SPECIES DIVERSITY OF SEVEN MAN-MADE BROAD-LEAVED MIXED FORESTS IN SOUTH CHINA

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REN, H., PENG, S. L. & YU, Z. Y. 2002. Species diversity of seven man-made broad-leaved mixed forests in south China. Seven man-made broad-leaved mixed forests with an area of 6.4 ha were established in 1964–1979 on an extremely degraded land in south China. The number of species and individuals and Shannon-Wiener Index (H) of the plantations increased gradually after afforestation. The H value of some of the plantations were close to that of the secondary forest. A total of 47 native species invaded and some planted species disappeared in the plantations in 30 years. However, no tree invaded the contrasting barren land since reforestation. This suggested that the process of natural restoration of the tropical seasonal rain forest is a potentially slow process in the extremely degraded ecosystem, but plant diversity of tropical seasonal rain forest can be restored after afforestation in natural condition. Natural succession cannot be considered as a useful management option in extremely degraded region.

Key words: Plant diversity - barren land - man-made broad-leaved mixed forest - secondary forest - rehabilitation - south China

REN, H., PENG, S. L. & YU, Z. Y. 2002. Kepelbagaian spesies tujuh hutan campur daun lebar buatan manusia di selatan China. Tujuh hutan campur daun lebar buatan manusia dengan kawasan seluas 6.4 ha ditubuhkan pada 1964–1979 di tanah yang teruk ternyahgred di selatan China. Bilangan spesies serta individu dan Indeks Shannon-Wiener (H) di ladang tersebut meningkat beransur-ansur selepas penghutanan. Nilai H bagi beberapa ladang hampir sama dengan nilai H hutan sekunder. Sejumlah 47 spesies asli menceroboh manakala sesetengah spesies yang ditanam hilang daripada ladang tersebut dalam masa 30 tahun. Bagaimanapun, tidak ada pokok yang menceroboh kawasan tanah tandus sejak penghutanan semula. Ini menunjukkan bahawa proses pemulihan semula jadi bagi hutan hujan tropika bermusim merupakan proses yang lambat dalam ekosistem yang teruk ternyahgred, tetapi kepelbagaian pokok tersebut dapat dipulihkan selepas penghutanan secara semula jadi. Sesaran semula jadi bukanlah pilihan pengurusan yang baik di kawasan yang begitu teruk ternyahgred.

Introduction

Tropical forest is destroyed at a rate of 1.7×10^7 ha year^{-1} (WRI 1992). Deforestation causes change of climate, soil erosion, decline of fertility in land, exhaustion of head-waters and rapid decline of biodiversity. The series of environmental changes can create long-term economic and ecological effects. Therefore, it is

not surprising that so much world attention is focused on the studies of tropical forest rehabilitation and sustainable management. One of these studies involves artificial restoration of the tropical rain forest (Parham 1993, Yu & Peng 1995).

Several long-term studies on restoration ecology were initiated in the severely eroded coastal region of Dianbai, Guangdong, south China in 1959. To date, seven man-made broad-leaved mixed forests of different ages and species diversities have been established in the barren land. This paper compares the biodiversity of the barren land, the seven man-made broad-leaved mixed forests and a natively occurring secondary forest. The rehabilitation problem of tropical forest is also discussed.

Materials and methods

Experimental site

The experimental area is situated in Dianbai County, Guangdong Province, south China in the northern border of the tropics (110° 54' 18" E and 21° 27' 49" N). The annual average temperature is 23 °C. The average temperatures are 36.5 and for 4.7 °C for the hottest and coldest months respectively. The annual precipitation is 1550 mm, of which 1105 mm occurs in the rainy season and 445 mm in the dry season.

The soils are tropical laterites derived from granites. Most of the top soils have been eroded. In certain places up to 100 cm of the top soil is lost leaving only subsoils. The fertility of the soils is extremely low: organic matter is less than 0.63% and the nitrogen concentration is only 0.03%. The soils have a high bulk density, low porosity and a low water holding capacity (Yao 1984). The indigenous vegetation is originally tropical seasonal rain forest. Most of this has been destroyed by human activities and only remnants of it adjoining the village and temple remain.

