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Vegetation succession process induced by reforestation in erosion areas

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Abstract Reforestation is one of the most important and efficient measures of water and soil conservation. Based on field investigations in the Shangyang Soil Conservation and Reforestation Station in Huizhou, Guangdong Province, China, we studied the variation in vegetation development, vegetation succession processes and soil erosion. The regional vegetation consists mainly of monsoon evergreen broad-leaved forests (MEBF). The area was deforested and became a denuded hill area with extremely high soil erosion in the 1960s and 1970s. Then, the area was closed in order to allow recovery of the vegetation. Under natural conditions the vegetation development and succession processes were slow during which soil erosion and strong sunshine and evaporation slowed down the development of the vegetation. About 25 years later, the vegetation cover was still merely 35% or so. The dominant vegetation types were heliophilous herbage and shrubs which formed a poorly developed shrub-herbage community and erosion remained high. In contrast, reforestation with selected tree species dramatically speeded up the vegetation succession process. About 12 years after reforestation, vegetation cover of the *Acacia auriculiformis* plantations in the Shangyang Station was 90% and erosion was under control. After 23 years, understory vegetation, consisting of indigenous species, had developed in the plantations. The planted trees and naturally developing herbage, shrubs, bamboo, local trees and liana formed a complex vegetation community in three layers. It will take 60 years for the vegetation to succeed

from bare land to a secondary growth forest under natural conditions. Reforestation may speed up the vegetation succession process. The time may be reduced to 20 years. Reforestation is the most effective measure of vegetation restoration and erosion control in this area.

Keywords vegetation succession, erosion, reforestation, water and soil conservation

1 Introduction

Soil erosion is a serious environmental problem in China. Vegetation is one of the major factors controlling soil erosion, while most severe soil erosion occurrences are the result of removal of vegetation and topsoil exposure to the air. Reforestation may facilitate vegetation re-development, control water and soil loss and improve the environment. It is therefore commonly used in water and soil conservation projects and has been one of the most important water and soil conservation methods and contributes to erosion control and environmental improvement in many erosion areas (Wang and Fang, 2000). It is of theoretical significance and practical importance to study and analyze quantitatively the succession processes of vegetation induced by reforestation in erosion areas for water and soil conservation. Presently, few studies focus on this area and most of these are still qualitative due to the complexity and indeterminacy of vegetation re-development and succession and the intricacy of the relations between weather, topography, soil, vegetation and erosion, interspersed with the effects of human activities. Wang et al. (2003, 2004, 2005) developed a new interdisciplinary science called vegetation-erosion dynamics that studies the laws of evolution of watershed vegetation and erosion under the action of various ecological stresses and human impacts, which has been successfully applied to the Xiaojiang Watershed in Yunnan Province, the Anjiagou Watershed in the Dingxi District, Gansu Province and the Wangjiagou Watershed in Lishi, Shanxi Province. As a continuation study, we have selected several erosion uplands in the Huiyang District,

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Guangdong Province, which is located in a region with a subtropical monsoon climate. We have investigated and analyzed vegetation development and soil erosion on typical sample plots and discussed vegetation succession processes induced by reforestation, as well as the relation between natural vegetation recovery and soil erosion.

2 Study area and methods

2.1 Study area

Our study area was situated in the Huiyang District, Huizhou City, which has a typical subtropical monsoon climate characterized and shown in Fig. 1: The area is exposed to high temperatures and plenty of rainfall, with an average annual temperature of 21.8°C and precipitation of 1726.3 mm. The annual dry and rainy seasons are clearly distinct. The rainy season starts in April and continues into September and accounts for about 82.8% of the annual rainfall, whereas the remaining months form the dry season. Especially from October to December, the rainfall curve lies slightly below the temperature curve (Fig. 1). The in-phase varied temperatures and precipitation is beneficial to the development of vegetation. At the same time, heavy rain and disastrous typhoons may induce severe soil erosion, damage forests and hinder the recovery of degraded ecosystems.

