SURVIVAL, GROWTH AND BIOMASS OF *ACACIA AURICULIFORMIS* AND *SCHIMA SUPERBA* SEEDLINGS IN DIFFERENT FOREST RESTORATION PHASES IN NAN'AO ISLAND, SOUTH CHINA

P Li[1, 2], ZL Huang[1], YC Xiang[1] & H Ren[1, *]

[1]*South China Botanical Garden, the Chinese Academy of Sciences, Guangzhou, 510650, China*
[2]*Graduate University of the Chinese Academy of Sciences, Beijing, 100049, China*

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LI P, HUANG ZL, XIANG YC & REN H. 2011. Survival, growth and biomass of *Acacia auriculiformis* and *Schima superba* seedlings in different forest restoration phases in Nan'ao Island, south China. Accelerating the succession of degraded ecosystems to regional natural forests has become a key goal in restoration ecology and forest management. Three plant communities (a degraded hilly land, an artificial *Acacia* plantation and a secondary forest) representing three restoration phases were used on Nan'ao Island in south China. Seedlings of the exotic *Acacia auriculiformis* and the native *Schima superba* were transplanted into each community. Leaf area index, litter stock, soil moisture and soil fertility were higher in the *Acacia* plantation and secondary forest than in the degraded hilly land. However, light transmission was much greater in the degraded hilly land than in the other two communities. Survival and growth of *A. auriculiformis* were greatest in the degraded hilly land but survival and growth of *S. superba* were greatest in the *Acacia* plantation. Growth responses of the transplanted seedlings were related to soil water content and light transmission rate. To accelerate the vegetation restoration of the islands, the existing secondary forest should be protected and the plantations should be improved by introducing native tree seedlings. As a possible two-stage restoration scheme, *Acacia* could be planted in degraded hilly land to serve as nurse plant for *S. superba*.

Keywords: Artificial forest, establishment limitation, regenerated ecosystem, restoration

LI P, HUANG ZL, XIANG YC & REN H. 2011. Kemandirian, pertumbuhan dan biojisim anak pokok *Acacia auriculiformis* dan *Schima superba* di kawasan pemulihan hutan yang berlainan fasa di Pulau Nan'ao, selatan China. Satu matlamat utama dalam pemulihan ekologi serta pengurusan hutan adalah mempercepatkan penggantian ekosistem tanah usang menjadi hutan semula jadi serantau. Tiga komuniti pokok (tanah usang berbukit, ladang hutan *Acacia* buatan dan hutan sekunder) yang mewakili tiga fasa pemulihan digunakan di Pulau Nan'ao, selatan China. Anak pokok *Acacia auriculiformis* yang eksotik dan *Schima superba* yang merupakan pokok asli diubah tanam ke dalam setiap komuniti. Indeks luas daun, stok sarap, kelembapan tanah dan kesuburan tanah lebih tinggi di ladang *Acacia* serta hutan sekunder berbanding tanah usang berbukit. Namun, pemancaran cahaya lebih tinggi di tanah usang berbukit berbanding dua komuniti yang lain. Kemandirian serta pertumbuhan *A. auriculiformis* paling tinggi di tanah usang berbukit tetapi bagi *S. superba*, nilainya paling tinggi di ladang *Acacia*. Gerak balas pertumbuhan anak pokok yang diubah tanam berkait dengan kandungan air di dalam tanah serta kadar pemancaran cahaya. Bagi mempercepat pemulihan tanaman di pulau, hutan sekunder sedia ada hendaklah dilindungi dan ladang hutan hendaklah ditambah baik menggunakan anak pokok spesies asli. Sebagai rancangan pemulihan dua peringkat yang mungkin dilaksanakan, *Acacia* boleh ditanam di tanah usang berbukit supaya bertindak sebagai pokok pengasuh bagi *S. superba*.