Seven man-made broad-leaved mixed forests were planted over an extended period from 1964 to 1979. The researched barren land is next to the plantation, and the secondary forest is about 20 km from the experimental area.

Study methods

The barren land was investigated before reforestation. There was not a single plant on the barren land before the plantations were established. Seven man-made broad-leaved mixed forests were then established in individual-mixed style or in row-mixed style since 1964, with a total area of 6.4 ha. All the plantations had been strictly protected and fertilised twice, once after planting and the second time, a month after that.

The scientific names of the trees and plants were recorded when the trees were planted in 1964 (community I and barren land), 1974 (community II), 1975 (community III), 1976 (community IV), 1977 (community V), 1978 (community VI) and 1979 (community VII) (Appendix 1).

The last field survey of all the communities was conducted in October 1994. A survey of two 10×10 m^2 tree quadrats (tree height > 1.5 m), four 5×5 m^2 shrub quadrats (0.5 m < height < 1.5 m), and four 1×1 m^2 herb quadrats (height < 0.5 m) was made in each plot. The scientific names of tree species, height, diameter at breast height (dbh, only for tree), crown size (only for shrub and herb) and growth status (live or dead) of each individual were recorded.

In the barren land, the plot area was 5×5 m^2. The plot comprised 25 quadrats of size 1×1 m^2. The scientific names, height and crown size of each individual were recorded.

In the secondary forest, eight quadrats (10×10 m^2) were surveyed. The items recorded were the same as those of the man-made forests. The only difference was that the secondary forest had a plot area of 800, 100 and 8 m^2 for tree, shrub and herb layers respectively. The areas used in this study were similar to those chosen by Wang (1982) who studied the lower subtropics.

The forest species diversity index applied here was the Shannon-Wiener index (Krebs 1985):

$$H = \sum_{i=1}^{S} (p_i)\ (\log_2 p_i), \text{ which is equal to } H = 3.3219[\log N - \frac{1}{N} \sum_{i=1}^{S} n_i \log n_i]$$

where

H = Shannon-Wiener index (index of species diversity),
S = number of species recorded in the sample,
p_i (or n_i) = proportion of total sample belonging to the ith species,
N = total individual of all the species and
3.3219 = coefficient switching $\log_2$ to $\log_{10}$.

The larger the value of H, the greater is the diversity.

Results and discussion

Plant diversity in the barren land

No plants grew in the barren land in 1964 and the H was 0 (Table 1). The barren land with an area of 3.7 ha had been protected since 1964 for comparison in this study. Several clumps of plants grew sparsely in the barren land in 1994. Nine species comprising 14 individuals (in 25 m^2 plot) were found. The plants recorded in the herb layer plants were *Eriachne pallescens, Aristida chinensis, Evolvulus alsinoides, Waltheria americana* and *Dicranthus dichotoma.* The H values for the herb and shrub layers were 1.316 and 0.201 respectively. The main shrubs were

Wikstroemia indica, Phyllanthus cochinchinensis, Clerodendrum fortunatum and *Breynia frusticosa.* No tree invaded the barren land in the past 30 years. This showed that a very long period is required for barren land to develop naturally into forest in an extremely degraded tropical land.

Plant diversity in the seven man-made broad-leaved mixed forests

Species richness and H values are two basic units for biodiversity measurement. Appendix 1 shows the species and total number of individuals recorded in 1994. Table 1 shows the development of species, number of individuals and the H values of the man-made forests.

