of disturbed slopes. The research results can provide scientific advice for vegetation eco-restoration and subsequent control and management of disturbed slopes in the Xiangjiaba project, and also can be helpful to other similar projects.

INTRODUCTION

Engineering disturbance can bring serious environmental problems (Ghanbarpour & Hipel 2009, Cao et al. 2018). However, a large number of hydropower stations have been built because of the demand for clean energy (Zhou & Chen 2012, Wang et al. 2019, Gyanwali et al. 2020). The construction of a hydropower station changes the surface structure on a large scale and results in vegetation destruction and strong ecosystem disturbance (Sati 2015). Take Xiangjiaba hydropower station as an example, the disturbed area accounts for more than 50% of the total construction area (Zhou et al. 2016, Xue et al. 2016a). The excavation disturbance results in the original overburden stripping and backfilling disturbance of the slope to form a loose exposed slope body, and the degradation of the slope ecosystem is extremely prominent, which affects the ecological environment and landscape of hydropower development projects (Li et al. 2018a). Therefore, it has become a key topic to reconstruct the vegetation of the disturbed slope of hydropower projects on the premise of ensuring the safety of the project (Cao et al. 2010, Xu et al. 2017). Though the instability of slope can be solved by traditional slope treatment methods, it is difficult to restore the natural vegetation and ecosystem functions. Vegetation eco-restoration technology can meet the demands of slope stability and vegetation reconstruction (Xu et al. 2006, Zhao et al. 2017). The vegetation restoration of disturbed slope should be carried out on the premise of fully considering the site conditions and restoration objectives. Healthy vegetation ecosystems are reconstructed by adopting artificial vegetation eco-restoration measures (Alday et al. 2010). A large number of scholars have studied the vegetation restoration of different engineering disturbed slopes from aspects of vegetation restoration technology selection, species allocation model, and vegetation succession law (Chiu 2004, Zhang et al. 2013, Xue et al. 2016b, Chen et al. 2018). The suitability of species for colonization should be taken into account when a plant is selected to use in vegetation restoration. Abiotic conditions, such as soil salinity, soil moisture, hydric stress, and limiting nutrients, could hinder plant establishment of the selected species (Tormo et al. 2006). Both vegetation type and its effect on controlling soil erosion should be considered when implementing vegetation restoration (Duan et al. 2016). Matesanz & Valladares (2007) carried out a multispecies controlled experiment simulating eight different communities with species typically used in the revegetation of gypsum motorways slopes and found that the selection of the species to use in gypsum motorway slopes is crucial for the outcome of the vegetation restoration. Inadequate species selection can render poor results in the long term, and appropriate native species could allow more gradual and stable colonization of the slopes (Matesanz & Valladares 2007). Bochet & García-Fayos (2015) built a large database of 296 species 10 traits based on the leaf, seed, and root measurements for selecting suitable species based on morphological and functional plant traits. Vegetation growth can effectively reduce soil erodibility of steep gully slope lands in semi-arid regions, and grassland is more effective than shrub on vegetation-restored gully slope lands on the Loess Plateau (Zhang et al. 2019). Grasses should be prioritized for the improvement of soil conditions during the implementation of vegetation restoration projects in highly fissured areas (Peng et al. 2020). Herbaceous-only vegetation restoration is not suitable for long-term restoration on disturbed slopes, whereas the composition of herbs, shrubs, and trees is a better vegetation construction model for the ecological restoration of disturbed slopes (Li et al. 2018b). To study the vegetation community structure characteristics of the engineering disturbed slope, this study takes the vegetation communities under different vegetation eco-restoration modes in the Xiangjiaba engineering disturbed area as the research object. By analyzing the vegetation community classification, species composition, and species diversity under different vegetation restoration modes, we can understand the structural characteristics of vegetation communities under different vegetation eco-restoration models, reveal the adaptive mechanism of vegetation communities constructed by artificial vegetation eco-restoration techniques to the habitat conditions in the disturbed area of Xiangjiaba project. The research results can provide a theoretical basis for the ecological restoration of the disturbed slope.