INTRODUCTION

Forest regeneration is a key issue in research concerning vegetation dynamics and restoration. During restoration of degraded ecosystems, the artificial renewal of plant population is required to accelerate succession, and such artificial renewal often involves the sowing of seeds and replanting of seedlings of desired species. However, seedling establishment may be limited by the environment or competition. These limitations can greatly influence forest regeneration or the rate at which climax forests are regenerated from artificial plantations (Munzbergova & Herben 2005, Wang et al. 2009a). Seedling establishment is also limited by the characteristics of seedling species (e.g. shade-tolerance), time of establishment, availability of

*Author for correspondence. E-mail: renhai@scib.ac.cn

resources and browsing by animals. In fact, the absence of native tree species in artificial forests is mostly due to the limited dispersal of forest plants and unsuccessful recruitment by native plants in artificial forests (Clarke & Davison 2004, Graae et al. 2004, Wang et al. 2010). The abundance and distribution of native plants are determined during early regeneration stages, i.e. when seedlings are most vulnerable to their immediate environment (Albrecht & McCarthy 2009).

The climax vegetation in south China is monsoon evergreen broad-leaved forest. Historically, this forest type was widely distributed but because of intensive anthropogenic disturbances, particularly in the last half century, most of this forest was turned into hilly land (Ren et al. 2002). To restore forest cover and ecological benefits, the government established large areas of plantations in this region but most of these plantations were planted with non-indigenous, fast-growing pioneer species such as *Acacia* and *Eucalyptus*. After decades of development, habitat conditions such as soil fertilities and microclimate in the plantations have improved somewhat, and some native shrub species have colonised the understory. However, such plantations are still dominated by pioneer trees, and indigenous tree species characteristic of the zonal climax community are scarce (Peng 2003, Wang et al. 2009b). Currently, the established plantations are experiencing low biodiversity and inadequate ecosystem services. Thus, a silviculture management system that can accelerate the succession of plantations to more natural stages is urgently required. For this reason, understanding how to promote establishment of native species in plantations is essential for restoration and forest management research.

The exotic heliophyte *Acacia auriculiformis* and the native mesophyte *Schima superba* are considered useful trees for rehabilitating/restoring degraded terrestrial ecosystems in south China. From previous studies of artificial forests in south China, forest re-establishment or restoration should address the problem of limited seedling recruitment (Xiang et al. 2002, Ren et al. 2007, Wang et al. 2009a). In this research, seedlings of *A. auriculiformis* and *S. superba* were transplanted into three plant communities, namely, hilly land, artificial forest and secondary forest. These communities represent three phases or levels of restoration; the hilly land is a moderately degraded ecosystem, the artificial forest represents a primary rehabilitated ecosystem and the secondary forest is a nearly restored ecosystem (Zhou et al. 2001). We attempted to answer two closely related questions: (1) how does the plant community affect seedling survival and growth of an exotic and native species? (2) which plant, *S. superba* or *A. auriculiformis*, grows better in each of the three plant communities and why?

MATERIALS AND METHODS

Study area

Nan'ao Island (23° 23'–23° 29' N, 116° 56'–117° 08' E) is the sole insular county in south China. It is near Shantou City in Guangdong Province. With an area of 105.2 km^2, the island has a typical lower subtropical oceanic climate with an average total radiation of 5416 MJ m^{-2} $year^{-1}$ and average annual temperature of 21.5 °C. The average annual precipitation is 1350.9 mm, and 80% of the total precipitation is distributed between April and September. The average annual relative humidity is 78% and the average annual evaporation is 2046 mm. The regional soil type of Nan'ao Island is reddish earth and, as noted earlier for south China in general, the original climax plant community is subtropical monsoon evergreen broad-leaved forest. According to historical records, most of the natural forest on Nan'ao Island was destroyed in the 1950s. Plant community types at Nan'ao Island currently include degraded hilly land, artificial plantation and secondary forest. Most of the secondary forests have been logged except for some small forested areas near a village border and a shrine site (Group of Comprehensive Investigation of Island Resources in Guangdong 1995). Since 1980, pine and acacia plantations have been established on the island, but none of the native plant species from the natural forest was found in these artificial forests (Zhou et al. 2001). Therefore, even after two decades of regeneration, the artificial forests are not transforming into regional natural forests, which can produce more ecosystem services. Recently, the artificial forests have reached mature age and some species such as *Acacia confusa* are beginning to die or decline in growth. The planting and establishment of native species in artificial forests is urgently needed to accelerate the succession of artificial forests into regional climax forests.

