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Ecological Restoration Technology and Benefit Assessment of Karst Rocky Desertification Mountains in Xixiu District of Anshun City

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Abstract Ecological restoration refers to the containment of soil erosion, restoration of water conservation, climate regulation, maintenance of ecological functions of biodiversity, and improvement of ecological environment and landscape pattern based on self-repairing capacity of the nature and combined with appropriate artificial measures. Since the natural restoration process of karst desertification mountain is very long, it needs to be supplemented by artificial vegetation restoration. This paper introduced the ecological restoration technologies implemented in karst rocky desertification mountains in Xixiu District, Anshun City of Guizhou Province, and also introduced the afforestation tending management measures. It assessed the ecological benefits of the ecological restoration project from five aspects: mountain community characteristics, vegetation coverage, species diversity, afforestation survival rate and landscape effect.

Key words Karst rocky desertification mountains, Ecological restoration, Technical measures, Benefit assessment, Xixiu District of Anhui City in Guizhou Province

1 Introduction

Karst rocky desertification is a kind of the landscape phenomenon and process similar to desertification caused by improper human activities and natural disturbances, surface vegetation destruction, soil erosion and large exposed area of bedrock in vulnerable habitats of karst areas. Rocky desertification will bring about a series of landscape ecological problems, such as decline of biodiversity, loss of rare animal and plant resources, and lower anti-interference ability. Rocky desertification severely restricts the sustainable development of the local economy and society. All the time, the ecological restoration has been the major work and difficulty of the management of vulnerable habitats of karst areas. Ecological restoration refers to the containment of soil erosion, restoration of water conservation, climate regulation, maintenance of ecological functions of biodiversity, and improvement of ecological environment and landscape pattern based on self-repairing capacity of the nature and combined with appropriate artificial measures. Because the natural restoration process of karst desertification mountain is very long, it needs to be supplemented by artificial vegetation restoration, the ecological restoration measures such as planting trees, planting grass, slope greening, returning farmland to forests and grasses, and accelerating vegetation restoration, to accelerate the vegetation restoration, improve the ecological environment in the karst areas as soon as possible, to solve the problem of rocky desertification.

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2 Vegetation restoration technology

In the process of rocky desertification ecological restoration, vegetation restoration is the key and core and is also one of the important means to improve the ecological environment and increase the forest coverage in karst rocky desertification areas. When implementing the vegetation restoration, apart from selecting tree species that are easy to survive in accordance with local conditions, it is also necessary to consider the adaptability of plants to the environment, drought and water retention capacity.

2.1 Afforestation land cleaning and soil preparation

2.1.1 Afforestation land cleaning. Because there are many weeds in the construction site, it is not favorable for afforestation. In order to eliminate obstacles and create excellent afforestation conditions, it is necessary to clean up the proposed afforestation land and keep the seedlings and saplings on the forest land when cleaning the forest land.

(i) Cleaning modes. Cleaning can be divided into three modes: strip cleaning, clumpy cleaning and comprehensive cleaning. In Xixiu District, the site conditions of mountains are poor, the rocky desertification is serious, the rock exposure rate is high, and the slope of the mountains is 45° -85°. Therefore, we mainly adopted clumpy cleaning, to clean the weeds and shrubs within a radius of 50 cm from the planting point.

(ii) Cleaning methods. There are weeding cleaning, stack cleaning, and chemical cleaning. In this project, we mainly adopted the weeding cleaning, specifically, cutting the surface weeds and shrub stems and leaves in the end of summer and beginning of autumn.

2.1.2 Soil preparation. (i) Soil preparation modes. The slope of the construction site is steep, so we adopted the partial land preparation method to turn the soil of the afforestation land. This mode needs low investment amount, it can partially improve the soil site conditions, maximize the original vegetation, and avoid or reduce soil erosion. The soil preparation modes are mainly hole-shaped soil preparation and scale-shaped pit soil preparation, as shown in Fig. 1.