MATERIALS AND METHODS

Description of Experimental Sites

The study was conducted at Xiangjiaba hydropower station, which is located at the convergence of Sichuan and Yunnan provinces, southeast of China. The experimental sites are in the upper Yangtze River's primary preventative region for soil and water conservation. The area is characterized by a subtropical monsoon climate with an annual average precipitation of 1078 mm, and approximately 90% of the total precipitation occurs between May and October. We considered typicality in vegetation eco-restoration technique and similarity in evolutionary time when selecting the sites. The selected experimental sites were vegetation concrete eco-restoration slope (VC), frame beam filling soil slope (FB), thick layer base material spraying slope (TB), external-soil spray seeding slope (SS), abandon slag slope (AS), and natural forest (NF). A brief description of the study sites is presented in Table 1. The unrestored disturbance site (AS) and the undisturbed site (NF) were served as control and used for comparison with those from the disturbed site to determine whether the vegetation eco-restoration technique had an effect on vegetation community characteristics.

Methods of Vegetation Investigation

The combination of field survey and quadrat sampling method was used to investigate vegetation community in all plots. 5 m × 5 m quadrats of tree and shrub layer or 1 m × 1 m quadrats of herb layer were set in every plot according to the types of vegetation, and quadrat was set 5 times repeatedly. The total coverage, name of each plant, fractional coverage, growth forms, average height, and plants numbers were recorded in every quadrat. The important values of different species are calculated according to the results of the quadrat investigation and the related data recorded in every quadrat (Xia 2010, Niu 2013, Liu et al. 2016).

$$IV = \frac{RH + RF + RC}{3} \quad \ldots(1)$$

Table 1: A brief description of the study sites.

Site	Technique	Latitude	Longitude	Altitude (m)	Slope gradient (º)	Eco-restoration time
VC	Vegetation concrete eco-restoration technique	28°38′N	104°24′E	328.50	63	2004.12
FB	Frame beam filling soil technique	28°38′N	104°24′E	288.9	40	2004.11
TB	Thick layer base material spraying technique	28°38′N	104°26′E	388.9	51	2004.12
SS	External-soil spray seeding technique	28°39′N	104°23′E	473.9	30	2005.06
AS	Abandon slag slope	28°38′N	104°24′E	520.5	42	
NF	Natural forest	28°39′N	104°23′E	502.4		

Where *IV* is an important value, *RH* is the ratio of the height of a plant species to the height of all plant species in the quadrat, *RF* is the ratio of the frequency of a plant species to the frequency of all plant species in the quadrat, *RC* is the ratio of the coverage of a plant species to the fractional coverage of all plant species in the quadrat. The diversity of the vegetation community is calculated by the following equation in Table 2 (Xia 2010, Niu 2013, Liu et al. 2016).

RESULTS AND DISCUSSION

Coverage and Species Composition of Vegetation Community

Vegetation coverage is the most visual influence of engineering disturbance on the environment. As shown in Fig. 1, vegetation coverage on the disturbed slope of Xiangjiaba hydropower station changed from 45.0% to 97.0%. The veg-

Table 2: Formula used to calculate vegetation community diversity index.

Vegetation community diversity index		Formula
The species diversity index of vegetation community	*Shannon-Wiener* diversity index (SW)	$SW=-\sum_{i=1}^{S} P_i \ln P_i$
	Simpson diversity index (SP)	$SP=1-\sum_{i=1}^{S} (P_i)^2$
	McIntosh diversity index (MI)	$MI=\frac{N-\sqrt{\sum_{i=1}^{S}(N_i)^2}}{N-\sqrt{N}}$
The species richness index of vegetation community	*Margalef* richness index (MA)	$MA=(S-1)/\ln N$
	Menhinick richness index（ME）	$ME=S/\sqrt{N}$
	Monk richness index (MO)	$MO=S/N$
The species evenness index of vegetation community	*Pielou* evenness index(J_{SW})	$J_{SW}=SW/\ln S$
	Alatato evenness index(J_A)	$J_A=\frac{\left(\sum_{i=1}^{S}(P_i)^2\right)^{-1}-1}{\exp(SW)-1}$
	Simpson evenness index(J_S)	$J_S=\frac{SP}{1-1/S}$
The similarity diversity index of vegetation community	*Jaccard* similarity diversity(JC)	$JC=\frac{a}{(b+c)-a}$
	Sorensen similarity diversity(SR)	$SR=\frac{2a}{b+c}$
	Mountford similarity diversity(MT)	$MT=\frac{2a}{2bc-ab-ac}$

