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Impacts of reforestation on woody species composition, species diversity and community structure in dry-hot valley of the Jinsha River, southwestern China

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Abstract: To understand the impacts of reforestation on woody species composition, species diversity and community structure, seven plantation forests in dry-hot valley of the Jinsha River in Southwest China were investigated, with adjacent wastelands, natural shrub grassland and a natural forest as references. Species importance value, species richness, species heterogeneity and Sorenson similarity index between plantations and the natural forest were analyzed. Results indicated that compared to wastelands and natural shrub grassland, reforestation improved species diversity and community structure, and more forest woody species found suitable habitats in plantations. Species diversity in understory of plantations and Sorenson similarity index were significantly negatively correlated with stem density in mature plantations (26-31 years old). Higher species diversity and Sorenson similarity index existed in mature sparse plantations due to lower stem density and more tree species planted initially. In contrast, reference natural forest, with species heterogeneity of 2.28 for shrub layer, showed the highest species diversity. It would take a long time for species composition and diversity to recover through reforestation in a dry-hot valley. Therefore, it was essential to protect remnant natural forests strictly and reforest with suitable management such as lower stem density and increasing genetic diversity of trees planted.

Keywords: Biodiversity; Plantations; Dry hot valley; Genetic resources; Natural forest; Reforestation

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Introduction

Plant species diversity plays an important role in ecosystem functions and services. There is a growing recognition that high plant species diversity helps promote nutrient cycling, resistance to diseases and pests, and enhances stability of ecosystems (Balvanera et al. 2006; Jactel and Brockerhoff 2007; Jakel and Roth 2004; Zeugin et al. 2010). Therefore, restoration of species is often the prime aim of ecological restoration. However, restoration of species diversity and species composition varies in different restoration efforts. Some studies reveal that species diversity increases quickly in the early and middle stages of vegetation restoration (Fang and Peng 1997; Ruiz-Jaen and Aide 2005), but other studies suggest that it is difficult to restore primary forest species composition by reforestation after severe disturbance (Jacobs et al. 1988; Meng et al. 2011). Jiang (1991) thought that both tropical forest species, and also species and their environment depended highly on each other, making it difficult to restore tropical forests. These differences probably reflect the fact that changes of species diversity and composition are affected by various factors, such as plant species attributes and interactions (Hacker and Gaines 1997; Zhang et al. 2001), soil nutrients (Brosofske et al. 2001), climatic conditions (Givnish 1999), and natural and anthropogenic disturbances (Hubbell et al. 1999; Guo et al. 2002; Chapin et al. 1997; Meier et al. 1995).

Apart from species diversity and species composition, community structure is also important in ecological restoration. The study of community structure can provide information on habitat suitability and change of species diversity, and predict the direction of ecological succession (Jones et al. 2004). Sharma et al. (2010) investigated tree diversity of 20 major forest types in the Garhwal Himalaya, India and found that stem density was negatively correlated with Shannon diversity index, that is, species diversity decreased with increase in stem density. Kalaba et al. (2013) found that community structure of firewood and slash and burn fallows over 25 years showed a reversed J-shaped size class, indicating that shade tolerant young trees could regenerate continuously under closed canopies and Miombo forest could achieve its mature community structure. Ruiz-Jaen and Aide (2005) found that herbaceous cover decreased and 22 woody species colonized into reforested site formerly dominated by grasses in the Karst valleys in Puerto Rico. These changes are probably attributed to the decrease of root competition belowground and physical barrier aboveground (Hooper et al. 2002). Andres and Ojeda (2002) reported that afforestation with pines in southern Spain resulted in lower woody species diversity and homogenization of floristic composition under pine trees, because thick needle litter layer and pine-tree cover hampered seed germination in the understory.