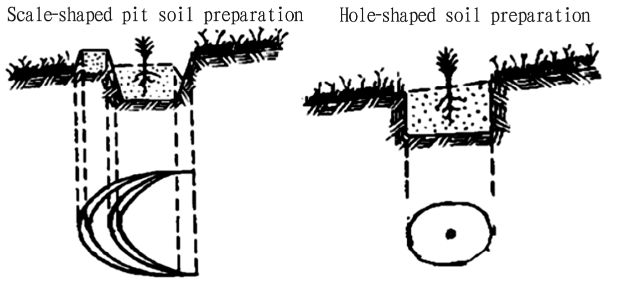

Fig. 1 Schematic drawing for scale-shaped pit and hole-shaped soil preparation

Hole-shaped soil preparation: dig round or square hole with the size depending on the tree species and site conditions. Hole-shaped soil preparation has wide scope of application, and there are not many requirements. It is suitable for afforestation and soil preparation in areas with mild mountain, and serious water and wind erosion.

Scale-shaped pit soil preparation: dig approximately half-moon shape pit. This method is suitable for afforestation and soil preparation in steep and sloping areas in arid and semi-arid areas and in rocky mountains where water storage and soil conservation are required.

(ii) Soil preparation seasons. Soil preparation can be carried out in all seasons, but should be 1 – 2 quarters earlier than the tree planting time.

For example, if trees are planted in autumn, the soil preparation should be carried out in summer or spring; if trees are planted in spring, the soil preparation should be carried out in the precious summer or autumn.

2.2 Plant cultivation

2.2.1 Selection of plants. (i) Plant requirements. Plants selected should have developed roots, many lateral roots and fibrous roots, and roots have a certain length; the stems are thick and straight, with heights commensurate with the thickness, the branches should be fully lignified, the branches are luxuriant, the color is normal, and the top and bottom are uniform; the ratio of height to diameter is small, the center of gravity is low, no pests and diseases are caused, and the conifers should have normal and plump top buds. Before planting, seedlings should be trimmed to increase the survival rate. (ii) Specifications of seedlings. Specifications of arbors: the ground diameter should be greater than 5 cm, and the whole crown is covered with soil balls. Specifications of shrubs: the ground diameter should be about 1 cm, and the seedling height is above 60 cm.

2.2.2 Planting technology. Hole planting is adopted, the hole diameter should be larger than the soil ball or bare root seedling roots for 40 – 60 cm, the hole depth should be 0.75 – 0.80 times the hole diameter. The seedlings are vertical and straight, the roots are stretched, and the depth is appropriate. After the half soil filling, promote seedlings and step firmly, and finally cover the virtual soil (Fig. 2).

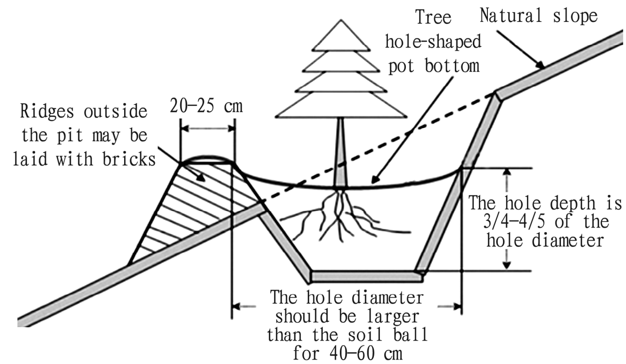

Fig. 2 Schematic drawing for plant cultivation

The plant cultivation is mainly carried out when the ground parts of seedlings stop growing and the roots are close to stop; or the ground parts of the seedlings have not yet grown, and the roots are about to begin to grow in the early spring. The plants with soil ball are not subject to seasonal restrictions, but afforestation in the rainy season is preferred.

2.3 Water conservation and saving measures for vegetation restoration

2.3.1 Water conservation and drought resistance measures. It mainly adopts mulching afforestation technology. Mulching not only increases the ground temperature, but also promotes soil microbial activities, promotes the decomposition of organic matter and nutrient release, which is favorable for the growth and absorption of plant roots, the synthesis and transformation of nutrients, so as to ensure the survival and growth of seedlings, and fully maintaining and utilizing the evaporation of water on the surface. It provides the water necessary for growth after the seedlings survive, preventing the seedlings from dying due to physiological drought.

2.3.2 Water saving and drought resistance measures. It mainly adopts water retention agent, anti-transpiration agent and ABT rooting powder technology.