Community I was established in 1964. The species planted were *Cinnamomum camphora, Castanopsis fissa, Liquidamar formosana, Lysidice rhodostegia* and *Helicia cochinensis.* A total of 72 individuals of the five species was cultivated in 200 m^2. In 1994, *Cinnamomum camphora* and *Castanopsis fissa* still existed, but their importance decreased greatly. *Helicia cochinchinsis* population declined while *L. rhodostegia* and *L. formosana* died. On the contrary, the invading species *Syzygium renderianum* became the largest population in the community; its density was 130 individuals per 200 m^2, and the important value was 58.14%. The number of other invaders such as *Clerodendrum fortunatum, Cratoxylon ligustrinum, Rhaphiolepis indica, Psychotria rubra* and *Symplocos chunii* were also great, ranging from 11 to 45. The species number of the plantation increased from 5 to 36 and the H value increased from 0.909 to 3.82 in the tree layer in 30 years. For the shrub the species number and H value increased from 0 to 33 and 0 to 3.81 respectively while for the herb layer the increments were from 0 to 17 and 0 to 2.16 respectively.

Community II was established with *Albizia odoratissima, A. procera, Cassia siamea, Aphanamixis polystachya, Acacia auriculiformis* and *Dalbergia odorifera* in 1974. The density was 72 individuals per 200 m^2. Native species such as *Elaeocarpus sylvestris* (49 individuals), *Syzygium bullockii* (24 individuals) and *Archidendron clypearia* (22 individuals) were found in the community in 1994. The invading populations took the place of *Albizia odoratissima, A. procera, Cassia siamea, Acacia auriculaeformis* and *Dalbergia odorifera.* Only six individuals of *Aphanamixis polystachya* were found in the plot in 1994. The species number increased from 6 to 27 and H increased from 0.221 to 3.68 in the tree layer in 20 years. The species number increased from 0 to 28 and H increased from 0 to 2.89 in the shrub layer. The species number increased from 0 to 18 and H increased from 0 to 3.51 in the herb layer.

The species planted in Community III were *Aphanamixis polystachya, Terminalia bellerica, Chukrasia tabularis* and *Ailanthus triphysa* in 1975, and the density was 52 individuals per 200 m^2. Only one individual of *Aphanamixis polystachya* survived and all the individuals of *Terminalia bellirica, Chukrasia tabularis* and *Ailanthus triphysa* died. A total of 150 individuals of *Syzygium bullockii,* 66 individuals of *Litsea glutinosa,* 64 individuals of *Rhaphiolepis indica* and 33 individuals of *Litsea rotundifolia* invaded the plot. The species number increased from 4 to 34 and H increased from 0.381 to 3.78 in the tree layer in 19 years. The species number increased from

Table 1 The development of species diversity of the communities

Community (Plantation year)	The biodiversity index planted at the first year					The biodiversity index in 1994								
	Tree layer			Shrub layer	Herb layer	Tree layer			Shrub layer			Herb layer		
	Species	Number	H	H	H	Species	Number	H	Species	Number	H	Species	Number	H
Barren land	0	0	0	0	0	0	0	0	4	5	0.201	5	9	1.316
Com. I (1964)	5	72	0.909	0	0	36	411	3.82	33	299	3.81	17	152	2.16
Com. II (1974)	6	72	0.221	0	0	27	152	3.68	28	137	2.89	18	69	3.51
Com. III (1975)	4	52	0.381	0	0	34	560	3.78	24	216	3.14	12	102	2.72
Com. IV (1976)	5	52	0.391	0	0	26	219	4.03	21	112	3.43	11	37	3.03
Com. V (1977)	2	52	0.659	0	0	24	220	3.66	17	85	3.62	16	56	3.44
Com. VI (1978)	3	52	0.700	0	0	22	145	3.56	21	274	2.98	17	66	3.18
Com. VII (1979)	10	52	0.584	0	0	11	47	2.28	14	21	2.81	11	245	0.68
Secondary forest	-	-	-	-	-	52	224	4.10	34	385	4.11	26	83	4.02

H = Shannon - Winner index (= index of species diversity)
Com. = Community

0 to 24 and H increased from 0 to 3.14 in the shrub layer. The species number increased from 0 to 12 and H increased from 0 to 2.72 in the herb layer.