Seedling transplant and growth

The three plant communities, which are located on the western part of Nan'ao Island, comprise a degraded hilly land, an *A. confusa* plantation and a secondary forest (Figure 1). Basic characteristics of the three plant communities are described in Table 1. The hilly land was mainly dominated by heliophyte shrubs and herbs. The hilly land community was at a degraded and early successional stage and it was characterised by sparse vegetation coverage, low plant height and infertile soil conditions. Soil in the *A. confusa* plantation was more fertile than in the hilly land. With the highest soil fertility between the three communities, the secondary forest was mainly dominated by native tree species accompanied by mesophyte and sciophyte shrubs and herbs.

Due to high winds that occur throughout the year, an extremely dry climate and poor soil, more than 30 native tree species (such as *Bischofia javanica, Cinnamomum camphora* and *Michelia macclurei)* that were planted in the hilly land and *Acacia* plantations by farmers failed to establish (P Li, personal observation). Most of the plants died after one year and the surviving seedlings grew poorly. Based on this, we decided to focus on two tree species, *A. auriculiformis* and *S. superba,* both of which have been widely used in rehabilitating/restoring degraded terrestrial ecosystems but have not yet been used in island ecosystems in south China (Zhou et al. 2001, Peng 2003). *Acacia auriculiformis,* which is native to Australia and Indonesia and was introduced to China from South-East Asia in 1961 (Peng 2003), is an exotic early successional tree species