Characterized by low precipitation, high evaporation and high temperature, the dry valleys of southwestern China are typical fragile and degraded ecosystems (Zhang 1992). Since the main vegetation is shrub grassland, the dry valleys are traditionally considered to be low-profit, tree-less, and barren lands. Therefore, great efforts have been made to restore forests and many species have been tested in the dry-hot valleys of the lower Jinsha River, but only *Leucaena leucocephala* seems to be successful so far. Since the 1980s, large scale reforestation has continued mostly with *L. leucocephala*. While there are studies on species diversity and community characteristics of *L. leucocehala* planted forests less than 20 years old (Fang et al. 2005; Lin et al. 2009; Liu et al. 2008), few studies have been conducted on whether reforestation can enhance species diversity and maintain species genetic resources. We present here a study on woody species diversity, woody species composition and community structure of 9-31-year-old planted forests in comparison with natural forest, natural shrub grassland and degraded wastelands in the dry-hot valley of the lower Jinsha River. The main objective of this study is to understand the impacts of reforestation on plant species composition, species diversity and community structure, so as to provide advice on maintenance of species diversity and management of existing forested lands and other vegetation types in the dry-hot valleys. We hypothesized that reforestation would improve community structure, promote woody species colonization, and increase species diversity, compared with degraded wasteland and natural shrub grassland.

1 Materials and Methods

1.1 Study area and sites

This study was carried out in the dry-hot valley of the lower Jinsha River in southwestern China, covering parts of Ningnan county of Sichuan province and Dongchuan municipality of Yunnan province. Mean annual temperature is 20°C-22°C and average annual rainfall is 700-800 mm, with an aridity index over 1.6, indicating a much higher evapotranspiration rate. This ecosystem is among the most fragile ones in southwestern China and is characterized by poorly developed shrub grassland and severe soil erosion (Tang et al. 2004; Peng et al. 2013). As specific humidity increases with increasing altitude, dense scrubland and forests are found at areas higher than 1600 m above sea level (asl) until around 2700 m asl. Soil is mainly

Chromic Cambisol in Food and Agriculture Organization (FAO) taxonomy, or Ustochrept in United States Department of Agriculture (USDA) taxonomy. Common native grass species include *Eulaliopsis binata*, *Eriophorum comosum, Heteropogon contortus*, and *Imperata cylindrica*. Native woody plants include *Albizia kalkora*, *Barleria cristata*, *Dodonaea viscosa*, *Phyllanthus emblica*, and *Pistacia weinmannifolia*.

Seven planted forest stands, at an elevation ranging from 770 to 1280 m asl and with different years of establishment (9-31 years), were selected, six in Ningnan and one in Dongchuan (Table 1). The six stands in Ningnan included four in Hulukou and two in Pisha towns. The one in Dongchuan was located in Tuobuka. Year of establishment, species, elevation of stand and other information are presented in Table 1. Of the species used, *L. leucocephala*, *Eucalyptus camaldulensis*, *Acacia confusa*, *Bombax ceiba*, *Melia azedarach*, *Tamarindus indica*, and *Trema tomentosa* were trees and the other species were shrubs. No herbaceous species were used. In each plantation forest stand, trees were planted during early rainy season (late May and June) at 2.0 m × 2.0 m and shrub seeds were broadcasted among trees. Irrigation, fertilization, and weeding were not applied after the plantations establishment. In 29- and 31-year-old planted forests, *L. leucocephala* seedlings were transplanted to other degraded wastelands. At present most of the planted forests are composed predominantly of *L. leucocephala*, with scattered *E. camaldulensis* and *A. confusa* in canopy, and *D. viscosa* in understory. For comparison, five reference stands were selected: three degraded wasteland stands at Hulukou, Pisha and Tuobuka, each adjacent to the selected planted forests, respectively, a natural forest stand adjacent to the selected planted forest at Pisha, and a naturally developed shrub grassland at Hulukou. The three degraded wastelands were heavily disturbed by anthropogenic activities such as free mowing and grazing. In contrast, the other two reference stands were within protected areas of soil conservation projects, where grazing and mowing were banned. Vegetation coverage (percentage of vertical projection area of foliage aboveground) averaged 40% for the reference wastelands, was 95% for both the natural forest stand and the naturally developed shrub grassland. Land of planted forests had not been cultivated for at least 20 years prior to reforestation. Details of the study sites are presented in Table 1.