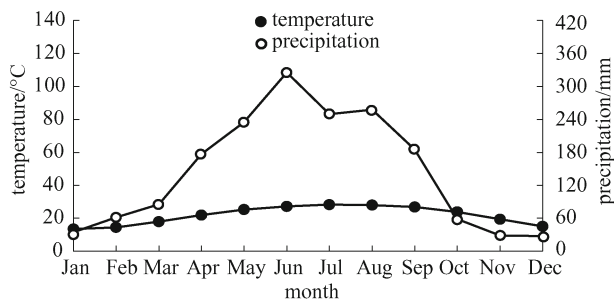


Fig. 1 Climate chart of Huiyang weather station

Huiyang District is characterized by hills and mesa landforms, crimson loam and granite/sand-shale. Because of long-term anthropogenic deforestation for cultivation of farmland and production of firewood, especially during the period from the 1950s to the 1970s, most of the forests were destroyed which resulted in severely eroded soils to the point where some hilly areas became entirely denuded. After 1978, intense reforestation projects were launched to control erosion and restore vegetation, establishing many plantations or secondary forests such as Masson pine forests, *Pinus elliottii* and *Acacia auriculiformis* plantations, as well as coniferous and broad-leaved mixed forests. Only a few small barren areas were not reforested, and are now covered with

grasses and shrubs developed from the plants surviving after the deforestation.

Three sloping fields of similar natural conditions was selected as our experimental plots, one lies to the south of Daishui Town in the Huiyang District (referred to as the “closed plot” thereafter), the other two are in the Shangyang Field Station, southeast of Daishui Town (referred to as the “reforested plots” thereafter), representing spontaneous and reforested landscapes, respectively. Due to the long-term impacts of human activities, little of the original vegetation was left, while soil sheet erosion and gully erosion fully developed, in some hilly areas even the bedrock became exposed. The slope gradients of the closed plot ranged from 5° to 30°, with a general northeast slope on purple sand-shale bedrock and crimson loam. The upper Quaternary Period sediment was washed out at most areas, leaving bare bedrock. The existing vegetation consisted of low, sparse secondary shrubs and grasses developed after the late 1970’s (Fig. 2a). Vegetation in the Shangyang Field Station developed in plantations after intense reforestation efforts during the 1980s, which turned into a variety of shrubs, herbage and trees (Liao et al., 1997). The *Acacia auriculiformis* stands, planted in 1981 on prepared and manured sloping land, has gradients ranging from 5 to 15°, a southerly slope direction on crimson loam and purple sand-shale bedrock and covered by Quaternary Period sediment (Liao et al., 1997). In 2004, crown density of about 65% had developed with plenty of shrubs and herbage in the shrublayer, the height of the trees was between 12 and 20 m with diameters at breast height (DBH) ranging from 7 to 30 cm (Fig. 2b). The *Acacia auriculiformis*–*Pinus elliottii* plantations were established in 1980 and 1984 on sloping land without land preparation and fertilization with gradients between 5° and 30° and other natural conditions similar to the *A. auriculiformis* plantations. Vegetation in most areas was less developed, with crown density of about 50%, tree height 4 to 12 m, DBH from 5 to 20 cm and some developed shrubs and herbage, partly forming an “undergrown forest”.

Some *A. auriculiformis* plantations on slopes at the right bank of the Fengtian Reservoir, northeast of the Shangyang Field Station, were selected to reinforce our study of the vegetation succession process by means of a spatial instead of a temporal series. These sloping lands were formed after excavation for road construction, with gradients from 5° to 15°, slope direction from east to northeast on granite bedrock and planted 3, 6, 8 and 12 years before our investigation.

2.2 Methods

Variation of vegetation and erosion, as well as vegetation succession processes at selected, typical plots were studied by vegetation investigations in the field, from previous records of vegetation surveys and runoff plots in the



Fig. 2 Present vegetation of (a) closed plots, (b) *Acacia auriculiformis* plantation at the Shangyang Field Station

Shangyang Station and from data of other erosion areas with similar natural conditions, to show the effects of reforestation on vegetation development, vegetation succession and erosion control in subtropical, erosion prone areas.

Our vegetation investigation was executed as follows: a number of sampling quadrats of 5 m × 5 m were selected according to the condition of the vegetation and size of each plot. Species, frequency, average height, coverage of each plant species and age configuration of shrubs and trees were measured and recorded. For the closed plots, several sampling quadrats were investigated to study the succession of natural vegetation. Several plantations of the same species and growing under similar natural conditions as our plantations were selected as reference plots at the right bank of the Fengtian Reservoir. Records of vegetation surveys in the Shangyang Station (Liao et al., 1997; Zhou and Deng, 2004) were consulted. Based on our observations and these previous records, the variation in vegetation and vegetation succession processes was derived.