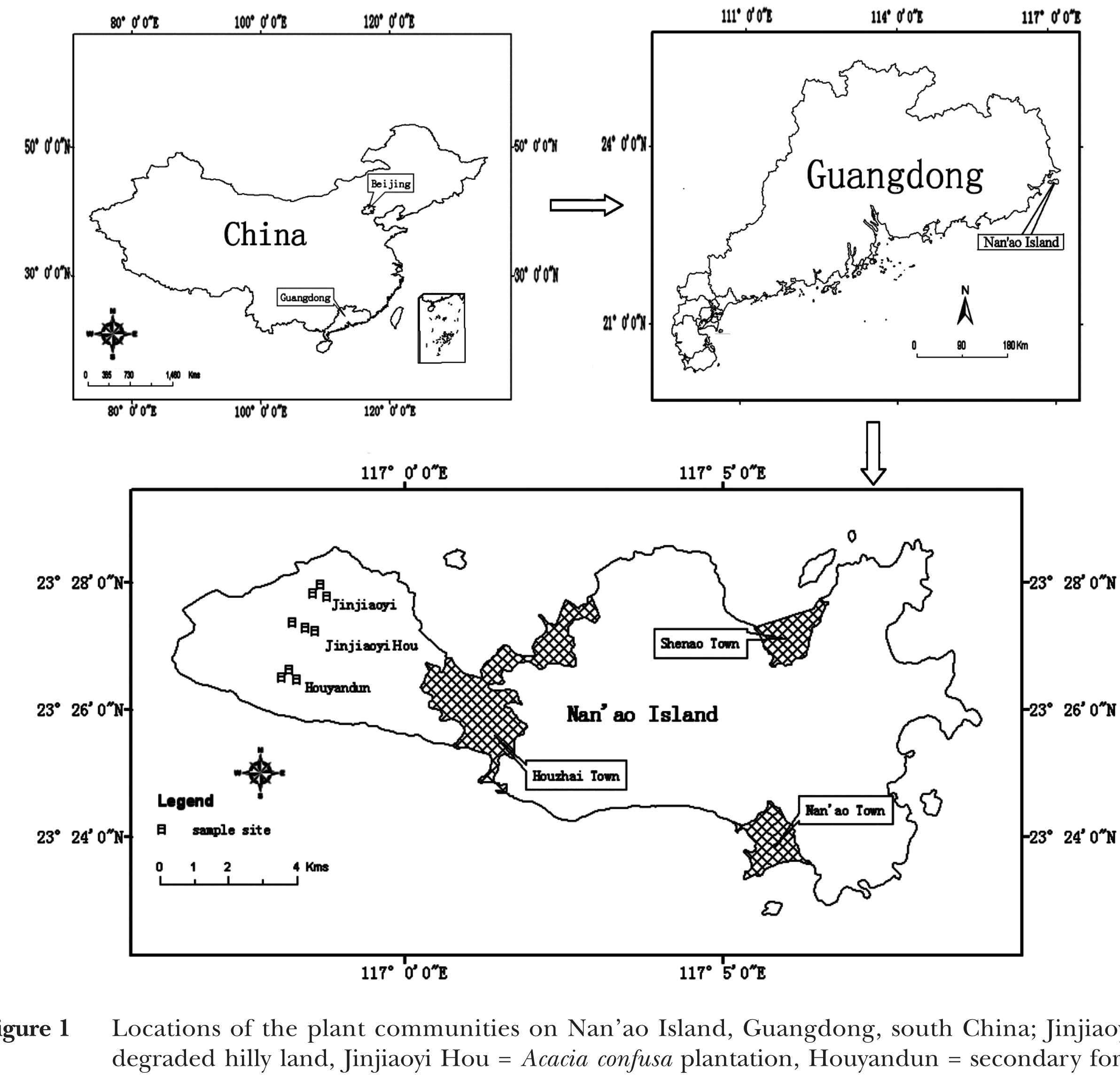

Figure 1 Locations of the plant communities on Nan'ao Island, Guangdong, south China; Jinjiaoyi = degraded hilly land, Jinjiaoyi Hou = *Acacia confusa* plantation, Houyandun = secondary forest. Each plant community is represented by three quadrats.

Table 1 Some characteristics of the three plant communities studied

Characteristic	Plant community		
	Degraded hilly land	*Acacia confusa* plantation	Secondary forest
Location	Jinjiaoyi	Jinjiaoyi Hou	Houyandun
Elevation (m)	110	370	320
Slope direction	SE	NE	SE
Slope grade (°)	30	15	15
Community height (m)	0.8	11.0	9.0
Community coverage (%)	65	75	90
Main species	*Dodonaea viscosa* *Strophanthus divaricotus* *Ischaemum indicum* *Cymbopogon torttilis* *Eriachne pallescens*	*Acacia confusa* *Ficus microcarpa* *Viburnum odoratissimum* *Litsea glutinosa* *Panicum brevifolium*	*Schefflera octophylla* *Viburnum odoratissimum* *Sterculia lanceolata* *Bridelia tomentosa* *Taxicodendron succedaneum* *Psychotria rubra* *Stenoloma chusana*

that grows well in relatively poor habitats. *Schima superba* is a native late-successional tree species that is frequently found in relatively fertile habitats. *Acacia auriculiformis* is shade intolerant and *S. superba* prefers shade to direct sunlight.

Seeds of the *A. auriculiformis* and *S. superba* were sown in early November 1998 at Huanghua Shan Nursery in Nan'ao Island. In March 1999, when the average height of *A. auriculiformis* and *S. superba* seedlings reached 5 and 4 cm respectively, they were transplanted into the three plant communities on cloudy days. Three quadrats (10 × 10 m) were established in each experimental site. Each quadrat was divided into two subquadrats, each planted with 30 seedlings of *A. auriculiformis* or *S. superba* with a spacing of 50 × 50 cm. After transplanting, seedlings were irrigated twice but were not fertilised.

Survival of seedlings was determined at 1, 4, 7, 10, 13, 16, 19 and 22 months after transplanting. The percentage of seedlings that survived for each species at each site was then calculated. The heights of all surviving seedlings were also measured. At 24 months after transplanting, the shoots of all surviving seedlings were collected, dried and weighed.

Habitat of the three plant communities

Habitats of the three plant communities were characterised by measuring leaf area index (LAI), light transmission rates (measured at 5 cm above the soil surface) and soil characteristics. LAI and light transmission rates were simultaneously measured using a CI-110 canopy image analyser. Soil water content (g of water per 100 g of dry soil) was measured by oven drying. LAI and soil water content were measured three times in 1999 (spring, summer and winter). Litter mass and soil nutrient content were measured when the quadrats were established in 1999. Litter collected from three 1-m^2 areas at each site was dried and weighed. Three soil cores (2.5 cm diameter by 50 cm depth) were collected from each subquadrat and divided into 10-cm segments. In the laboratory at the South China Botanical Garden, the soil samples were air dried and then milled. The pH was determined with a pH meter using 1.0:2.5 soil:water extracts. Also determined were soil organic matter content (digested with $H_2SO_4/K_2Cr_2O_7$ and titrated with $FeSO_4$), nitrogen concentration (digested with NaOH, absorbed with boric acid and titrated with hydrochloric acid), and available P (extracted with HCl/NH_4F and analysed spectrophotometrically) (Olsen et al. 1954, Chinese Academy of Sciences 1978, MEWAM 1986).