Table 1 Basic information of study stands in Ningnan of Sichuan province and Dongchuan of Yunnan province, China

Sites	Stand description	Slope aspect (°)	Slope (°)	Altitude (m)	pH	Clay (%)
Tuobuka town, Dongchuan municipality, Yunnan (N26°25'12"; E103°04'43")	9 years old plantation established with *Leucaena leucocephala, Acacia confusa, Eucalyptus camaldulensis* and *Dodonaea viscosa* (9 years)	NE80	20	895	7.5	11.8
	Reference wasteland in Tuobuka (RWa)	NE80	20	910	7.7	10
Pisha town, Ningnan county, Sichuan (N27°04'15"; 102.43'42")	26 years old plantation established with *L. leucocephala, E. camaldulensis* and *Cajanus cajan* (26a years)	NE75	20	1273	5.8	57
	26 years old plantation established with *L. leucocephala* and *C. cajan* (26b years)	NE76	19	1273	6.9	57.5
	Reference wasteland in Pisha (RWb)	NE77	22	1260	7.1	52.3
	Reference natural forest (RNF)	NE45	27	1230	5.6	52.2
Hulukou town, Ningnan county, Sichuan (N26°57'24"; E102°53'01")	28 years old plantation established with *L. leucocephala* and *Tephrosia candida* (28 years)	NE60	17	840	7.4	18.3
	29 years old plantation established with *L. leucocephala, E. camaldulensis, A. confusa* and *T. candida* (29 years)	NE 65	19	820	\	\
	30 years old plantation established with 18 woody species, including *A. confusa, Bombax ceiba, E. camaldulensis, L. leucocephala, Tamarindus indica, Trema tomentosa*, *C. cajan* and *D. viscosa* (30 years)	NE70	18	805	7.9	12.8
	31 years old plantation established with the same species as 30-year-old plantation (31 years)	NE76	21	770	8	10.1
	Reference natural shrub grassland (RS)	NE63	21	840	8.1	10.1
	Reference wasteland in Hulukou (RWc)	NE35	21	821	8.1	13.3

1.2 Sampling

Field investigation was carried out in 2013. In natural shrub grassland and each planted forest stand, five 10 m × 10 m plots were sampled randomly and five 20 m × 20 m plots were sampled from the natural forest stand. Three 10 m ×10 m plots were sampled from each degraded wasteland. Slope aspect and elevation of each reference wasteland stand, natural shrub grassland stand and natural forest stand were similar to the adjacent plantation forest stands.

Floristic investigation was performed for three layers: (1) herbaceous layer, (2) shrub layer and (3) tree layer. The tree layer was sampled throughout the plots. The shrub layer was sampled from four 5 m× 5 m quadrats (including shrub and tree sapling) nested within each plot. The herbaceous layer was investigated in four 1 m × 1 m quadrats nested within each plot. The woody species were identified by a botanist from Sichuan University. In each plot, number of individuals, height and DBH (diameter measured at breast height of 1.37 m) were recorded for each tree species. In each quadrat, height and cover of each species, and number of individuals were noted for all shrub plants. The cover of each species, community cover of each layer (i.e. herbaceous, shrub and tree), and tree height were estimated visually by two observers working together. Three surface soil samples (0-20 cm) were collected randomly in each plot and then were thoroughly mixed. In laboratory, soil samples were air dried, and pebbles and plant roots larger than 2 mm were filtered out with a screen (2 mm mesh). The soil pH was measured with a combination electrode (soil-to-water ratio of 1:2). The clay contents were determined by the pipette method in a sedimentation cylinder (Lu 2000).