(i) Water retention agent. The water retention agent for agriculture and forestry can quickly absorb the pure water that has 400 – 500 times of its own volume, and it can be mixed with the soil at a ratio of 1% to the seedling roots. It can absorb and store the rainwater or water that has been evaporated, leaked and lost, to form a "micro-reservoir" and release the water during dry days. Its water retention capacity is up to 13 – 14 kg/cm^2, so the retained water will not flow and leak, and will not be squeezed out by ordinary physical methods. By comparison, the water absorption of common plant roots is 16 – 17 kg/cm^2, so it can be easily absorbed and utilized by plant roots.

The water retention agent absorbs water when the soil moisture is high, and releases water when the soil moisture is low. It can increase soil water storage and water retention performance, improve soil water utilization efficiency, reduce soil water loss, and gradually release moisture when the soil is dry, and extend the water supply time and improve the water supply capacity for plants, so as to increase the survival rate of plants.

(ii) Anti-transpiration agent. S-ABA, also known as abscisic acid, is a stomatal inhibitor that acts on stomatal guard cells, reduces stomatal opening or closes stomata, increases stomatal transpiration resistance, thereby reducing the water transpiration. Its use method is as follows: after the newly planted trees are watered for rooting, dilute this product with 1 500 times of water, and spray on the leaves; 15 – 20 d later, spray again, and not spray the back side of leaves during spraying.

(iii) ABT rooting powder. The ABT rooting powder is used to treat the seedlings, to induce a certain number of adventitious roots in the seedlings, promote the recovery of the injured roots of the plants, and develop new absorption roots faster. Besides, it can accelerate the plant metabolism, accelerate cell division, promote the absorption and transformation of nitrogen, phosphorus and potassium in plants, and improve the resistance of plants themselves.

2.4 Arrangement of planting points

2.4.1 Arrangement principle. The plants are arranged in accordance with the principle of plant types, site conditions, and afforestation density.

2.4.2 Direction of planting row. For afforestation on flat land, planting rows should be in north-south direction; for afforestation on slopes, planting rows should be taken along the contour line; for planting in areas with severe wind damage, planting row should be perpendicular to the prevailing wind direction.

2.4.3 Arrangement methods. (i) Square arrangement: the planting point is arranged at the four vertices of the square. This arrangement method is suitable for timber forest and economic forest. (ii) Rectangular arrangement: generally, the row spacing is greater than the plant spacing, favorable for intercropping and mechanized operation. This arrangement method is suitable for afforestation in plain regions and mechanized afforestation. (iii) Upsidedown T-shaped arrangement: the relative positions of the adjacent plants in the two rows are staggered into an Upsidedown T-shape or an isosceles triangle, and the planting point is located at the vertices of the isosceles triangle. This arrangement method is suitable for ecological public welfare forest. (iv) Equilateral triangle arrangement: the distances of adjacent plants are equal, the row spacing is smaller than the plant spacing, and the planting point is located at the vertices of the equilateral triangle. This is a special case of the upsidedown T-shaped arrangement. This arrangement method is suitable for economic forest. (v) Group arrangement: plants are distributed unevenly on the afforestation land, and the plants in the group are dense (3 – 20 plants), and the distance between the groups is large. This arrangement method is suitable for ecological public welfare forest in areas where the conditions for secondary forest are poor or the site conditions are poor. (vi) Natural arrangement: planting points are randomly arranged on the afforestation land. In this arrangement, there is no regular plant spacing, so it is similar to the forest distribution in natural forests. This arrangement method is suitable for ecological public welfare forest. (vii) Irregular arrangement: irregular planting point arrangement is carried out according to the soil distribution conditions of the afforestation land or the conditions in the forest. This arrangement is suitable for afforestation under stony mountains and crown canopy.

The above arrangement methods should be flexibly selected according to the site conditions of the mountains.

3 Tending management measures

Tending management is an indispensable measure to increase the survival rate of seedlings and promote the growth of seedlings. It mainly includes watering, fertilization, soil loosening, weeding, fire prevention, prevention and control of plant diseases and insect pests.

3.1 Watering in proper time Watering should be carried out during and after afforestation. In order to ensure the irrigation of the newly added forest land, water conservancy facilities may be provided according to the construction conditions, and water-saving irrigation technology can be adopted.

