REHABILITATION OF ERODED TROPICAL COASTAL LAND IN GUANGDONG, CHINA

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YU, Z. Y., WANG, Z.H. & HE, S.Y. 1994. Rehabilitation of eroded tropical coastal land in Guangdong, China. Forest rehabilitation studies were initiated in 1959 on a severely eroded 430-ha land in southern China. This 30-year project has shown that (a) a diverse tropical forest can be re-established on severely degraded sites, (b) an increase in plant diversity leads to an increase in the diversity of other organisms, and (c) increasing ecosystem diversity appears to be related to a decrease in the extent of insect herbivory.

Key words: Rehabilitation - degraded lands - China - mixed species plantations

YU, Z. Y., WANG, Z.H. & HE, S.Y. 1994. Pemulihan tanah hakisan pesisir pantai tropika di Guangdong, China. Kajian mengenai pemulihan hutan telah dimulakan pada tahun 1959 di tanah seluas 430 ha yang mengalami hakisan teruk di Cina Selatan. Projek 30 tahun ini menunjukkan (a) hutan tropika yang pelbagai boleh tumbuh di kawasan yang ternyahgred, (b) pertambahan dalam kepelbagaian tumbuhan membawa kepada pertambahan dalam kepelbagaian organisma lain, dan (c) penambahan kepelbagaian ekosistem nampaknya berhubung kait dengan berkurangnya takat herbivor serangga.

Introduction

Increasing human populations and the intensification of agriculture and industry have resulted in environmental impacts including the rapid destruction of tropical forest. Deforestation is followed by soil erosion, a loss of soil fertility, hydrological changes and a loss of economic productivity. There is, therefore, an urgent need for research into forest rehabilitation and the restoration of ecosystem function.

Since 1959 rehabilitation studies on severely eroded land have been carried out by the South China Institute of Botany, Academia Sinica and the Xiaoliang Station of Water and Soil Conservation, Dianbai, Guangdong (Yu & Pi 1985, Yu & Wang 1988). The approach taken was to firstly reforest the degraded lands using *Pinus* and *Eucalyptus* species. Subsequently, parts of these plantations were replaced by mixed species plantations of broad-leaved trees and, later, by commercially important cash crops. The aim of the study was to find an effective means of reforestation and to study the inter relationships between structure and function of the man-made forest ecosystems.

Study site

The experimental area is at 110° 54' 18" east and 21° 27' 49" north.

The climate in the area is quite seasonal. The total rainfall varies between 1400 mm and 1700 mm with 75% being received between May and September. Much of this falls in heavy storms. The daily temperatures range from an annual maximum of 36.5 °C to a minimum of 4.7 °C. The monthly mean varies from about 16 °C to 29 °C (Yu & Wang 1988).

The vegetation at the site was originally tropical monsoon forest (Guangdong Institute of Botany 1976). Most of this has been destroyed by human activities although small remnants remain in the region, the nearest being about 20 km from the experimental area (Figure 1). In 1959 this area of remaining forest was found to contain 293 species of higher plants belonging to 243 genera and 87 families. Vegetation in the degraded areas of the site is mostly sparse tufts of grass and scattered shrubs. The species present include grasses and herbs such as *Eriachne pallescens, Aristida chinensis, Evolvulus alsinoides* and *Waltheria americana.* Common shrub species are *Wikstroemia indica, Phyllanthus cochinchinensis, Clerodendrum fortunatum, Breynia fruticosa* and *Aporosa chinenis* (Yu & Wang 1988).