1.3 Species diversity analysis

To describe species composition and community structure of the sampling stands, species importance value (*IV*), IV_{tree} = (Relative frequency + relative basal area + relative density)/3, IV_{shrub} = (Relative coverage + Relative height)/2, was calculated for each species (Curtis and McIntosh 1951). To compare species diversity, species richness (*S*) and species heterogeneity measured by Shannon-Wiener index (H') (Shannon & Weaver 1963) were calculated for all the planted forests, reference wastelands, naturally developed shrub grassland, and natural forest. Species richness (*S*) was measured in each sampling stand as the number of species recorded by the plots. To compare the difference of species composition between planted communities and the reference natural forest, Sorenson similarity index (*Cs*), $Cs = 2J/(a+b)$ (Whittaker 1972), was used, where *J* was the number of species in common of two communities, and *a* and *b* were the number of species in two communities, respectively.

1.4 Statistical analyses

To assess differences among 7 planted forests, 1 reference natural forest, 1 natural shrub grassland and 3 reference wastelands, results of species richness, species heterogeneity (H') were analyzed using one-way ANOVAs followed by least significant difference tests. Pearson correlation analysis was performed to determine whether relationships existed between Sorenson similarity index (*Cs*) and tree stem density, and between species diversity (*S* and H') and variables of community structure (tree stem density and basal area). Analyses were performed using SPSS 18.0 for Windows. Significance levels were set at p = 0.05 and extreme significance levels at p = 0.01 in all statistical analyses.

2 Results

2.1 Woody species composition and species diversity

Compared with degraded wastelands (only one shrub species *D. viscosa*), reforestation facilitated more woody species colonizing into planted forests, one species *Eriolaena candollei* into tree layer and 15 woody species into shrub layer, including *Cotinus coggygria, Reinwardtia indica, Bauhinia brachycarpa* (Appendix 1). More forest woody species found suitable habitats in planted forests than in natural shrub grassland. Nine woody species in plantations were the same as those in the reference natural forest, including *Vernicia fordii*, *A. kalkora*, *R. indica*, and *C. coggygria*, while 2 woody species in natural shrub grassland were the same as those in natural forest, including *C. coggygria* and *A. kalkora* (Appendix 1). But in 30-31 years old planted forests, more than three fourths woody species initially planted disappeared. In all planted forests, *L. leucocephala* dominated the community, and its importance value ranged from 66.0% to 100.0% for tree layer and from 87.8% to 97.3% for shrub layer, respectively (Appendix 1).

A total of 15 species in tree layer and 33 species in shrub layer (including saplings of 8 tree species) were found in reference natural forest. In terms of importance values, the most important tree species was *Castanopsis delavayi*, followed by *A. kalkora*, *P. weinmannifolia, Toxicodendron succedaneum*, and *Neocinnamomum delavayi,* and the most important shrub species was *Desmodium yunnanense*, a nitrogen-fixing species. Eleven woody species were found in naturally developed shrub grassland and the dominant woody species was *D. viscosa* (Appendix 1).

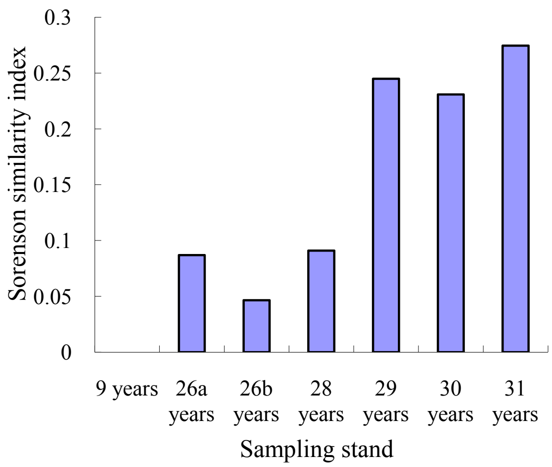

Figure 1 Sorenson similarity index between plantation forests and reference natural forest.
Notes: 26a years, mixed plantation with *Leucaena leucocephala*, *Eucalyptus camaldulensis* and *Cajanus cajan,* aged 26; 26b years, mixed plantation with *L. leucocephala* and *C. cajan*, aged 26.