Community IV was established with *Albizia procera, Aphanamixis polystachya, Acacia auriculiformis, Albizia lebbek* and *Dalbergia odorifera* in 1976. The density was 52 individuals per 200 m^2. In 1994, the invader *Litsea glutinosa* became the largest population in the community with 43 individuals. *Aphanamixis polystachya, Albizia lebbek* and *Acacia auriculiformis* grew well, while the *Dalbergia odorifera* population had died. The species number increased from 5 to 26 and H increased from 0.391 to 4.03 in tree layer in 18 years. The species number increased from 0 to 21 and H increased from 0 to 3.43 in the shrub layer. The species number increased from 0 to 11 and H increased from 0 to 3.03 in the herb layer.

Community V was established with *Aphanamixis polystachya* and *Acacia auriculiformis* in 1977. The density was 52 individuals per 200 m^2. In 1994, both populations still grew in the community but their numbers decreased to 12 and 7 respectively. The native species *Schefflera octophylla* (44 individuals), *Carallia brachiata* (28 individuals), *Clerodendrum cyrtophllum* (20 individuals) and *Symplocos chunii* (13 individuals) became the dominant population in the plantation. The species number increased from 2 to 24 and H increased from 0.659 to 3.66 for tree layer in 17 years. The species number increased from 0 to 17 and H increased from 0 to 3.62 in the shrub layer. For herb layer the species number increased from 0 to 16 and H increased from 0 to 3.44.

Community VI was established with *Albizia odoratissima, Acacia auriculiformis* and *Aquilaria sinensis* in 1978, and the density was 52 individuals per 200 m^2. All the individuals of the *Albizia odoratissima* and *Aquilaria sinensis* population died out after 16 years, while all the individuals of *Acacia auriculiformis* population survived. Some native species such as *Psychotria rubra* (37 individuals) and *Schefflera octphylla* (13 individuals) entered the community naturally and grew well. The species number increased from 3 to 22 and H increased from 0.700 to 3.56 in the tree layer in 16 years. The species number increased from 0 to 21 and H increased from 0 to 2.98 in the shrub layer. The species number increased from 0 to 17 and H increased from 0 to 3.18 in the herb layer.

Community VII was established with *Acacia auriculiformis, Carallia brachiata* and eight other species in 1979. The density was 52 individuals per 200 m^2. All the 28 individuals of the *A. auriculiformis* survived but most individuals of *C. brachiata* and other populations died out after 15 years. However, eight new species of plants invaded the community at the same time. The species number increased significantly, and H increased from 0.584 to 2.28 in the tree layer. The species number for shrub layer increased from 0 to 14 and H increased from 0 to 2.81. The species number increased from 0 to 11 and H increased from 0 to 0.68 in the herb layer.

The species richness and the number of individuals in the man-made mixed forests developed rapidly in natural condition. Although the plantations were established at the same severely eroded land some trees planted in the communities disappeared gradually. However, new species entered the communities and grew well. The number of species and individual of the plantations increased

continuously. We found 72 species in the tree layer of the seven communities in the 1400 m^2 plot in 1994. Thus it was clear that the communities increased plant diversity during the vegetation restoration.

The plant diversity in secondary forest

We found 52 species and 224 individuals per 800 m^2 in the tree layer of the secondary forest. Among the populations present were *Aporosa chinensis, Aquilaria sinensis, Camellia caudata, Cinnamomum camphora, Psychotria rubra, Schefflera octophylla, Sterculia lanceolata, Symplocos chunii,* Syzygium *levinei* and *Syzygium rehderianum.* Only *Symplocos chunii, Carallia brochiata* and *Rhaphiolepis indica* appeared in all the seven man-made forests and the secondary forest. The H for tree layer was 4.10 in 1994. There were 34 species and 385 individuals per 100 m^2 in the shrub layer and H was 4.11. In the herb layer, there were 26 species and 83 individuals per 8 m^2 and H was 4.02.