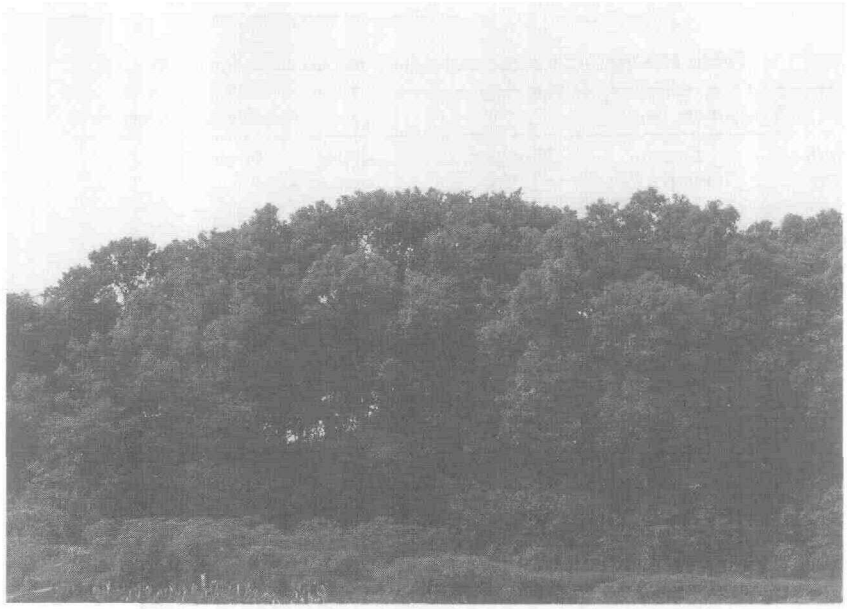

Figure 1. The natural secondary forest near a village

The soils are tropical laterites derived from granites (Tu & Yao 1983). Most of the topsoils have been eroded and in places up to 100 cm of topsoil has been lost leaving only subsoils (Yao *et al.* 1984) (Figure 2). The fertility of the soils is extremely low: organic matter was less than 0.63 % and the nitrogen concentration was only 0.03 % (Table 1). The soils have a high bulk density, low porosity and a low water holding capacity (Table 2).

Figure 2. The bare eroded land

Table 1. Organic matter and nitrogen content of eroded soil

Bare land			Residual secondary forest		
Depth (cm)	Organic matter (%)	Nitrogen (%)	Depth (cm)	Organic matter (%)	Nitrogen (%)
0-7	0.63	0.03	1-7	4.14	0.212
30-40	0.37	-	10-20	2.09	0.120
100-110	0.35	-	35-45	n.a.	0.078

Table 2. Physical characteristics of eroded soil

Depth (cm)	Bulk density (g cm $^{-3}$)	Total porosity (%)	Capillary porosity (%)	Moisture holding capacity (%)
0-1	2.11	39.4	38.8	18.4
10-20	2.08	25.9	35.1	16.9
20-30	2.04	35.5	35.0	17.1
30-40	2.03	41.4	40.8	20.1
40-50	1.94	41.4	41.2	21.3
50-60	1.93	31.3	31.0	21.6
60-70	1.87	46.9	46.1	24.7
70-80	1.82	48.5	48.0	26.3

The region has a high population density. Overall the population is 534 people per km ^{2} and there are five villages within 2 km of the experimental site each with a mean population of 200 - 300 people. The people use higher hill slopes to graze

buffalo and cattle and lower slopes are terraced for sweet potato or cassava cultivation. Grasses in the area are cut for fuel.

Rehabilitation procedure

Stage 1, 1959-1973: Establishment of pioneer communities

The primary goal during this stage was to control soil erosion. Plantations of mainly *Pinus massoniana* (134 ha) and *Eucalyptus exserta* (300 ha) (Figure 3) were established, most being planted by 1964. These species were chosen because of their ability to tolerate both drought and the poor soils at the site. The trees were initially grown in bags containing fertile nursery soil but were not fertilised further after being planted in the field. Planting densities varied from 900 to 3450 trees per hectare.

These trees grew well initially but the rate of growth declined after 8-10 years. One of the reasons for this was that villagers were permitted to harvest litter from the plantation forest floor to use as fuel. In 1976 part of the *E. exserta* forest was felled and the trees allowed to coppice and produce a new forest (Anonymous 1977).

Figure 3. Pioneer forest of *Eucalyptus exserta*

Stage 2: Establishment of a mixed forest

First attempts to enrich *Eucalyptus* and *Pinus* plantation with other tree species were made between 1964 and 1966. Various broad leaved species were planted beneath the eucalypts and pines and although these commonly survived for 12

months, most died within 2 years. In the case of the eucalypt plantation, only a few individuals of *Cinnamomum camphora* survived while several *Uvaria microcarpa* and *Cratoxylon ligustrinum* persisted beneath the pines.