The Sorenson similarity indexes (*Cs*) for comparing species composition between planted forests and reference natural forest were 0-0.27 (Figure 1). Woody species in 9-year-old planted forests were different completely from those in natural forest. In mature planted forests (26-31 years old), *Cs* was significantly negatively correlated with stem density (R^2 = - 0.918, p = 0.010, n = 6).

Mean species richness (*S*) and species heterogeneity measured by the Shannon index (*H'*) for tree layer of all plantations were 1-3 and 0-0.26, respectively, significantly lower than that of reference natural forest (*S* = 9; *H'* = 1.57) ($p < 0.05$) (Figure 2A and 2B). *S* and *H'* for shrub layer of all plantations were 3-6 and 0.20-0.66, respectively, significantly higher than that of degraded wastelands (no tree layer and only one for shrub layer) ($p < 0.05$), but significantly lower than that of reference natural forest (*S* = 15; *H'* = 2.28) ($p <$ 0.05).Species diversity (*S* and *H'*) of mature sparse plantations (29-and 31-year- old) was significantly higher than that of natural shrub grassland (*S* = 4; *H'* = 0.46). In mature planted forests (26-31 years old), species richness was significantly negatively correlated with stem density and species heterogeneity (*H'*) was significantly negatively correlated with stem density and basal area (Table 2).

Table 2 Correlation coefficients between species diversity variables of shrub layer and structure variables of tree layer in mature plantations (26-31 years old). Significances of correlations are indicated as: *$p < 0.05$; **$p < 0.01$ (n = 6)

Variable	Stem density	Basal area
Shrub species richness	R^2 = -0.924; p = 0.008**	R^2 = -0.748; p = 0.087
Shrub species heterogeneity	R^2 = -0.966; p = 0.002**	R^2 = -0.823; p = 0.044*

2.2 Community structure

Tree layer of planted forests was 5.0-16.5 m high, averaged 7.5 m, lower than that of natural forest (averaged 11.7 m). Stem densities ranged from 2264 to 6880 N ha^{-1}, significantly higher than that of natural forest (1368 N ha^{-1}) ($p < 0.01$). Basal area of planted forests was lower than that of the reference natural forest, ranging from 5.29 to 25.59 m^2 ha^{-1}. DBH of planted forests ranged from 5.7 to 7.9 cm, with more than 86% of stems with DBH less than 10 cm, a reversed J-shaped size class pattern as observed in reference natural forest. Compared with natural forest, mature planted forests had poorly-developed understory. Woody species, except for *L. leucocephala*, had few individuals in understory. Herbaceous layer of mature planted forests was below 0.3 m high and its cover was below 40%.

In natural shrub grassland, there were only shrub and herbaceous layers. Height of shrub layer ranged from 0.3 to 1.8 m, averaged 0.8 m. Herb layer was 0.1-1.1 m high, averaged 0.5 m. In all vegetation types, coverage of herbaceous layer in natural shrub grassland, 95%, was the highest.