3.2 Proper fertilization

3.2.1 Fertilization principle. Formula fertilization should be adopted promptly, properly and reasonably according to tree species, growing season and soil nutrient conditions.

3.2.2 Use of base fertilizer. Base fertilizer may be used for barren land. The base fertilizer should use fully decomposed organic fertilizer. Before planting, the base fertilizer is applied to the bottom of the pit.

3.2.3 Use of topdressing. Topdressing should adopt compound fertilizer. Topdressing is generally carried out 1 – 3 years after planting.

3.3 Soil loosening and weeding After afforestation, combined with promoting seedlings and removing vines, it is necessary to conduct weeding in time, and remove dense weeds that affect the development of saplings. In the first year, soil loosening and weeding are carried out twice during May and August. Later, the soil loosening in the hole is carried out one time annually. Three years after the afforestation, it is generally required to expand the hole and conduct weeding once a year.

3.4 Fire prevention and plant diseases and insect pest prevention and control It is required to pay special attention to fire prevention and plant diseases and insect pest prevention and control for new afforestation mountains. The prevention and control of plant diseases and insect pests should take the biological prevention and control as the major method, combined with various prevention and control measures, to improve the resistance of forests to various plant diseases and insect pests.

4 Assessment of ecological benefits

The ecological benefits should be assessed on the basis of stable plant communities. Stable plant communities play an important role in environmental improvement and sustainable development in karst rocky desertification areas. Ecological functions of plant communities come mainly from (i) the environmental remediation effects brought by the physiological and biochemical characteristics of the plant materials that constitute the plant community, such as carbon fixation and oxygen release, purification of harmful gases, sterilization, radiation protection, and endothermic transpiration, soil activation and nutrient cycling; (ii) the green ecosystem system constructed by plant communities that is used to alleviate the overall ecological benefits of urban pressure, such as dust resistance and containment, water conservation, humidification and cooling, landscape landscaping, disaster prevention and mitigation, and so on. In this study, we mainly assessed the ecological benefits of the karst rocky desertification mountain ecological restoration project in Xixiu District. We selected four mountains and assessed the ecological benefits from five aspects: plant community characteristics, vegetation coverage, species diversity, afforestation survival rate and landscape effect.

4.1 Community characteristics Through literature review and field survey, we listed the tree species before the ecological restoration and the tree species added after the ecological restoration in Table 1. The number of trees increased in the 10# mountain is the highest, reaching six species, followed by four species in the 21# mountain, then the 17# mountain, increasing by three species, and finally the 3# mountain, increasing by two species. The species of the four mountains have different level of increase. The increase of plant species is favorable for the ecological restoration of the mountains, accelerating the vegetation restoration of the mountains, and curbing the deterioration of rocky desertification in the karst area.

4.1.1 Abundance. Abundance refers to the number of individuals of certain species in a defined location or community. It is a relative indicator of the number of individuals in different species. The species abundance can be surveyed by two methods. One is the direct calculation method, namely, the name calculation method, and the other is the visual estimation method. For 3# mountain, 10# mountain, 17# mountain, and 21# mountain, select two to four 25 m^2 (shrubs) – 100 m^2 (arbors) samples for each mountain, and then directly calculate to evaluate the abundance after planting shrubs and arbors. The results are listed in Table 2.