Note: S is the numbers of plant species in the quadrat, $P_i = N_i/N$ is the ratio of the individual numbers of species *i* to the individual numbers of all species, N_i is the individual numbers of species *i*, N is the individual numbers of all species in the quadrat, *a* is the numbers of the same plant species in two quadrants, and b and c is the numbers of all plant species in two quadrants.

etation coverage of FB was 96.1%, which is slightly higher than the vegetation coverage of other artificial sample sites. Based on the statistical analysis of families, genera, and species, the vegetation community in different vegetation eco-restoration modes has been preliminarily analyzed (Table 2). The vegetation community of NF was belonging to 18 families, 22 genera, and 23 species. The vegetation community of AS was a total of 8 families, 14 genera, and

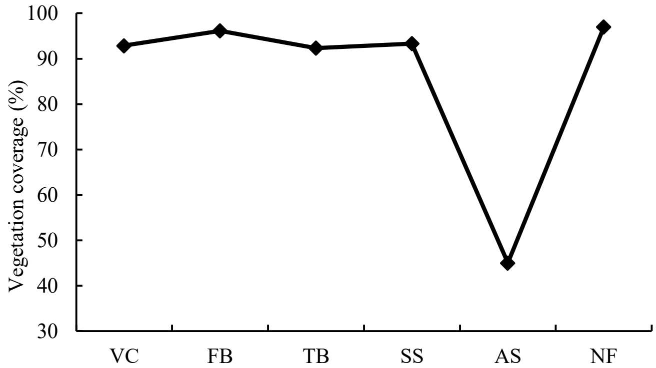

Fig.1: Vegetation coverage in different vegetation eco-restoration modes.

Table 3: Family, genus, and species in different vegetation eco-restoration modes.

Number	Latin name	Site					
		VC	FB	TB	SS	AS	NF
1	*Liliaceae*						1/1
2	*Plantaginaceae*				1/1		
3	*Labiatae*	1/1			1/1		
4	*Euphorbiaceae*		2/2				
5	*Aquifoliaceae*						1/1
6	*Leguminosae*	4/4	4/4	3/3	2/2		2/2
7	*Pteridaceae*			1/1			
8	*Lygodium*		1/1	1/1	1/1		1/1
9	*Gramineae*	4/4	10/11	3/3	5/5	4/4	2/2
10	*Betulaceae*						1/1
11	*Malvaceae*		1/1				
12	*Compositae*	1/1	6/6		3/3	3/3	
13	*Fagaceae*						1/1
14	*Gesneriaceae*		1/1		1/1	1/1	
15	*Gleicheniaceae*				1/1		1/1
16	*Malvaceae*		1/1				
17	*Polygonaceae*				1/1		
18	*Lindsaeaceae*						1/1
19	*Asclepiadaceae*		1/1				
20	*Verbenaceae*	2/2	2/2				
21	*Loganiaceae*		1/1				
22	*Ranunculaceae*						1/1
23	*Equisetaceae*				1/1		

Table cont....

Number	Latin name	Site					
		VC	FB	TB	SS	AS	NF
24	*Lythraceae*				1/1		
25	*Rosaceae*		1/1		1/1		2/2
26	*Solanaceae*		1/1				
27	*Caprifoliaceae*						1/1
28	*Umbelliferae*		1/1		1/1		
29	*Moraceae*	1/1	3/3	1/1		1/1	
30	*Cyperaceae*						1/1
31	*Theaceae*						2/3
32	*Phytolaccaceae*	1/1					
33	*Pinaceae*						1/1
34	*Oleandracea*		1/1	1/1	1/1	1/1	
35	*Amaranthaceae*	1/2	1/1			2/2	
36	*Scrophulariaceae*					1/1	1/1
37	*Urticaceae*		1/1				
38	*Commelinaceae*		1/1				
39	*Rutaceae*					1/1	1/1
40	*Lauraceae*						1/1
41	*Oxalidaceae*		1/1		1/1		
Total (family)		8	20	6	15	8	18
Total (genus)		15	41	10	22	14	22
Total (species)		16	42	10	22	14	23

15 species, and much simpler than NF. The FB had the most plant species in artificial vegetation eco-restoration sites and totaled 20 families, 41 genera, and 42 species, and 40% of the total number of species were *Gramineae* and *Compositae*. The TB had the simplest species, and belonging to 6 families, 10 genera, and 10 species. And the dominant species were *Gramineae* and *Leguminosae*, making up for 60% of the total species.