Data analysis

In this kind of large-scale field experiment, replicating plant communities is difficult. Although the communities were not replicated, the selected communities were typical, and the quadrats were replicated and randomly distributed within the communities.

Data are presented as means ± standard errors (SE). All variance analyses were processed by SPSS 13.0 (2004). The effect of different communities on seedling performance was analysed by one-way ANOVA. When ANOVAs were significant ($p < 0.05$), means were separated by the LSD test. Stepwise regression analysis and associated regression coefficient were used to examine relationships between seedling growth and environmental factors (soil physical and chemical properties, light transmission rate and litter stock). The figures were generated by SIGMAPLOT 9.0 (2007, Chinese version).

RESULTS

Leaf area indices, light transmission rates and soil characteristics

LAI, soil water content and litter stock were lowest in the degraded hilly land and highest in the secondary forest (Table 2). On the contrary, the light transmission rate was very high in the degraded hilly land compared with the secondary forest and *A. confusa* plantation. However, pH values were similar between the three plant communities.

Soil organic matter content and fertility in the top 10 cm were lowest in the degraded hilly land and highest in the secondary forest. The total N concentration and available P content (from 0 to 10 cm depth) were lowest in the degraded hilly land but highest in the secondary forest.

Seedling survival, height and mass

Acacia auriculiformis seedlings survived much better in the degraded hilly land than in the secondary forest or *A. confusa* plantation (Figure 2a). In the secondary forest and *A. confusa* plantation, survival of *A. auriculiformis* sharply decreased about 50% from 12 to 16 months after transplanting and then seemed to stabilised. At 22 months, however, most of the surviving seedlings in the secondary forest were in poor health while those in the degraded hilly land and *A. confusa* plantation were generally healthy.

Survival of *S. superba* seedlings was highest in the *A. confusa* plantation and lowest in degraded hilly land (Figure 2b). By the last sampling time, survival was relatively constant in the *A. confusa* plantation but was decreasing rather rapidly in the other two plant communities.

The initial heights of the seedlings were similar and thus the final heights could be used as indicators of growth. *Acacia auriculiformis* grew fastest on degraded hilly land (final height 81.7

Table 2 Leaf area indices, light transmission rates and soil characteristics of the three plant communities

Characteristic	Plant community		
	Degraded hilly land	*Acacia confusa* plantation	Secondary forest
Leaf area index	1.01 ± 0.34 a	3.82 ± 0.32 a	5.91 ± 0.63 a
Light transmission rate (%)	86 ± 21 a	27 ± 12 a	19 ± 6 a
Soil pH	4.6 ± 0.2 a	4.6 ± 0.4 a	4.8 ± 0.2 a
Soil water content (0–10 cm, %)	21 ± 6 a	26 ± 4 a	29 ± 3 a
Soil organic matter (0–10 cm, %)	2.02 ± 0.34 a	2.81 ± 0.19 a	3.24 ± 0.82 a
Nitrogen concentration (0–10 cm, %)	0.042 ± 0.013 a	0.185 ± 0.008 a	0.225 ± 0.005 a
Available P (0–10 cm, mg kg^{-1})	1.750 ± 0.063 a	3.513 ± 0.103 a	5.113 ± 0.148 a
Litter stock (tonne ha^{-1})	0.42 ± 0.21 a	3.70 ± 0.13 a	4.90 ± 0.46 a

Values are means ± SE (n = 3); means within a row followed by the same letter are not significantly different at $p < 0.05$ according to one-way ANOVA.