Table 1 Tree species before and after ecological restoration of mountains

Mountain number	Tree species before restoration	Tree species increased after restoration
3#	*Pyracantha fortuneana*, *Rhus chinensis*, *Nerium oleander*, *Cupressaceae* (*Cupressus duclouxiana*, *Cupressus torulosa*, *Sabina chinensis*, *and Platycladus orientalis*)	*Koelreuteria paniculata*, *Ligustrum* (*arbors and shrubs*)
10#	*Coriaria nepalensis*, *Rhus chinensis Cupressaceae* (*Cupressus duclouxiana*, *Cupressus torulosa*, *Sabina chinensis*, *and Platycladus orientalis*), *Pyracantha fortuneana*, *Rosa roxburghii*, *Nerium oleander*, *Punica granatum*	*Koelreuteria paniculata*, *Cercis chinensis*, *Amygdalus persica*, *Prunus cerasifera Ehrhar* '*Atropurpurea*', *Ginkgo biloba*, *Osmanthus fragrans*
17#	*Pyracantha fortuneana*, *Coriaria nepalensis*, *Cupressaceae* (*Cupressus duclouxiana*, *Cupressus torulosa*, *Sabina chinensis*, *and Platycladus orientalis*), *Rosa roxburghii*, *Rhus chinensis*, *Ligustrum* (*arbors and shrubs*)	*Acer buergerianus*, *Ginkgo biloba*, *Cinnamomum camphora*
21#	*Pyracantha fortuneana*, *Caesalpinia decapetala*, *Nerium oleander*, *Coriaria nepalensis*, *Rhus chinensis*, *Rosa roxburghii*, *Cupressaceae* (*Cupressus duclouxiana*, *Cupressus torulosa*, *Sabina chinensis*, *and Platycladus orientalis*), *Ligustrum* (*arbors and shrubs*), *Caesalpinia decapetala*	*Lagerstroemia indica*), *Koelreuteria paniculata*, *Photinia × fraseri*, *Cassia surattensis*

From Table 2, it can be directly seen that after the four mountains have been ecologically restored, the abundance of plants has increased, indicating that vegetation restoration and plant community improvement have better effect.

4.1.2 Density. According to studies of many scholars, the suitable density of afforestation trees in areas with poor site conditions is 2 490 – 3 300 plants/ha. From Table 3, it can be seen that the afforestation density of the four mountains is within a reasonable range.

4.2 Vegetation coverage We surveyed the vegetation coverage of the 3# mountain, 10# mountain, 17# mountain and 21# mountain by the traditional visual method. The results are shown in Fig. 3. From Fig. 3, it can be seen that after the restoration, the vegetation coverage of all mountains is obviously increased, and the 10# mountain has the largest increase, followed by 21#, 3# and 17# mountains. Before ecological restoration, the types of vegetation were mainly low-lying shrubs and herbaceous plants with strong resistance. The main means of ecological restoration is to plant trees and shrubs under the premise of not destroying the original vegetation as much as possible, and to improve and optimize the plant community structure, optimize the low-lying shrubs and grass structure into plant communities combining arbors, shrubs and grasses. After nearly two years of tending, the undergrowth vegetation has been better restored, and the plant communities of arbors, shrubs and grasses have stabilized. Arbor, deciduous and cut weed stems and leaves form a dead cover and effectively curb the soil erosion and loss. Under the condition of artificial tending, water and nutrients are well protected, and new native plant species are found, showing that there is an increasing trend in biodiversity, so that the vegetation succession and soil accumulation restored the benign process, and made phased achievements in ecological restoration. Most of the trees planted are landscaping trees, with colored leaves and seasonal changes, they can effectively enhance the landscape effect (Fig. 4 to Fig. 6).

Table 2 Changes in the abundance before and after ecological restoration of mountains

Mountain number	Tree species surveyed	Abundance before restoration plants	Abundance after restoration plants
3#	*Platycladus orientalis*	8	32
	Pyracantha fortuneana	2	8
	Koelreuteria paniculata	0	29
	Ligustrum lucidum Ait	0	30
10#	*Koelreuteria paniculata*	0	28

(To be continued)

(Continued)

Mountain number	Tree species surveyed	Abundance before restoration plants	Abundance after restoration plants
	Platycladus orientalis	5	27
	Cercis chinensis	0	33
	Osmanthus fragrans	0	24
	Amygdalus persica	0	32
	Prunus cerasifera Ehrhar ‘Atropurpurea’	0	31
	Ginkgo biloba	0	32
17#	*Ginkgo biloba*	0	32
	Platycladus orientalis	3	32
	Acer buergerianus	0	29
	Cinnamomum camphora	0	32
21#	*Pyracantha fortuneana*	1	9
	Platycladus orientalis	7	27
	Lagerstroemia indica	0	31
	Koelreuteria paniculata	0	30
	Photinia × fraseri	0	35
	Cassia surattensis	0	30