Growth Forms of Vegetation Community

The growth forms of vegetation community under different vegetation eco-restoration modes were shown in Fig. 2 and classified by trees, shrubs, lianas, perennial herbs, and annual herbs or biennial herbs. Growth forms of different vegetation eco-restoration modes were different significantly. Perennial herbs and shrubs accounted for 43.75% and 31.25% of the vegetation community in VC, respectively. Perennial herbs accounted for 42.86% of the vegetation community in FB. The growth forms of the vegetation community in VC and FB were diverse and included all five growth forms. There were only trees, perennial herbs, and annual herbs or biennial herbs, and herbs were dominant and accounted for 78.57% of total species in AS. There were trees, shrubs, perennial herbs, and annual herbs or biennial herbs in TB, and the quantities of trees, shrubs, and annual herbs or biennial herbs were almost equal. There were only trees, shrubs, perennial herbs, and annual herbs or biennial herbs in SS. Perennial herbs were dominant and accounted for 59.09% of the total species, and trees and lianas only accounted for 9.09% in total. Trees and shrubs were dominant in NF, and shrubs, trees, and perennial herbs accounted for 34.78%, 30.43%, and 26.09%, respectively.

Important Value of Plant Species

As shown in Table 4, the species composition of vegetation communities in different vegetation eco-restoration modes was surveyed, and vegetation species of all plots were 87 in total. Plant species composition and dominant species were obviously different. Some initial herb species disappeared gradually in VC, FB, and SS, and the importance value of some alien invasive species was increasing, especially some trees, shrubs, and lianas, and the vegetation community began to change from herb layer to herbs-shrubs-lianas layer. The dominant species of TB was *Leucaena leucocephala* (Lam.)

de Wit with an importance value of 57.14%. Some initial species in TB disappeared gradually, such as *Festuca elata* Keng ex E. Alexeev, *Medicago sativa* L., and *Cynodondactylon* (Linn.)Pers. The importance values of invasive species *Broussonetia papyrifera* (L.) L'Hér. ex Vent. and *Sophora xanthantha* C. Y. Ma was 9.46% and 5.61%, respectively. The important value of dominant species *Alnus cremastogyne* Burk. was 12.21% in NF.

The Diversity Indexes of Vegetation Community

As shown in Fig. 3, the species diversity index of vegetation communities in different vegetation eco-restoration modes was different, but the highest value of species diversity indexes appeared in NF. The lowest *Shannon-Wiener* diversity index appeared in VC. The changing trend of the *McIntosh* diversity index and *Simpson* diversity index were similar in all plots. The lowest species diversity index occurred in AS. The change trends of species richness indexes of all plots were basically identical (Fig. 4). The highest value of the *Margalef* diversity index and *Menhinick* diversity index appeared in FB, and the lowest value of the *Margalef* diversity index and *Menhinick* diversity index appeared in TB. The *Monk* diversity index of NF (0.223) was the highest, and the *Monk* diversity index of TB (0.075) was the lowest. *Simpson* evenness index and *Alatato* evenness index in NF were both the highest, but *Simpson* evenness index and *Alatato* evenness index of the abandon slag slope (AS) were both the lowest (Fig. 5). The *Pielou* evenness index of NF was the highest (0.923), and the *Pielou* evenness index of VC was the lowest (0.498). As shown in Table 5, the range of *Jaccard* similarity index, *Sorensen* similarity index, and *Mountford* similarity index was 0.000~0.244, 0.000~0.393, and 0.000~0.043 respectively. The lowest size of the three similarity indexes all appeared between VC and NF.