In 1974 part of the *E. exserta* plantation was felled and a variety of broad-leaved trees were planted in an area eventually covering 20 ha. Most of the species planted were natives. These included trees such as *Terminalia hainanensis, Aquilaria sinensis, Chukrasia tabularis, Santalum album, Cassia siamea, Erythrophloeum fordii, Syzygium hancei, Syzygium levinei* and *Aphanamixis polystachya.* Understorey plants used included *Alpinia oxyphylla, Amomum villosum* and *Gardenia jasminoides.*

Some exotic species were also used such as nitrogen fixing species like *Acacia auriculiformis, Albizzia odoratissima, Albizzia procera* and *Leuceana leucocephala.*

The seedlings were planted in large holes that were refilled using soil brought from nearby paddy fields plus organic fertiliser from fish ponds or litter or green manure together with some phosphorus fertiliser. Once planted the seedlings were tended and no collection of litter or fuel was permitted.

In contrast to the pine and eucalypt monocultures used earlier, these species were planted in mixtures (He & Yu 1984, Liao *et al.* 1984). Various combinations were used. These included nitrogen fixers with non-nitrogen fixers, deep rooted with shallow rooted, fast-growing with slower-growing, and evergreen species with deciduous species. Eight types of mixture were finally established:

i. *Choerospondias axillaris, Aphanamixis polystachya, Terminalia myriocarpa, Homalium hainanensis, Chukrasia tabularis* and *Lysidice rhodostegia* (block mixture)
ii. *Aphanamixis polystachya, Albizzia odoratissima, Albizzia procera* and *Cassia siamea*
iii. *Aphanamixis polystachya, Acacia auriculiformis, Dalbergia odorifera* and *Albizzia procera*
iv. *Chukrasia tabularis var. velutina, Terminalia bellirica* and *Aphanamixis polystachya*
v. *Aquilaria sinensis, Acacia auriculiformis, Albizzia odoratissima, Dalbergia balansae* and *Leucaena leucocephala vc. Salvador*
vi. *Aphanamixis polystachya* and *Acacia auriculiformis* (planted in alternate strips)
vii. *Syzygium hancei, Syzygium lerinei, Terminalia hainanensis* and *Podocarpus nagi*
viii. *Acacia mangium, Acacia auriculiformis* and *Acacia holosericea*

All were planted at a spacing of 2 × 3 m. In some cases various species were underplanted to create multi layered forests (Figure 4). Such underplantings included *Calamus tetradactylus, Alpinia oxyphylla* and *Amomum villosum.*

The first plantings were carried out in 1974 when 10 species were established in a one hectare site. By 1980, 320 species, including 75 legumes, had been planted in an area of 20 hectares.

Figure 4. Broad-leaf mixed forest of several layers

Stage 3: Site changes and successional studies

Permanent sampling plots were established in the barren land, eucalypt forest and mixed forest to measure changes in soil physical and chemical properties, as well as hydrological changes (Anonymous 1977, Lu & Li 1982, Tu & Yao 1983). Hydrological measurements were made in small (3 - 4 ha) experimental watersheds in each forest type.

Changes to the microclimate were monitored using meteorological stations established in 1980 in each vegetation type (Huang *et al.* 1984, Yi *et al.* 1984).

The population of other biota present at the sites were examined over the period to assess the development and integration of the evolving forest ecosystem.

Results

Tree growth in the mixed forest

The growth of some of the main tree species is shown in Table 3. The leguminous trees had the fastest early growth but the native species began to catch up at later stages. Best growth for most species was noted among trees planted in lower slope positions. By 14 years the *Acacia auriculiformis* had a height of 11.4 m and a DBH of 11.7 cm. The native species *Aphanamixis polystachya* at age 15 years was 10.6 m tall with a DBH of 14.3 cm. The *Leucaena leucocephala* died after about three years.

Table 3. Growth of some of the main species grown in different topographic positions in the mixed forest plantations

Species	Age (years)	Topographic position *	Mean height (m)	Mean DBH (cm)
Aphanamixis polystachya	9	L	9.6	13.2
		M	6.2	9.2
		U	4.7	8.2
Albizzia procera	9	L	8.2	11.2
		M	5.0	6.8
		U	4.0	5.7
Cassia siamea	8	L	10.6	13.3
		M	8.3	9.3
Acacia auriculiformis	9	M	9.9	8.9
	6	U	7.0	11.0
Albizzia odoratissima	8	L	7.3	9.6
	7	U	6.5	7.0
Terminalia hainanensis	9	M	5.2	4.8
Chukrasia tabularis	7	M	4.8	6.0
Aquilaria sinensis	7	M	4.7	9.0
Santalum album	5	M	6.3	7.1

* L= lower, M = mid, U = upper.