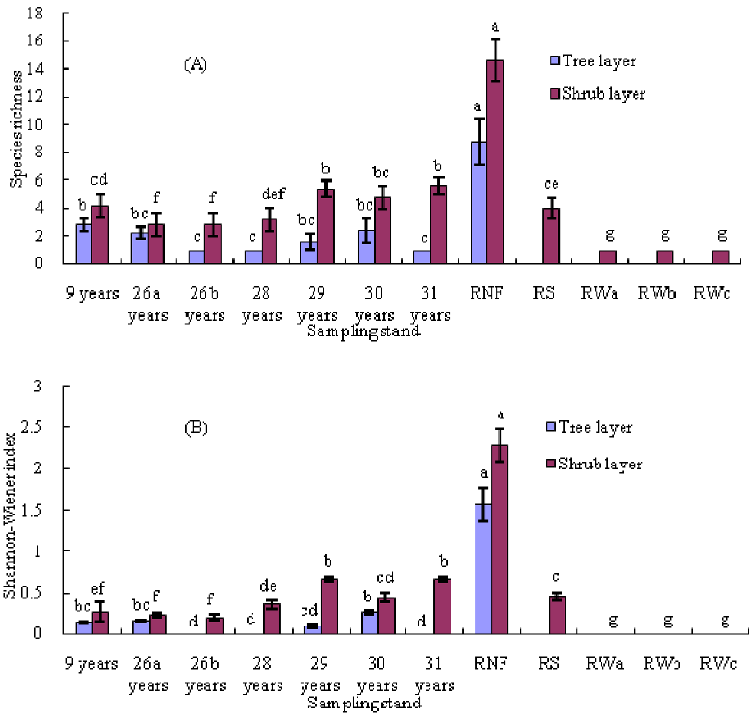

Figure 2 Woody species richness (A) and species heterogeneity measured by Shannon-Wiener index (B) of plantation forests and reference stands.

Note: RWa, reference wasteland in Tuobuka, Dongchuan, Yunnan province; RWb, reference wasteland in Pisha, Ningnan, Sichuan province; RWc, reference wasteland in Hulukou, Ningnan, Sichuan province. RNF, reference natural forest; RS, reference naturally developed shrub grassland; 26a years indicating mixed plantations of *Leucaena leucocephala, Eucalyptus camaldulensis* and *Cajanus cajan*, aged 26; 26b the same as 26a but without *E. camaldulensis*. Error bars indicating within-stand SD, with the same letter in each layer of sampling stands are not significantly different (n = 3 for reference wastelands and 5 for other stands; p = 0.05).

3 Discussion

This study indicated that planted forests played an important role in protecting forest genetic resources by providing habitats for some forest woody species. Nine forest woody species were found in planted forests, while only 2 forest woody species in natural shrub grassland. In the dry-hot valley of Jinsha River, forest genetic resources are endangered for great decrease of natural forest areas. While the dominant vegetation is shrub grassland, the dry valleys are traditionally considered to be tree-less and barren lands. Therefore, species conservation would be more significant in a dry region than in a species-rich ecosystem (McNeely 2003). Mature planted forests have lower tree layer and herbaceous coverage compared to natural shrub grassland, which increases environmental heterogeneity and facilitates more forest woody species colonization. Planted forests are more suitable habitats for some natural forest woody species than natural shrub grassland. Zhang et al. (2010) found abundant late-successional tree species in understory of planted pine forests in the Qinling Mountains. Some studies indicate that planted forests can be used as a nurse habitat for establishing late-successional tree species (Lugo 1997; Brockerhoff et al. 2003). Planted forests have a complementary conservation value for forest woody species.

Forest woody species varied greatly among planted forests and the Sorenson similarity indexes (*Cs*) between planted forests and natural forest ranged from 0 to 0.27. The minimum value of *Cs* existed between 9-year-old planted forest and natural forest. This can be attributed to a feature of an early stage of reforestation of a degraded ecosystem where the structures and functions of the biological communities are so unstable that the ecosystem is incapable of accommodating most natural forest woody species. In mature planted forests, *Cs* increased with declining stem density. More forest woody species were found in understory of mature sparse planted forests. This may be attributed to gaps caused by death of mature trees, important for new species colonizing, especially in mature planted forests and natural forests (Hubbell et al. 1999). Increased sunlight into forests promotes seedling recruitments and growth in understory (Chazdon and Fetcher 1984).

Besides, the decrease of stem density in mature planted forests reduces root competition belowground and physical barrier aboveground, beneficial to other woody species colonization (Hooper et al. 2002). In 29- and 31-year-old planted forests, stem density decreased further for seedlings transplanted to other degraded wastelands for reforestation and *Cs* was higher than other planted forests. Higher importance value of forest woody species in 29- and 31-year-old planted forests also implies the increase of relative importance and habitat suitability for these forest woody species. Some studies also find that thinning may facilitate development of indigenous understory in planted forests (Brockerhoff et al. 2003; Langer et al. 2008). In 29 to 31-year-old planted forests, higher *Cs* can also be attributed to more tree species planted initially. Therefore, management could revegetate at lower density and with greater tree species diversity.