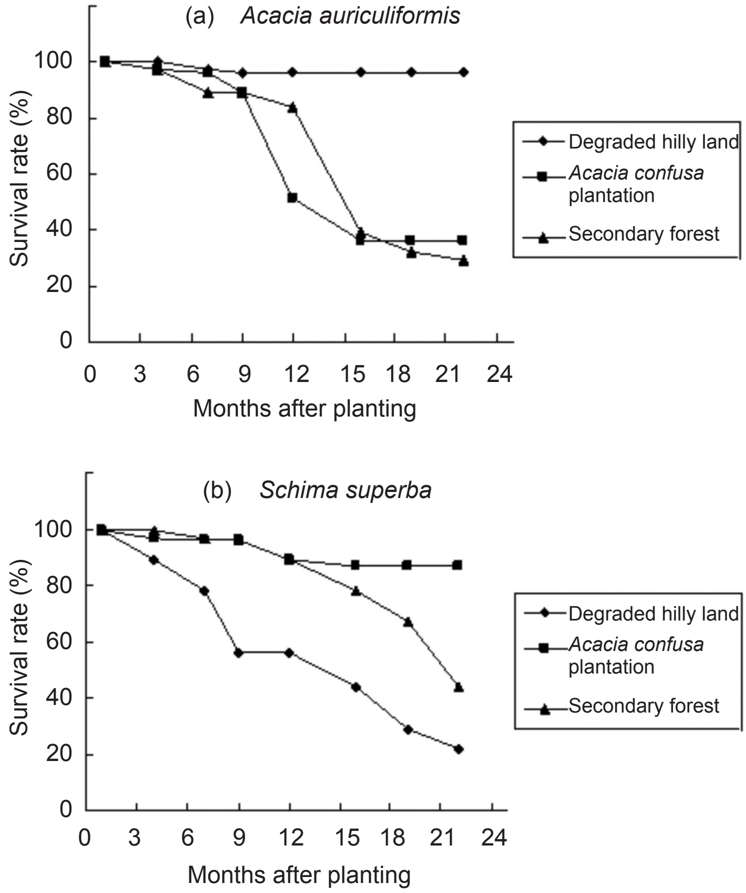

Figure 2 Survival rate of (a) *Acacia auriculiformis* and (b) *Schima superba* seedlings in the three plant communities

± 0.6 cm) compared with *A. confusa* plantation (41.3 ± 0.8 cm) and secondary forest (18.6 ± 1.0 cm) (Figure 3a). *Schima superba* grew fastest in the *A. confusa* plantation (51.4 ± 0.6 cm), slowest in the degraded hilly land (16.5 ± 0.8 cm) and at an intermediate rate in the secondary forest (41.5 ± 0.7 cm) (Figure 3b).

At 22 months, the biomass of *A. auriculiformis* seedlings was greatest (286.5 ± 8.7 g/individual) on degraded hilly land and lowest (3 ± 5.9 g/individual) in the secondary forest. The biomass of *S. superba* seedlings was highest in the *A. confusa* plantation (201.3 ± 11.1 g/individual), intermediate in the secondary forest (161.7 ± 8.9 g/individual) and lowest in the degraded hilly land (121.5 ± 3.5 g/individual) (Figure 4).

We analysed the relationship between seedling performance (survival and growth) and environmental factors (soil physical and chemical properties, light transmission rate and litter stock) by stepwise regression analysis. Survival rate was not significantly related ($p > 0.05$) to soil properties for either species (data not shown). For *A. auriculiformis*, seedling height was positively related to soil water content and light transmission rate, and seedling biomass was positively related to soil water content (Table 3). For *S. superba*, seedling height was positively related to soil water content and negatively related to light transmission rate, while seedling biomass was positively related to soil water content and soil organic matter (Table 3).

DISCUSSION

The three plant communities in this study differed in light transmission rates, litter quantity and soil water content. Although the light resource was most abundant on the degraded hilly land, soil water content and litter quantity were greater in the secondary forest and in the *A. confusa* plantation. It has been reported that 1 ha of litter on the hilly land, *Acacia* plantation and secondary forest could absorb 1.26, 11.1 and