Soil properties

Soil erosion continued to occur in the untreated bare land. Soil organic matter, nitrogen and phosphorus concentration continued to decline (Table 4). Reforestation using eucalypts resulted in a small increase in topsoil organic matter but no real benefit over the measurement period in nitrogen or phosphorus levels, presumably because of continued litter harvesting. Even so, these levels were higher than those in the non forested bare land. Substantial increases followed the establishment of the mixed species forest, especially when this contained a legume component, and these changes continued to increase during the measurement period. All these levels were still well below those present in a patch of residual natural forest although restoration was clearly well advanced. At the current rate of change it could take up to 150 years to restore soil organic matter levels to their original state (Insam *et al.* 1990).

Hydrological changes

Measurements of average annual rainfall and runoff are given in Table 5. These show that the highest runoff (7043 m^3 h^{-1}) occurred in the eucalypt plantation while only 490 m^3 h^{-1} was measured as runoff in the mixed forest area.

Erosion occurred at the rate of 52 t ha^{-1} from the bare land but only 0.18 t ha^{-1} from the mixed forest area.

Table 4. Soil fertility in various forest types

Forest	Organic matter (%)	Total N (%)	Total P (%)
Bare land			
1979 (0-15 cm)	0.64	0.031	0.006
1989 (0-20 cm)	0.45	0.028	0.007
Eucalypt forest			
1979 (0-15 cm)	1.03	0.05	0.022
1989 (0-20 cm)	1.06	0.05	0.014
Mixed forest (without legumes)			
1979 (0-15 cm)	1.20	0.065	0.010
1989 (0-20 cm)	1.47	0.070	0.017
Mixed forest (with legumes)			
1979 (0-15 cm)	1.30	0.068	0.026
1989 (0-20 cm)	1.82	0.099	0.052
Natural secondary forest			
1989 (0-20 cm)	4.18	0.215	0.054

Measurements of ground water levels in each area showed the depth to the water table varied between 3.6 and 4.1 m at the bare site, 1.8 and 4.5 m at the mixed forest site and 8.9 and 13.1 m at the eucalypt forest site. These levels varied with the seasonal and annual variations in rainfall.

Table 5. Comparison of hydrological effects of different forest types based on measurements carried out in 3-4 hectare catchments between 1983 and 1989. Data given are the annual averages over this period

	Average rainfall mm y^{-1}	Average runoff m^3 ha^{-1}	Average erosion t ha^{-1}
Bare land	1598	3789	52.32
Eucalypt forest	1629	7043	10.79
Mixed forest	1615	490	0.18

Microclimatic changes

Reforestation modified the microclimate of the area (Huang *et al.* 1984). Before reforestation (1958-59) the annual average temperature was 23.2 °C with

an annual amplitude of 14.4 °C. The monthly temperatures were also higher than those at the meteorological station at Dianbai county, 13 km distant, except during January to March. After reforestation (1988-89) the annual temperature declined to 22.6 °C with an amplitude of 12.2 °C and was lower that the temperatures at Dianbai County Meteorological station. Temperatures tended to be lower and the amplitude of temperature variations tended to be smaller in the mixed forest than in the eucalypt forest and both were less than in the bare site. Highest relative humidities were found in the mixed forest.

Development of the mixed forest ecosystem

The trees and understorey plants in the mixed forests grew well. In some cases competition led to the exclusion of certain species. For example, the use of *Quercus acutissima* tended to exclude *Calamus bonianus* and most other species. By contrast certain species were also found to colonise the site from outside. For example, in one area of 1.4 ha, 41 species were planted between 1975 and 1980. In 1982, however, 119 species were present on the site, the additional species having been able to colonise the site over the period. Thirteen of these species were brought in by birds.

In the early stages of development of the mixed plantation several trees were severely attacked by insects. *Arlanthus malabaricus,* which is a native of Yunnan Province, was planted in 1974 and grew well initially but most plants were attacked and killed by the insect *Eligma narcissus* in 1976 - 1977. *Chukrasia tabularis* was also planted in 1974 but was badly attacked by *Anoplophora chinensis.* In one experimental plot of 1 ha, 20 herbivorous insect species were observed. Besides the two insects mentioned *Catopsilia crocale* also caused severe damage.