Erosion rates on selected plots were calculated, primarily based on runoff plot data at the station, while modified using data of vegetation variation on each plot and vegetation coverage – erosion rate curves on erosion areas with the similar natural circumstance. It should be mentioned that the rates of erosion are ten-year-moving-averages which should eliminate the effect of rainfall on the erosion rates and represent fairly the trends in soil erosion.

3 Results and analyses

3.1 Variations of vegetation and soil erosion induced by reforestation

Variations of vegetation coverage and soil erosion at different plots are shown in Fig. 3.

As seen from Fig. 3, spontaneous vegetation restoration was very slow at the severely eroded sites in the subtropical monsoon area. The long-term nature of severe erosion due

to vegetation destruction resulted in very infertile soil, exposed bedrock and other adverse conditions for vegetation restoration. About 25 years after closure, vegetation coverage of the closed plot was barely 35%. Of the sloping fields, about 40% of the area was exposed to bedrock. The dominant vegetation was heliophilous herbage and shrubs, forming sparse *Rhodomyrtus tomentosa*, *Baeckea frutescens*–*Dicranopteris pedata* communities, while soil erosion remained high.

In comparison, vegetation restoration on the reforested plots had dramatically accelerated due to appropriate reforestation strategies, inducing quick control of soil erosion and promotion of understory vegetation development and succession (Fig. 3). Vegetation in the *Acacia auriculiformis* plantation recovered quickly due to proper reforestation measures and soil preparation. About 12 years after tree planting, the canopy coverage was 70% and vegetation coverage 90%. About 23 years after the reforestation, large local species of herbage, shrubs, liana and trees had developed, forming a complex community with the planted trees. At the same time, soil erosion decreased quickly. About 10 years after reforestation, soil erosion was under control. Initially, vegetation recovery in the *A. auriculiformis*–*P. elliotii* plantations was similar to that of the *A. auriculiformis* plantation, but the growth of planted trees decreased later. Vegetation restoration and development was slow when compared with the *A. auriculiformis* plantation. About 15 years after reforestation, the canopy coverage had reached 50% while the vegetation cover was 90%. Soil erosion was under control about 14 years later.

3.2 Vegetation succession process induced by reforestation

3.2.1 Vegetation succession mode in subtropical monsoon area

Without anthropogenic impact, forest communities in subtropical monsoon areas succeed to high-level climax