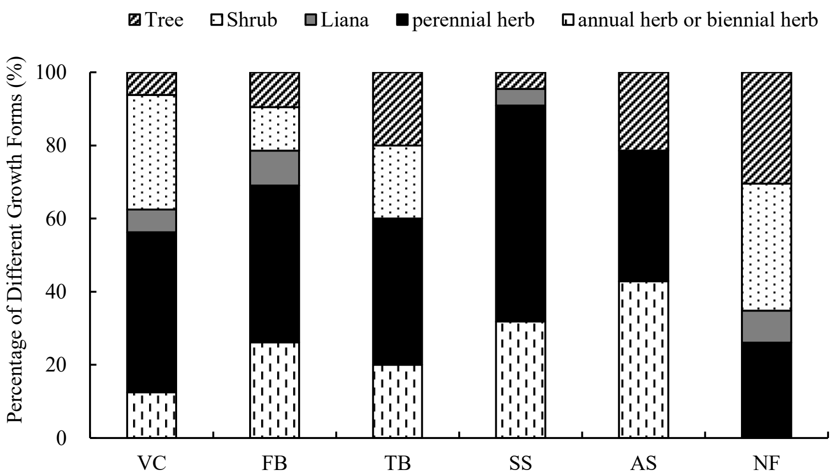

Fig. 2: Growth forms of vegetation community in different vegetation eco-restoration modes.

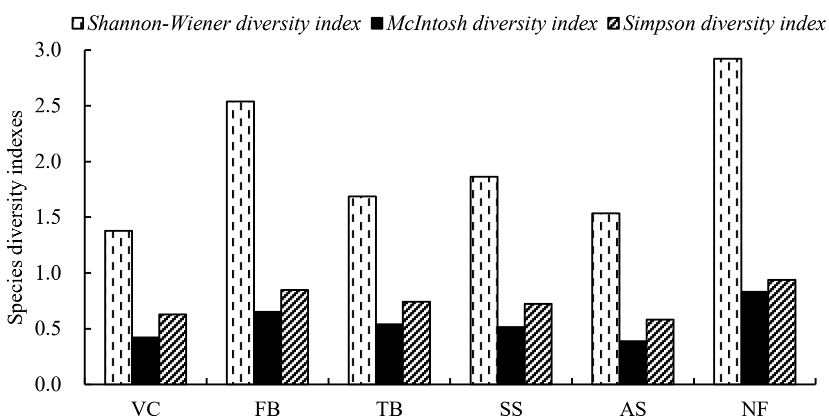

Fig. 3: Species diversity indexes of vegetation community in different vegetation eco-restoration modes.

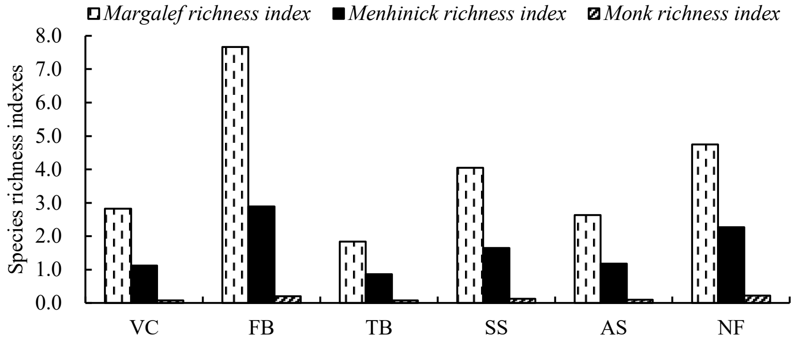

Fig. 4: Species richness indexes of vegetation community in different vegetation eco-restoration modes.