Table 3 Planting density of tree species

Mountain number	Tree species surveyed	Area of sample land m^2	Q'ty of tree species plants	Planting density plants/ha
3#	*Platycladus orientalis*	100	32	3 195
	Pyracantha fortuneana	25	8	3 195
	Koelreuteria paniculata	100	29	2 895
	Ligustrum lucidum Ait	100	30	3 000
10#	*Koelreuteria paniculata*	100	28	2 805
	Platycladus orientalis	100	27	2 700
	Cercis chinensis	100	33	3 300
	Osmanthus fragrans	100	24	2 400
	Amygdalus persica	100	32	3 195
	Prunus cerasifera Ehrhar ‘Atropurpurea’	100	31	3 105
	Ginkgo biloba	100	32	3 195
17#	*Ginkgo biloba*	100	32	3 195
	Platycladus orientalis	100	32	3 195
	Acer buergerianus	100	29	2 895
	Cinnamomum camphora	100	32	3 195
21#	*Pyracantha fortuneana*	25	9	3 600
	Platycladus orientalis	100	27	2 700
	Lagerstroemia indica	100	31	3 105
	Koelreuteria paniculata	100	30	3 000

From Fig. 4 to Fig. 6, it can be that after the restoration, the vegetation coverage of the original four rocky desertification mountains increased, and the mountain landscape was improved. With elapse of the time, plants grow gradually, and they can also conserve water, regulate microclimate, carbon sequestration, prevent soil erosion and loss, and improve soil conditions.

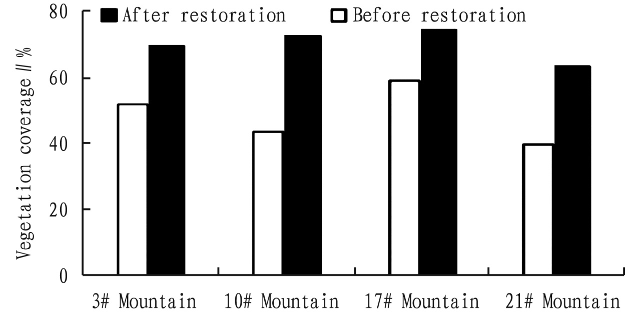

Fig. 3 Vegetation coverage before and after restoration

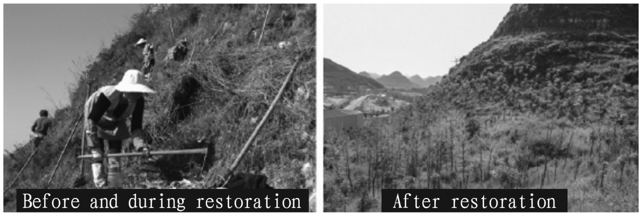

Fig. 4 Before, during, and after restoration of 21# mountain

Fig. 5 Before, during, and after restoration of 3# mountain

Fig. 6 Before and after restoration of 10# mountain

4.3 Species biodiversity Species diversity is expressed by the Gleason diversity index, and the higher the Gleason diversity index, the higher the species diversity. From Fig. 7 an Fig. 8, it can be seen that after the ecological restoration of the four mountains, the Gleason diversity index is increased, the Gleason diversity index of the arbor layer is increased obviously, and the shrub layer

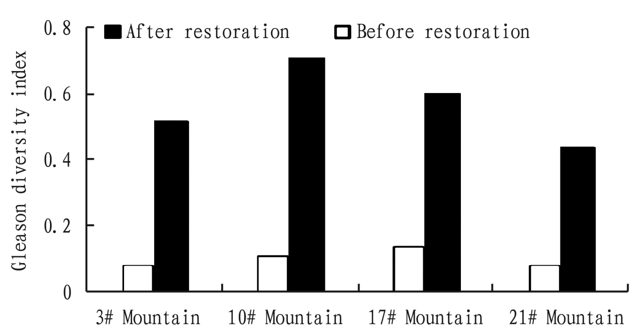

Fig. 7 Gleason diversity index of arbor layer of mountains before and after restoration

is also increased. The increase of the arbor layer is more obvious because arbors are planted more in the four mountains. The arbor layer of the 3# mountain increased by 0.434 3 and the shrub layer increased by 0.232 9; the arbor layer of the 10# mountain increased by 0.597 2 and the shrub layer increased by 0.193 2; the arbor layer of the 17# mountain increased by 0.462 0, the shrub layer did not increase; the arbor layer of the 21# mountain increased by 0.352 5 and the shrub layer increased by 0.155 3. On the whole, the abundance of the four mountain species after the restoration has increased.