Conclusions

The extremely degraded tropical land could be revegetated through natural succession if given abundant protection and over a long period. However, the vegetation could be restored quickly by afforestation.

It was obvious that the plant diversity of the man-made forests increased gradually in the tree, shrub and herb layers. The shrub and herb plants gradually invaded the plantations after afforestation. Hereafter, the species number of shrubs and herbs increased constantly. When the man-made forest had developed for about 10 years, the native species appeared in the tree layer and a closed tree layer formed gradually.

All the man-made broad-leaved mixed forests developed towards the climax community in spite of the different initial species and age. Among the 72 species of trees that appeared in the 1400 m^2 plot, 47 species of trees were natural invaders. The invaders belonged to the common species in climax of this zone and could be found in the secondary forest. This meant that the plant diversity of tropical seasonal rain forest could be restored in severely degraded ecosystem after the establishment of plantations.

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Appendix 1 The species and their numbers in the seven man-made and one secondary forests in 1994

Species	Com. I	Com. II	Com. III	Com. IV	Com. V	Com. VI	Com. VII	Secondary forest
Abarema lucida	-	-	-	-	-	-	-	1
Acacia auriculiformis	8	-	1	13	7	23	28	-
Acacia confusa	-	-	-	4	-	-	-	-
Acronychia pedunculata	9	-	1	-	-	-	-	-
Aglaia odorata	-	-	-	-	-	-	-	2
Alangium chinensis	-	-	2	-	1	-	-	-
Albizia procera	-	-	-	2	-	-	-	-
Albizia lebbek	-	-	-	11	-	-	-	-
Albizia odoratissima	-	-	-	12	-	-	-	-
Alchornea trewioides	-	-	-	-	-	-	-	1
Aphananmixis polystachya	-	6	1	20	12	17	-	-
Aporosa chinensis	8	1	7	4	-	2	-	15
Aquilaria sinensis	-	-	-	-	4	-	-	4
Archidendron clypearia	-	22	-	-	-	-	-	-
Ardisia quinquegona	-	-	-	-	-	-	-	2
Artocarpus styracifolius	-	-	-	-	-	-	-	1
Bischofia javanica	-	-	-	-	-	-	-	1
Breynia fruticosa	-	2	1	-	2	1	-	-
Bridelia monoica	3	-	7	18	2	6	-	-
Camellia caudata	-	-	-	-	-	-	-	51
Carallia brochiata	7	7	13	12	28	3	3	1
Castanopsis fissa	17	-	-	-	-	-	-	-
Chrysophyllum lanceolatum	-	2	-	-	-	-	-	-
Cinnamomum camphora	24	-	1	-	1	2	-	5
Clerodendrum cyrtophllum	2	-	22	10	20	-	-	-
Clerodendrum fortunatum	45	-	-	15	-	3	-	-
Clerodendrum japonica	-	-	-	3	-	5	-	-
Cratoxylon ligustrinum	25	-	-	-	-	-	-	1
Cryptocarya chinensis	-	-	-	2	1	-	-	2
Dalbergia hainanensis	-	-	-	1	-	-	-	-
Desmodium dunnii	1	-	15	-	-	-	-	-
Desmos chinensis	-	-	-	-	-	-	-	2
Elaeocarpus sylvestris	-	49	20	6	-	2	1	3
Eurya nitida	1	-	-	-	-	-	-	-
Evodia meliaefolia	-	2	-	-	3	-	2	-
Ficus hirta	-	-	-	-	-	-	-	1
Ficus variolosa	-	-	-	-	-	-	-	1
Fissistigma glaucescens	-	-	-	-	-	-	-	3
Fissistigma glaucescens var. *Lin*	-	-	-	-	-	-	-	1
Garcinia oblongifolia	1	1	-	-	-	-	-	-
Gardenia jasminoides	-	-	-	1	-	-	-	1
Gelonium glomerulatum	-	-	-	-	-	-	-	3
Glochidion hongkongense	5	-	1	1	-	-	-	-
Helicia cochinchinensis	8	1	1	-	-	-	-	-
Helicia reticulata	3	3	-	-	-	-	-	-
Ilex anglata	1	-	6	-	2	-	-	-
Ilex rotunda	-	-	4	-	-	-	-	1
Ilex triflora	-	-	-	-	-	-	-	1
Ixora hainanesis	-	-	-	-	-	-	-	2
Lantana camara	2	-	-	2	-	1	-	-
Liquidambar formosana	2	-	-	-	-	-	-	-
Litsea glutinosa	-	2	66	43	-	-	-	1