DISCUSSION

Vegetation community characteristics can be used as a measuring index to describe the process of vegetation restoration (Wang et al. 2012). And according to a large number of studies, vegetation community characteristics include vegetation coverage, species composition, dominant species, and species diversity (Ding & Zang 2005, Ruiz-Jaen & Aide 2010, Wortley et al. 2013). Vegetation coverage is an important index to evaluate the growth status of vegetation communities and the ability of conservation of soil and water, and low vegetation coverage is easier to lead to soil erosion than high vegetation coverage (Yuan et al. 2016, Chen et al. 2019). There was a litter difference between artificial vegetation eco-restoration plots in vegetation coverage, which basically reached the level of vegetation coverage of NF. However, there were differences in community species composition among various plots. Species composition is an important index to describe community characteristics (Ding & Zang 2005). The number of species in FB (20 families, 41 genera, and 42 species) increased greatly compared to AS, but the plants were primarily herb and accounted for 69.05% of the total species. The species composition among artificial vegetation eco-restoration plots was different but was dominant by perennial plants all, and vegetation community structure began to change from herb layer to herbs-shrubs-lianas layer mixed. Perennial plants being dominant, especially the trees and shrubs showed that the vegetation community is stable (Fike & Niering 1999). The important value of the dominant species reflects the complexity of vegetation community structure, and dominant species influence both species and functional composition of the vegetation community (Kompala-Baba et al. 2020). The important value of a dominant species called *Leucaena leucocephala* (Lam.) de Wit was far higher than other accompanying species in TB, which showed that the complexity of vegetation community structure was low. The invasive plants can affect native plants by producing allelochemicals (Mignoni et al. 2017).

The α diversity is an important index to describe community characteristics, which include species diversity indexes, species richness index, and species evenness index (Zhang et al. 2005, Wang et al. 2006). The α diversity level of vegetation community was discussed from three aspects: the number of species, the individual difference of species, and the evenness of species distribution (Zhang et al. 2005,

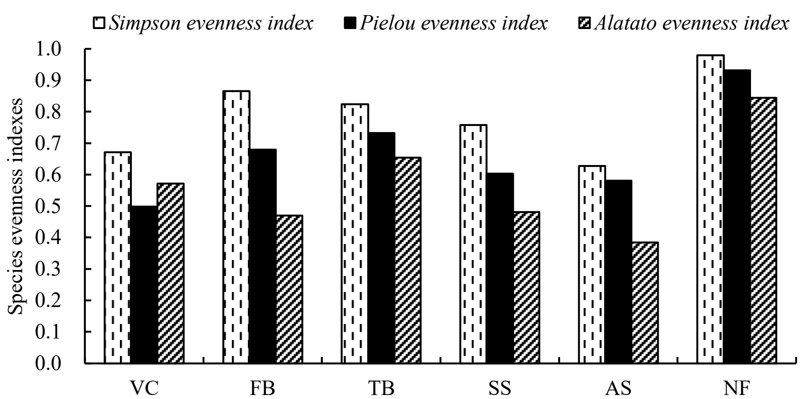

Fig. 5: Species evenness indexes of vegetation community in different vegetation eco-restoration modes.

Table 4: Species composition and important value of vegetation community in different vegetation eco-restoration modes.

Number	Latin name	*IV* (%)					
		VC	FB	TB	SS	AS	NF
1	*Artemisia argyi* Levl. et Van.		4.42			4.72	
2	*Smilax china*						1.33
3	*Imperata cylindrica* (L.) Beauv.		11.47		15.49	3.98	
4	*Saccharum arundinaceum* Retz.	4.30					
5	*Plantago depressa* Willd.				1.96		
6	*Clerodendrum bungei* Sterd.	2.88	1.23				
7	*Solanum torvum* Swartz		1.00				
8	*Euphorbia humifusa* Willd. ex Schlecht.		0.59				
9	*Ilex chinensis* Sims						4.25
10	*Indigofera amblyatha*	6.49					
11	*Commelina bengalensis*		0.93				
12	*Urena procumbens* Linn.		1.50				
13	*Pteris cretica* Linn. var. *nervossa* (Thunb.)Ching et S.H.Wu			5.57			
14	*Festuca elata* Keng ex E. Alexeev				6.89		
15	*Pueraria lobata* (Willdenow) Ohwi	8.74	3.26		5.23		
16	*Setaria viridis* (L.) Beauv.		1.11			15.66	
17	*Broussonetia papyrifera* (L.) L'Hér. ex Vent.	7.68	4.58	9.46		6.50	
18	*Lygodium japonicum* (Thunb.)Sw.		3.81	3.42	1.82		1.19
19	*Albizia julibrissin* Durazz.						6.55
20	*Polygonum orientale* L.				2.93		
21	*Lespedeza bicolor* Turcz.	2.94		4.73			
22	*Zanthoxylum bungeanum* Maxim.					10.75	
23	*Artemisia annua*				3.72		
24	*Sophora xanthantha* C. Y. Ma	2.46		5.61			
25	*Themeda villosa* (Poir.) A. Camus		1.13				
26	*Pogonatherum crinitum* (Thunb.) Kunth				2.28		
27	Lonicera japonica Thunb.						1.59
28	*Arthraxon hispidus* (Thunb.) Makio	11.81	7.83	4.95	3.39	3.86	
29	*Citrus reticulata*						1.87
30	*Alternanthera philoxeroides*	1.69					
31	Conandron ramondioides S. et Z.		0.86		2.90	2.49	
32	*Melia azedarach* Linn.		3.41				
33	*Pennisetum alopecuroides* (L.) Spreng.	25.61	1.42				
34	*Diplopterygium glaucum* (Thunb. ex Houtt.) Nakai				7.08		2.49
35	*Quercus mongolica* Fisch. ex Ledeb.						4.92
36	*Arundo donax*	4.19					
37	*Metaplexis japonica* (Thunb.) Makino		1.45				
38	*Humulus japonicus*		0.64				
39	*Digitaria sanguinalis* (L.) Scop.		1.68	4.31	1.91	2.74	
40	*Pinus massoniana* Lamb.						6.96
41	*Alternanthera sessilis* (L.) DC.	3.64	1.98			5.58	
42	*Miscanthus sinensis* Anderss.		1.52				1.59
43	*Paulownia tomentosa* (Thunb.) Steud.					7.55	7.09
44	*Vitex negundo* L.	9.39	0.91				
45	*Eleusine indica* (L.) Gaertn.		0.63				
46	*Rubus hirsutus* Thunb.						3.35