Few birds were noticed in the early stages of plantation development but the numbers increased sharply after 1979 and by 1983 at least 20 species were observed. Spiders also increased in number. One of these was *Nephila imperialis* which was first observed at the area in 1978 in low numbers. Its population subsequently increased and by 1980 - 1981 it was the chief predator of harmful insects. In 1982 the biomass of the spider was estimated to be 5.46 kg ha^{-1} and it was estimated to consume 36 kg ha^{-1} of insects. Many of the birds were also effective in reducing the number of insect herbivores. As a result of the spiders and the birds, surviving *Ailanthus* and *Chukrasia* trees recovered. After 1982 frogs and lizards contributed to the reduction in leaf herbivory by insects (Chen & Liao 1984, Liao & Chen 1984, Xie & Liao 1984, Liao 1985).

A summary of some of the main differences in species composition of the three site types is given in Table 6.

In 1984 an outbreak of the tree rat *Rattus rattus slandeni* occurred, the population reaching 13.3 animals per hectare. These ate a variety of food resources including fruits, seed, locusts and lizards. It also became a serious predator of birds eggs (Liao & Chen 1986).

Table 6. A summary of some biological diferences between the degraded site, the eucalypt forest site and the broad-leaved forest site

Ecological group	Degraded land	Eucalypt forest	Mixed forest
Higher plant species	10	12	320
Bird species	4	7	13
Insect species (estimates)	50	100	300
Small mammal species	3	1	3
Biomass of soil animals (g m^{-2})	0.33	8.92	18.20
Biomass of soil micro organisms (mg g^{-1} dry soil)	30	78	198

Discussion and conclusion

Rehabilitation of degraded barren land was achieved using this two-stage approach. The new forest has several layers and about 320 plant species and is therefore beginning to achieve some structural and floristic similarities with the residual mixed forests in the district. Soil conditions have improved dramatically, especially where legumes were incorporated into the species mix, although organic matter concentrations are still far poorer than in the residual forest. The amounts of topsoil lost were substantially reduced in the mixed species plantation.

The creation of a diverse plant cover has led to the development of diverse food webs both above and below the ground. There is some evidence that insect pest outbreaks have decreased as these webs have developed.

The use of eucalypts and mixed forest plantings to improve the soil and environment in the area has allowed a variety of other commercially useful plants to be established (Figure 5). These include *Piper nigrum, Livistonia chinensis, Litchi chinensis, Carica papaya, Averrhoa carambola, Artocarpus heterophylla* and *Cocus nucifera.*

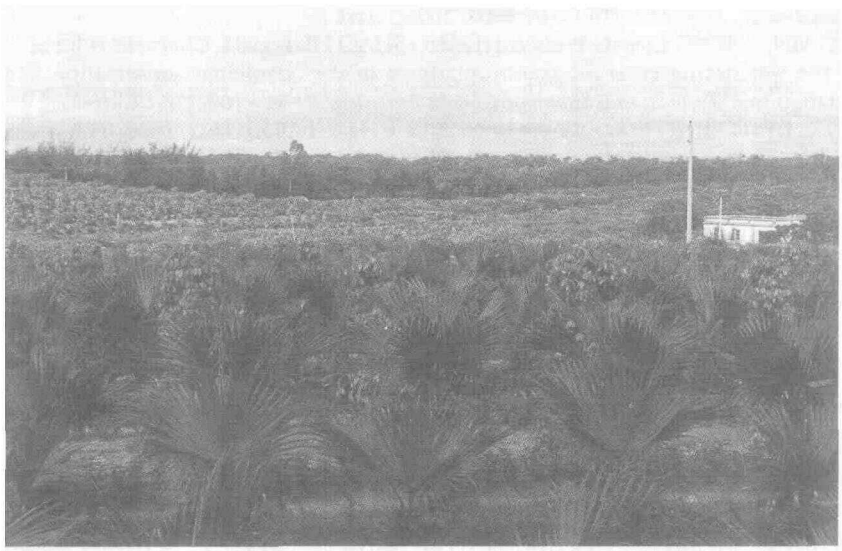

Figure 5. Economic crops and fruit trees

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