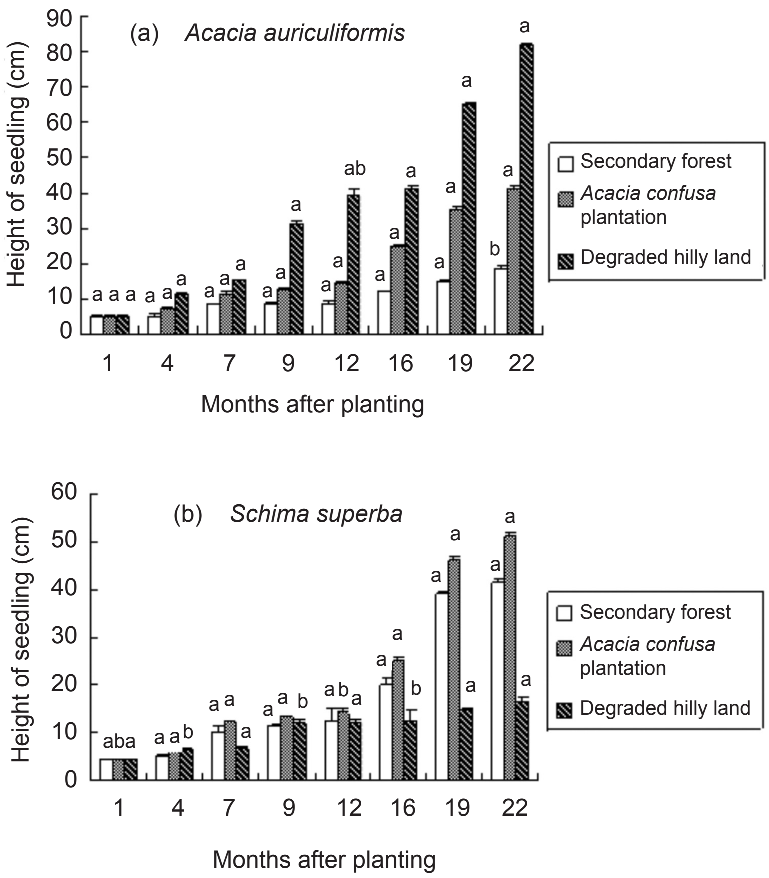

Figure 3 Heights of (a) *Acacia auriculiformis* and (b) *Schima superba* seedlings in the three plant communities; values are means ± SE (n = 9); for a given species, means followed by the same letter are not significantly different at $p < 0.05$ according to one-way ANOVA.

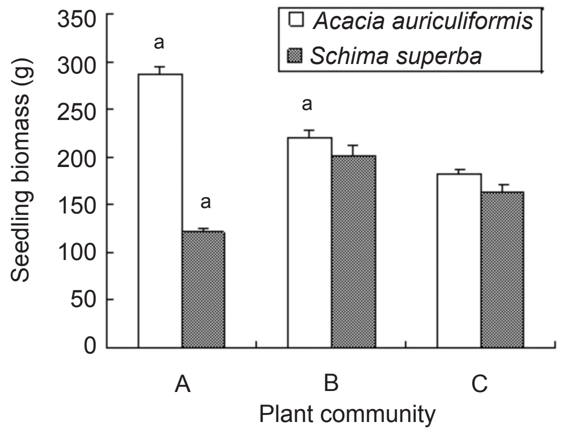

Figure 4 Biomass of *Acacia auriculiformis* and *Schima superba* seedlings in three plant communities; A = degraded hilly land, B = *Acacia confusa* plantation, C = secondary forest; values are means ± SE (n = 9); for each species, means followed by the same letter are not significantly different at $p < 0.05$ according to one-way ANOVA.

14.7 tonnes of water (Ren et al. 1998). Water absorbed by litter can help seedlings under the vegetative canopy survive and grow during the dry season (Facelli 1994). The relatively high quantities of litter in the secondary forest and in the *A. confusa* plantation can also partially explain the higher soil fertility in these communities than in the degraded hilly land.

Soil fertility was relatively high in both the *A. confusa* plantation and in the secondary forest. Thus, it is possible that, like the introduced *A. confusa*, the native tree species that dominate the secondary forest can also improve soil quality.

Seedling height and biomass of both transplanted species were positively correlated with soil water content. The two transplanted species, however, responded differently to light transmission. The height of *A. auriculiformis* seedlings was positively correlated with light transmission but the height of *S. superba* seedlings was negatively correlated with light transmission. Survival of *A. auriculiformis* was much greater in

Table 3 Stepwise regression analysis and associated regression coefficient for the relationships between seedling growth and environmental factors (soil physical and chemical properties, light transmission rate and litter stock)

Dependent variable (y)	Regression equation	r^2	p
Acacia auriculiformis seedlings			
Seedling height	y = -1.125 + 28.586 SWC + 16.648 LTR	0.179	0.006
Biomass	y = -107.221 + 521.257 SWC	0.112	0.012
Schima superba seedlings			
Seedling height	y = -2.394 + 21.765 SWC – 0.328 LTR	0.085	0.000
Biomass	y = -77.284 + 298.173 SWC + 3.589 SOM	0.128	0.007