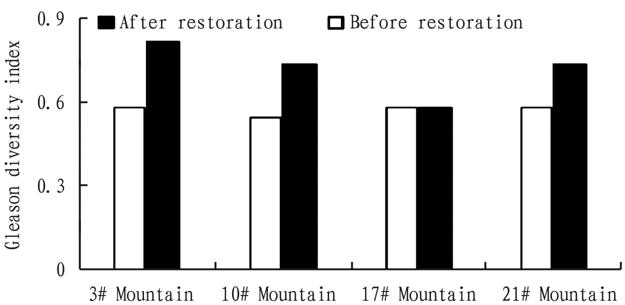

Fig. 8 Gleason diversity index of shrub layer of mountains before and after restoration

4.4 Afforestation survival rate We surveyed the afforestation survival rate of the 3#, 10#, 17# and 21# mountains. According to the construction drawing, we selected four representative sample points in each mountain to survey the survival tree, calculate the survival rate and take the average survival rate of all samples. The survey results are listed in Table 4 to Table 7.

Table 4 Survival rate of afforestation on 3# Mountain

3# Mountain	Designed number of plants//plants	Number of survival plants//plants	Survival rate//%
A	94	90	96
B	64	59	92
C	72	68	94
D	76	69	91

Table 5 Survival rate of afforestation on 10# Mountain

10# Mountain	Designed number of plants//plants	Number of survival plants//plants	Survival rate//%
A	49	43	88
B	67	62	92
C	70	59	84
D	72	62	86

Table 6 Survival rate of afforestation on 17# Mountain

17# Mountain	Designed number of plants//plants	Number of survival plants//plants	Survival rate//%
A	92	87	95
B	54	50	92
C	63	56	89
D	84	76	91

According to Table 4 to Table 7, we selected the appropriate tree species and mixing modes, planting techniques, irrigation facilities, and new materials and technologies such as agricultural and forest water retention agents and anti-transpiration agents in accordance with the site conditions. The average survival rate of 3#, 10#, 17# and 21# mountains is higher, all above 87%, of which 3# mountain has the highest survival rate, up to 93.3%, followed by 17# mountain, up to 91.8%. According to the requirements of the *Technical Specifications for Afforestation* (GB/T15776-2006), the survival rate of afforestation in areas with an average annual precipitation of greater than 400 mm should be higher than 85% (included). Thus, it indicates that the entire ecological restoration project meets the requirements for the survival rate of tree planting.

Table 7 Survival rate of afforestation on 21# Mountain

21# Mountain	Designed number of plants//plants	Number of survival plants//plants	Survival rate//%
A	50	45	89
B	70	60	86
C	40	35	88
D	60	56	94

4.5 Landscape effect With the development of the economy and the improvement in the people's living standards, people's requirements for the environment are getting higher and higher. They not only demand the restoration of the environment and ecology, but also demand certain ornament, the plant communities have seasonal changes, and the plants are rich in layers and abundant in types. In the ecological restoration of Xixiu District, we not only selected the appropriate tree species, but also took into consideration the ornamental characteristics of the plants. The landscape effect of the mountains after restoration is shown in Fig. 9.

Fig. 9 Some landscape after restoration of the mountain

Through the above technical measures, the vulnerable karst rocky desertification mountains are better restored, the plant community structure is improved, the species diversity is increased, the ecosystem function is gradually restored, and soil erosion and loss is effectively curbed. With the elapse of time, litter and plant roots of deciduous trees can improve soil physical structure and increase soil biomass, and will also gradually increase the species diversity. With the increase of the species diversity, the stability of the ecosystem will increase, and constructed ecosystem will be more stable, it will be more favorable for the karst desertification and benign development of the ecological environment. With the change of the seasons, it will bring visual enjoyment and pleasant mood. The beautiful mountain landscape is expected to greatly promote the development of tourism in Xixiu District and realize the sustainable development of regional ecology and economy.