Table cont....

Number	Latin name	IV (%)					
		VC	FB	TB	SS	AS	NF
47	*Ficus tikoua* Bur.		0.93				
48	*Alnus cremastogyne* Burk.						12.21
49	*Leptochloa chinensis* (L.) Nees		1.17				
50	Senecio scandens Buch.-Ham. ex D. Don				2.65		
51	*Carex breviculmis* R. Br.						2.52
52	*Celosia argentea* L.					3.57	
53	*Oplismenus undulatifolius* (Arduino) Beauv.			9.54			
54	*Bidens pilosa* Linn.		2.89			5.28	
55	*Camellia japonica* L.						5.18
56	*Lindera glauca* (Sieb. et Zucc.) Bl						5.76
57	*Phytolacca acinosa* Roxb.	2.76					
58	*Cnidium monnieri* (L.) Cuss.		0.90				
59	*Nephrolepis cordifolia* (L.)Presl		2.03	3.84	1.91	3.54	
60	*Mosla scabra* (Thunb.) C. Y. Wu et H. W. Li	2.32					
61	*Hydrocotyle sibthorpioides* Lam.				2.31		
62	Sesbania cannabina (Retz.) Poir.		1.53		2.37		
63	*Potentilla chinensis* Ser.				2.00		
64	*Equisetum arvense* L.				2.23		
65	*Sapium sebiferum* (L.) Roxb.		2.71				
66	*Sphenomeris chinensis* (L.) Maxon						2.72
67	*Miscanthus floridulus* (Lab.) Warb. ex Schum. et Laut.		1.80				
68	*Capillipedium parviflorum* (R. Br.) Stapf.		9.73				
69	*Eurya nitida* Korthals						2.65
70	Prunella vulgaris L.				1.82		
71	*Conyza canadensis* (L.) Cronq.		4.01		2.77	5.45	
72	*Boehmeria spicata* (Thunb.) Thunb.		2.55				
73	*Cirsium setosum* (Willd.) MB.		1.21				
74	*Leucaena leucocephala* (Lam.) de Wit			57.14			
75	*Rosa rubus* Lévl. et Vant.		2.16				
76	*Paeonia delavayi* Franch.						3.65
77	*Rosa multiflora* Thunb.						2.76
78	*Erigeron annuus* (L.) Pers.		0.69				
79	*Camellia oleifera* Abel.						3.73
80	*Caesalpinia decapetala* (Roth) Alston		1.30				
81	*Crotalaria pallida* Ait.		0.77				
82	Oplismenus compositus (L.) Beauv.						2.83
83	*Eupatorium coelestinum* L.	3.09	1.30				
84	*Wisteria sinensis*						4.46
85	*Lagerstroemia indica* L.				22.90		
86	*Buddleja lindleyana*		3.15				
87	*Oxalis corniculata* Linn.		0.78		1.21		