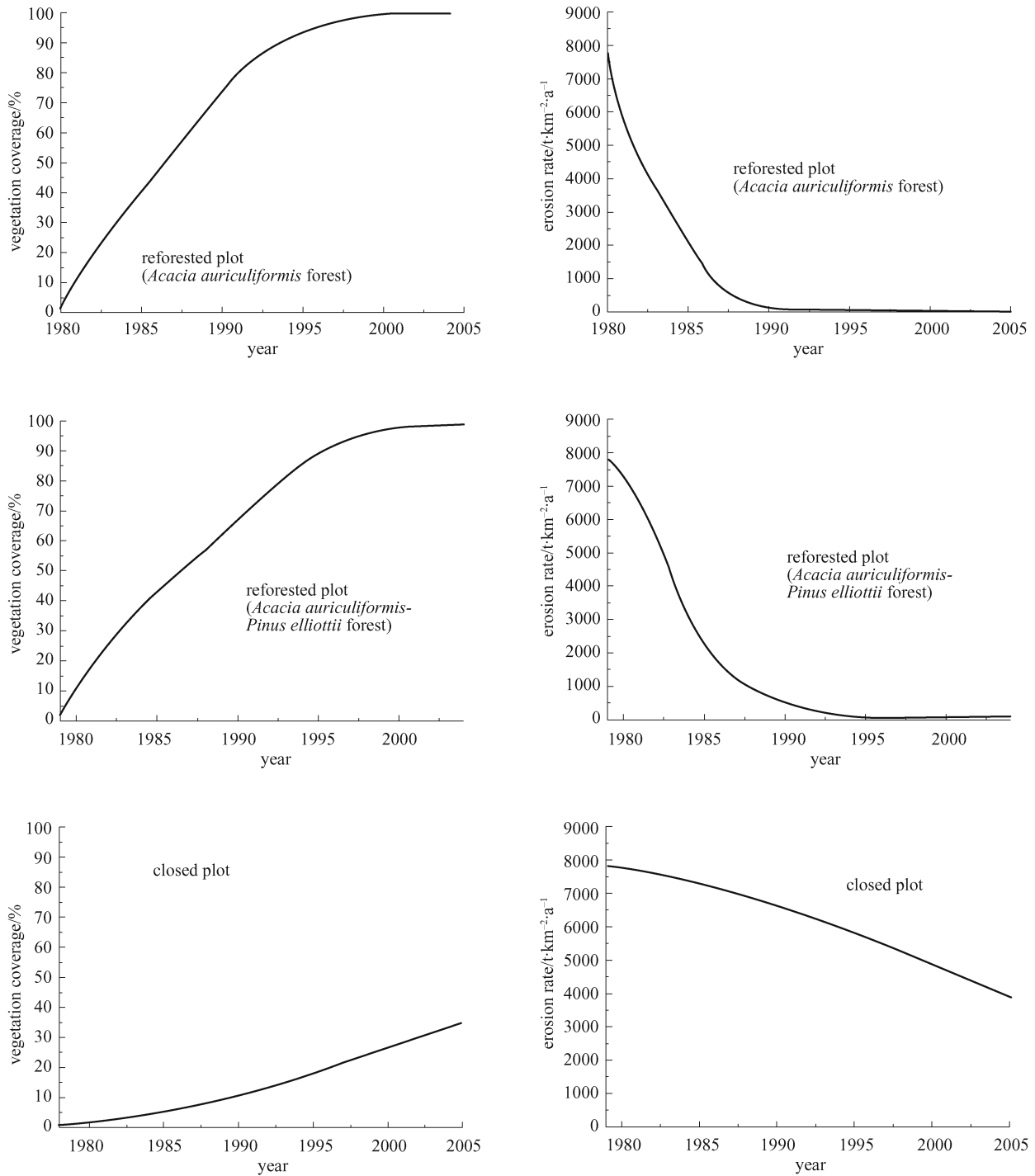


Fig. 3 Evolution of vegetation coverage and erosion rates at different sample plots

communities following certain regular patterns, including six serial stages (Fig. 4) (Peng, 1996; Liu et al., 1998). Combined with the serial stages of grass and shrubbery from bare lands to forests, a representative succession mode in this subtropical monsoon area was derived, as shown in Fig. 4.

Before the secondary forests were formed in the eroded area, soil erosion was the primary factor limiting

vegetation restoration due to severe damage of the vegetation. However, once the secondary forests were formed, climate, vegetation type and other environmental circumstances became the dominating restricting factors after soil erosion was controlled. Thus, serial stages from secondary bare lands to secondary forests in our study area were discussed while forest succession stages were left out of consideration.



Fig. 4 Pattern of vegetation succession of monsoon evergreen broad-leaved forest in lower subtropical China

3.2.2 Spontaneous vegetation succession processes

Vegetation succession processes of the closed plot and reforested plots (*A. auriculiformis* plantations) are illustrated in Fig. 5. From this figure it is seen that spontaneous vegetation on the secondary bare lands of this subtropical erosion area recovered gradually since the impacts of severe erosion and lean soil on vegetation started to be felt. After 26 years, the closed plot was dominated by heliophilous herbage and shrubs. It could take decades or even hundred of years for this closed plot to develop into a forest with a relatively stable species composition.

The vegetation succession in the closed plot began with sparse wild grassland composed of strong heliophilous annual herbage tolerant to drought and lean conditions (e.g. *Eriachne ciliaris* and *E. pallescens*). Later, some other heliophilous herbage tolerant to lean conditions, such as *Eragrostis poaeoides*, *Melinis minutiflora*, *Exacum* and the fern species *Dicranopteris pedata*, gradually appeared. About 10 years after closure, heliophilous shrubs, such as *Rhodomyrtus tomentosa*, *Baeckea frutescens* and *Cleodendrum fortunatum* also appeared and many kinds of herbage colonized the habitat. About 20 years after closure, other heliophilous shrubs developed, whereas the pioneer species, such as *Eriachne ciliaris*, gradually disappeared, forming a community consisting of *Rhodomyrtus tomentosa* and *Baeckea frutescens*-*Dicranopteris pedata*. The Shannon-Wiener diversity index reached 2.359. After that, shrubs and herbage would

continue developing, pioneer trees would appear, and the community would succeed from savanna shrubs and grass to a secondary forest.