Compared to degraded wastelands, reforestation facilitated more woody species colonizing into planted forests. Species richness and species heterogeneity for shrub layer in planted forests were significantly higher than those in degraded wastelands. These results are probably attributed to less anthropogenic disturbance such as mowing and grazing, and pioneer species that can change community structure and improve soil fertility (Tang and Li 2013). Improved soil helps other species to colonize into the reforested sites (DeWalt et al. 2003; Ruiz-Jaen and Aide 2005). Establishment of pioneer species on extremely degraded ecosystems can change community structure considerably. Increased vegetation cover reduces drastic fluctuation of temperature and soil water content in planted forests. Moreover, soil nutrients in planted forests can also be improved by pioneer species in various ways, including litter fall, root detritus and root secretion. In turn, improved soil conditions assist plant germination and root growth and influence successional vegetation dynamics (Lemma et al. 2006; Lugo 1997; Holmes 2001).

However, species richness and species heterogeneity for tree and shrub layers of the planted forests were significantly lower than those of reference natural forest ($p < 0.01$). The woody species diversity is even lower than that of planted forests in the Qinling Mountains in northwestern China (Zhang et al. 2010). All planted forests in the present study are dominated by the same species *L. leucocephala* in both tree layer and shrub layer, regardless of many species planted initially, which differs from what is found in the study of Fang and Peng (1997). Their investigation on species diversity change in 15-30-year reforestation on tropical degraded ecosystem reveals that species richness increases from originally 2 or 3 to several dozen species and that most colonizing native species become dominant species and replace pioneer species, concluding that tropical seasonal rainforest can restore in degraded ecosystem by reforestation. Our study, however, reveals that only *L. leucocephala* can form dense forests in the dry-hot valley, as it is found in a few other studies (Fang et al. 2005; Lin et al. 2009), because the local environment does not support growth of many other trees to form forest. *L. leucocephala* is the sole tree species that can survive the harsh environment to form dense forests in the dry-hot valleys of the lower Jinsha River, characterized by high temperature and evaporation, low precipitation, and poor soil (Tang et al. 2004; Yang et al. 2003). Soil moisture in the dry-hot valleys is the determining factor for plant fate. There is a long dry season of over six months and seeds of many species cannot germinate or seedlings would die shortly after germinating. In severe droughts, soil moisture content is usually below the plant withering moisture for up to 7-8 months, which makes many plants unable to survive (Zhong 2000). In 30-31 years, low seedling survival rate and strong competition have likely caused failure of more than three-fourths of the 18 woody species planted initially in the mixed-species plantation forests. Some species, i.e., *C. cajan* and *T. candida*, do not survive because they do not produce viable seeds in the area.

Success of *L. leucocephala* is likely attributable to its pioneering nature, such as being fast growing, having nitrogen fixation, and high regeneration. Its seed yield, for instance, is 1100-1300 grains per tree, much higher than all other woody species in this area (Ma et al. 2006). Such a high seed-yield ensures a high seedling crop and a large number of young plants under canopy (Costa and Durigan 2010).

In addition, much reduced genetic resources in the valleys hinder more species from restoring naturally in planted forests. Natural forest areas have decreased greatly and the main vegetation below 1600 m asl is grassland and scrubland, traditionally considered to be no-use lands. Seed bank indispensable for species diversity restoration is mostly lost. Reduced seed dispersal vectors may have also been a factor, as our investigation on bird diversity in the region reveals much lower bird diversity in dry-hot valley *L. leucocephala* planted forests than in middle and high mountain natural forests (unpublished data). Therefore, more forest tree species should be introduced into plantations to facilitate biodiversity increasing and vegetation succession.