(Continued)

(Table 1 - continued)

Species	Com. I	Com. II	Com. III	Com. IV	Com. V	Com. VI	Com. VII	Secondary forest
Litsea rotundifolia	1	-	33	1	-	-	-	-
Machilus breviflora	-	4	-	-	-	-	-	-
Mallotus paniculatus	2	-	-	-	-	-	-	-
Melastoma candidum	-	-	-	-	1	-	-	-
Memecylon ligustrifolium	-	4	-	-	-	1	1	-
Memecylon octocostatum	-	-	-	-	-	-	-	4
Michelia macclurei	-	1	-	-	-	-	-	-
Microdesmis casearíaefolia	-	-	-	-	-	-	-	1
Mimosa sepiaria	-	-	1	-	-	-	-	-
Mischocarpus sundaicus	-	-	-	-	-	-	-	8
Olea dioica	-	-	-	-	-	-	-	11
Pavetta hongkonggensis	-	-	-	-	-	-	-	1
Photinia benthamiana	6	6	31	5	6	-	-	-
Phyllanthus cochinchinensis	-	1	-	-	-	-	-	-
Prunus phaeosticta	-	-	-	-	-	-	-	2
Psychotria rubra	21	-	-	-	-	37	-	38
Pterospermum heterophyllum	-	6	-	-	-	-	-	-
Randia acuminatissima	-	-	-	-	-	-	-	1
Randia spinosa	2	-	-	-	-	2	1	2
Rapanea neriifolia	-	1	-	-	-	-	-	2
Rhaphiolepis indica	26	4	64	15	3	1	2	1
Rhodomyrtus tomentosa	2	-	1	-	4	-	-	-
Rhus succedanea	3	-	8	-	-	-	-	1
Santalum album	-	-	9	11	-	-	-	-
Schefflera octophylla	1	-	1	-	44	13	2	5
Schima superba	-	1	-	-	-	-	-	-
Scolopia chinensis	-	-	-	-	-	-	-	1
Sterculia lanceolata	-	-	-	-	-	-	-	11
Streblus asper	-	-	-	-	-	-	-	1
Strychnos angustiflora	2	-	-	-	-	-	-	2
Symplocos chunii	11	7	5	1	13	9	3	18
Symplocos cochinchinensis	-	2	-	-	-	-	-	4
Symplocos racemosa	1	-	-	-	-	-	-	-
Syzygium bullockii	-	24	150	-	7	-	-	-
Syzygium levinei	53	-	4	3	5	2	1	4
Syzygium odoratum	-	-	-	-	-	-	-	1
Syzygium rehderianum	130	30	7	16	-	4	1	6
Tarrietia octophylla	-	-	1	-	-	-	-	-
Terminalia bellirica	-	-	-	-	5	-	-	-
Ternstroemia pseudoverticillata	3	2	39	6	1	-	-	-
Tricalysia dubia	1	-	-	-	-	-	-	2
Uvaria microcarpa	-	3	1	-	9	8	2	8
Vitex quinata	-	1	-	-	-	-	-	-
Wrightia laevis	-	-	-	2	-	-	-	-
Xylosma longifolium	-	-	17	-	-	-	-	-
Zanthoxylum avicennae	-	-	-	-	-	2	-	-