3.2.3 Vegetation succession induced by reforestation

In comparison, the vegetation succession at the reforested plot (the *Acacia auriculiformis* plantation) was much faster than that of the closed plot because the planted trees provided the initial functions of shade, water household and erosion control. During the four years following reforestation, herbage, such as *Dicranopteris pedata*, *Imperata cylindrical* and *Melinis minutiflora*, appeared under the trees. About eight years later, *Rhodomyrtus tomentosa* and *Baeckea frutescens* developed in the plantation. About 12 years later, as the *Acacia auriculiformis* started to develop into trees, strong heliophilous herbage, e.g. *Eriachne ciliaris* and *E. pallescens* disappeared due to the shade from the tree canopy. Many other herbage species and shrubs, as well as indigenous saplings and lianas, e.g. *Ailanthus altissima*, *Schefflera actinophylla* and *Smilax china* began to grow in the forest. After that, *Dicranopteris pedata*, *Melinis minutiflora* and *Rhodomyrtus tomentosa* developed quickly, occupying the herbaceous and shrub layers, while the presence of *Baeckea frutescens* declined. In 2004, a complex vegetation community consisting of herbage, shrubs, liana and trees had developed, in which some mesophytic or shade tolerant species (e.g. *Psychotria rubra*), regional saplings

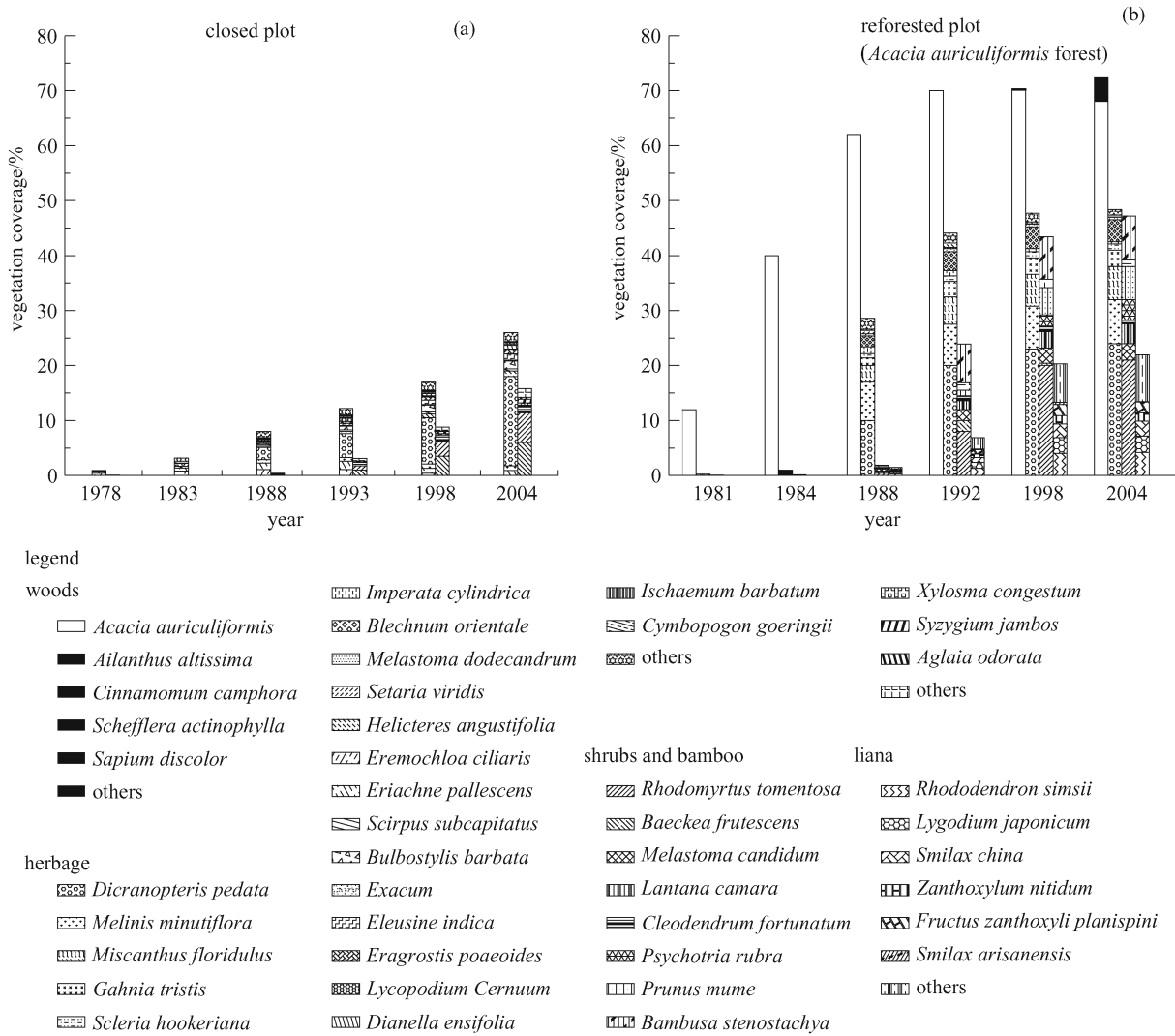


Fig. 5 Vegetation succession in the closed plot (a) and in the *Acacia auriculiformis* plantation (b)