Woody species richness and heterogeneity in understory varied greatly among planted forests, with the value of 3-6 and 0.20-0.66, respectively. In mature planted forests (26-31 years old), species richness and heterogeneity of shrub layer were significantly negatively correlated with stem density (Table 2), indicating that woody species diversity in understory increased with decrease of stem density. In 29- and 31-year-old planted forests, with lower stem density than other planted forests caused by inter-shoot competition and seedlings transplanted for reforestation, species diversity was higher than other planted forests and natural shrub grassland. This result is consistent with the findings of some other studies (Alrababah et al. 2007; Sharma et al. 2010). This can be attributed to declining canopy shading, physical barrier and strong competition for resources such as soil water and nutrients in mature sparse planted forests, which is beneficial to species diversity increasing. In planted forests of 29-31 years, higher species diversity in understory can also be due to more tree species planted initially. Therefore, species diversity can be improved by suitable management such as thinning and increasing genetic diversity of trees planted initially.

In comparison, the species heterogeneity of the shrub layer of the reference natural forest (2.28) in the study region, indicated that natural forests maintained rich shrub genetics. Barbour et al. (1980) pointed out that species heterogeneity ≥ 2 could indicate medium to high species diversity. The present study revealed higher species diversity than a previous study in the region (Liu et al. 2012). This could be possibly because of less anthropogenic disturbance, as the reference natural forest in the study area is protected as so-called "fengshui" forests. Besides, the high species diversity of natural forest in this study can be attributed to more complicated community structure and species composition. Natural forest has tree, shrub, and herbaceous layers, with well-developed understory. Shade-tolerant species regenerate continually under the canopy. Both species, and also species and their environment depend highly on each other in natural forests.

This study also revealed that species composition of natural forest was greatly different from that of planted forests. *Cs* between natural forest and planted forests was low (0-0.27). Some previous studies show that low similarity exists in the case of *Cs* with the range of 0.25-0.5 and extremely low similarity in the case of *Cs* less than 0.25 (Felix et al. 2013; Liu et al. 2008). The increase of *Cs* between natural forest and planted forests is also slower than the findings of Fang and Peng (1997) in tropical rain forest region. Therefore, our results suggest that once natural forests in dry-hot valley of the Jinsha River are cleared, it will take a long time to restore diversity of woody species and species composition. This is consistent with the findings of Jiang (1991) in tropical forests. Some previous studies also suggest that it will take hundreds of years to restore plant species of native vegetation in planted forests and that native vegetation of severely-disturbed forest lands cannot be recovered (Jacobs et al. 1988; Meng et al. 2011). Rich species resources in fragmented natural forest serve as an important gene bank for vegetation restoration in the dry-hot valleys and a strict protection is needed.

4 Conclusions

Reforestation after 31 years in dry-hot valley resulted in more woody species colonizing into plantation forests and improvement of community structure compared with reference wastelands. Fifteen woody species colonized into the understory of plantations, among which 9 species were the same as those of natural forest. Plantation forests were more suitable shelters for some forest woody species than natural shrub grassland. Due to harsh environment and much reduced plant genetic resources and seed dispersal vectors, species richness and species heterogeneity of plantations were significantly lower than that of natural forest. Regardless of the combination of woody species that was used to establish a restored forest, *L. leucocephala* dominated in both tree layer and shrub layer. However, species diversity in understory of plantations varied greatly. In mature plantations, species richness, species heterogeneity and Sorenson similarity between plantations and the natural forest were significantly negatively correlated with stem density. In mature sparse planted forests (29-31 years old), higher species diversity and Sorenson similarity index were due to lower stem density and more tree species planted initially. Therefore, we could improve plantation species diversity and conservation value for forest woody species through suitable management such as thinning and increasing genetic diversity of trees planted. In comparison, reference natural forest was an important gene bank, with species heterogeneity of 1.57 and 2.28 for tree layer and shrub layer, respectively. In spite of reforestation after 31 years, *Cs* between plantations and natural forest was low. Therefore, we concluded that it would take a long time to restore species diversity and species composition in dry-hot valleys once natural forests were cleared and it was very important to protect remnant natural forests strictly.

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