Liu 2015). As a result of the positive succession of the vegetation community, the α diversity increased. (Wang et al. 2006). The results of the α diversity indexes embody the structure and complex degree of vegetation community, and artificial vegetation eco-restoration patterns can promote the recovery of vegetation community effectively (Pueyo et al. 2006). The β diversity indexes of vegetation communities focus on reflecting the different degrees of species structure and composition among different vegetation communities and expressing heterogeneity among communities (Han et al. 2009). Results of this study showed that species composition among all plots was different, especially between

Table 5: Species similarity indexes among vegetation communities in different vegetation eco-restoration modes.

Site	Species similarity indexes		
	Jaccard similarity index	Sorensen similarity index	Mountford similarity index
VC-FB	0.160	0.276	0.018
VC-TB	0.182	0.308	0.037
VC-SS	0.056	0.105	0.006
VC-AS	0.111	0.200	0.017
VC-NF	0.000	0.000	0.000
FB-TB	0.106	0.192	0.017
FB-SS	0.185	0.313	0.017
FB-AS	0.244	0.393	0.039
FB-NF	0.032	0.062	0.002
TB-SS	0.143	0.250	0.026
TB-AS	0.200	0.333	0.043
TB-NF	0.031	0.061	0.005
SS-AS	0.200	0.333	0.030
SS-NF	0.047	0.089	0.004
AS-NF	0.028	0.054	0.003

NF and artificial vegetation eco-restoration plots, and the disturbed vegetation community needs a long time to return to the natural level.

Decrease or even loss of soil and water conservation function is a prominent problem of engineering disturbed slope while increasing the surface vegetation coverage is the most direct and effective method to control soil erosion (El Kateb et al. 2013, Wang et al. 2016). Numerous studies have shown that community structure with primary near-surface herbs can effectively intercept rainfall and weaken the role of rainwater erosion through the interception precipitation and extend infiltration time to reduce slope runoff (Zhou & Shangguan 2008, Du et al. 2017, Zhang et al. 2017, Gao et al. 2020). Vegetation coverage of the four artificial vegetation eco-restoration sample sites increased obviously than AS, especially in VC and FB which herbaceous were main dominant species. Therefore, it can be considered that the vegetation concrete eco-restoration technology, the frame beam filling soil technology, and the external-soil spray seeding technology can improve soil and water conservation function of engineering disturbed slope effectively. In TB, *Leucaena leucocephala* (Lam.) de Wit resulted in the species and quantity of vegetation community is low, and fail to form the healthy multilayer community structure. Therefore, the surface vegetation coverage of TB was much lower than the other three artificial vegetation eco-restoration sample sites. Studying the allelopathy of *Leucaena leucocephala* (Lam.) de Wit and seeking the best species composition that can coexist with it is significant to promote the positive succession of the vegetation community in TB. It is also of great significance to improve the soil and water conservation function of the disturbed slope.

CONCLUSIONS

The results of field investigation and analysis undertaken in disturbed slopes at Xiangjiaba hydropower station have revealed that there was a big difference in vegetation community characteristics between different vegetation eco-restoration modes. The vegetation coverage, species numbers, growth type composition, and family, genus, and species of vegetation community of AS were significantly lower than that of artificial vegetation eco-restoration slopes and NF. The simple vegetation community structure indicates that the vegetation community of AS was unstable. The absolute advantage of the two perennial plants indicates that the vegetation community of VC is in a stable state. The species and number of TB were low and fail to form a healthy multilayer community structure due to the invasion of *Leucaena leucocephala* (Lam.) de Wit. It is significant to study the allelopathy of *Leucaena leucocephala* (Lam.) de Wit and seek the best species composition that can coexist with it. The frame beam filling soil technique, external-soil spray seeding technique, and vegetation concrete eco-restoration technique can effectively promote the succession process of the vegetation community. And the absolute advantage of herbs in FB, SS, and VC can also prove that these three techniques have good water and soil conservation capacity.

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