(e.g. *Ailanthus altissima*, *Schefflera actinophylla* and *Ailanthus altissima*) and various lianas had grown. The Shannon-Wiener diversity index reached 3.007.

Vegetation at the *Acacia auriculiformis*-*Pinus elliottii* plantation was similar to that in the *Acacia auriculiformis* plantation, but the number of species and biodiversity as well as canopy coverage were much smaller than that of the pure *Acacia* plantation. The Shannon-Wiener diversity index was only 1.263, *Dicranopteris pedata* and *Rhodomyrtus tomentosa* occupied most of the underlayer herbage and shrub layers, respectively. There were very few other species.

4 Discussion

4.1 Factors on vegetation restoration

Climatic conditions may be the crucial factors in the rate of vegetation recovery. The warm and humid climate in

this subtropical area is beneficial to vegetation growth, which in this area is very resilient.

Restoration of spontaneous vegetation at the different kinds bare land, owing their origin to various levels of human damage, changed with the variation of rates of erosion, the condition of the retained soil, availability of initial vegetation propagules and the condition of the surrounding vegetation. The burnt forest at the Shangyang Station recovered relatively quickly, as vegetation roots, seeds and nutrients had partly remained in the soil, although trunks, branches and foliage of all plants were burnt out and soil erosion increased. About six years after the forest fire, the recovered vegetation was similar to that of the closed plot. According to Zhang (1998), natural recovery of vegetation on slopes, made bare by human intervention, is relative quick after about six years vegetation cover had reached 100%. In contrast, vegetation at the closed plot was severely damaged by human activities, inducing serious erosion, responsible for the slow recovery of the vegetation after its removal as the result of human impact.

Restoration may promote vegetation development in eroded areas, while appropriate plantation species and suitable engineering measures can dramatically accelerate vegetation restoration and development (Guo et al., 2002). For instance, the *Acacia auriculiformis* plantation was restored much faster than the *Acacia auriculiformis*–*Pinus elliottii* forest due to suitable cultivation measures and ground preparation.

4.2 Duration of vegetation succession

Natural vegetation restoration in severely eroded areas is very slow. Vegetation restoration of our closed plot indicates that it takes 25 years for bare, sloping land with severely eroded soil to establish a poor shrub-herbage community without human intervention. According to vegetation investigations at areas with similar natural conditions (Zhuang and Corlett, 1997; Liu et al., 1998; Zhuang and Qiu 1998; Xie et al., 2001), vegetation succession from a shrub-herbage community to a steady forest requires about 30–40 years in this area, of which about 20 years is needed to progress from shrubs to trees. Thus, without human intervention, it takes about 60 years for the vegetation succession in this area to develop from bare slopes to a steady forest.

Vegetation succession processes may be clearly accelerated by reforestation. The *Acacia auriculiformis* plantation at Shangyang Station demonstrates that suitable reforestation efforts can dramatically facilitate vegetation recovery and vegetation succession. About 20 years after reforestation, a steady plantation can be established. In other words, human activity may accelerate vegetation succession dramatically in the subtropical zone.

5 Conclusions

The warm and humid climate in subtropical areas is beneficial to vegetation growth, but heavy rain and typhoons may induce severe soil erosion, damage forests and hinder the recovery of degraded ecosystems. Thus, there is a strong dynamic interaction between vegetation and erosion in this area. We selected several erosion upland areas in the Huiyang District, Guangdong Province, as study plots. Based on our investigation of vegetation and erosion, the process of vegetation development, vegetation succession and soil erosion under spontaneous conditions compared with plantation efforts was discussed. We found that natural vegetation in this area has high resilience, while soil erosion is one of the key limiting factors of vegetation restoration. Reforestation with selected tree

species may dramatically speed up vegetation recovery and the process of succession, soil erosion control and improvement of the environment. The success in reforestation and erosion control at the field station may be an important experience in water and soil conservation to emulate in other erosion uplands in subtropical areas of China.

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