SWC = soil water content, LTR = light transmission rate, SOM = soil organic matter

the degraded hilly land than in the other two plant communities. This apparently reflected the different environments in each community and especially the heliophytic nature of *A. auriculiformis*. As a shade-intolerant species, *A. auriculiformis* survived and grew better in the relatively open but less fertile environment of the degraded hilly land than in the shadier but more fertile environments provided by the secondary forest and *A. confusa* plantation. Only a few *A. auriculiformis* seedlings died in the degraded hilly land, most of which occurred in summer, perhaps because the seedlings had not yet established and therefore could not tolerate the high summer temperatures and irradiation. In the other two plant communities, the survival of *A. auriculiformis* reduced sharply from 10 to 17 months after planting, presumably because the light was inadequate (Xiang et al. 2002). Height and mass of *A. auriculiformis* seedlings were also greater in the degraded hilly land compared with the other two plant communities. In contrast, *S. superba* survived and grew best in the plantation. Since they provide shade and fix nitrogen, the adult *A. confusa* trees may have a nursing effect on *S. superba* seedlings (Zhou et al. 2001).

The period from germination to seedling establishment is the most sensitive phase during the life of a plant, and moisture and sunlight greatly influence seedling establishment. In addition, litter and plant foliage may affect moisture and illumination, and consequently affect seedling establishment too. Therefore, understanding the structure and dynamics of some plant communities that arise from seeds requires knowledge about seedling responses to different environments. Shade tolerance is a key factor affecting recruitment of native plant species in forest communities. In this study, growth status of transplanted seedlings was due to the intolerance of seedlings to light and moisture in the different plant communities. Competition for light, moisture and nutrition within forest communities may also affect seedling recruitment. Hence, improving the microenvironment by watering, fertilising, preventing grazing and selective cutting of established trees at the beginning of vegetative restoration is important for overcoming recruitment limitations (Onyekwelu et al. 2008, Wang et al. 2009a).

Plants do not actively seek ideal habitats but they exhibit distinct differences in tolerance to extrinsic factors at different developmental stages. It follows that when plants are being selected for restoration of a site, the plant species and stage should be matched to the site environment. For instance, *A. auriculiformis* is most suitable for growing on degraded hilly land where sunlight is abundant but the soil is barren. Heliophytic species such as *Pinus massoniana*, *Castanopsis chinensis* and *Diospyros morrisiana* thrive in high light conditions, and these species also improve soil conditions by nitrogen fixation. *Acacia* plantations, which have relatively high soil nutrient levels and abundant shade, are suitable for mesophytes such as *S. superba*, *C. chinensis* and *C. concinna*, which require good soil fertility but only moderate light. In addition, the placement of desirable species beneath established canopies can in some cases protect seedlings from high irradiance, extreme temperatures, high rates of transpiration and predation. Seedlings may also take advantage of the local increase in fertility beneath tree canopies.

Island ecosystems are relatively isolated and often have simple structures and thus are often fragile and can be difficult to restore once destroyed (Lugo 1988). The restoration of island vegetation can be thought of as a process of community succession. The restoration must consider the entire plant community and even the entire ecosystem but appropriate population management may also help in restoring the island. One aspect of population management could involve the judicious use of exotic species. Although they are exotic, eucalyptus, acacia and pines have been commonly used to restore degraded hilly land (Ren et al. 2006), and the current study demonstrates that a suitable native plant species such as *S. superba*, can re-colonise in an artificial forest of an exotic species. Such re-colonisation would be invaluable in transforming the artificial forest into a native forest.

CONCLUSIONS

This research has implications both for understanding vegetation restoration mechanisms and for promoting ecosystem restoration. In addition to demonstrating that restoration efforts must match plant characteristics with the environment, and that light and soil moisture can be key factors, the research indicated that both native and exotic species could be useful for restoration on Nan'ao Island and in other lower subtropical islands worldwide. The native *S. superba* could be useful for restoration of *A. confusa* plantations but not for secondary forests. *Schima superba* also could not be used for restoration of degraded hilly land if planted without a nurse plant that provided shade. It is suggested that restoration of degraded hilly land be divided into two stages in which *S. superba* seedlings are planted after exotic *A. auriculiformis* seedlings had been planted and established, i.e. acting as a nurse plant. Once *S. superba* and perhaps other natives are established, *A. auriculiformis* can be selectively logged or permitted to decline on its own.

Identifying a native tree species that can act as nurse plant in place of *A. auriculiformis* for *S. superba* and other native mesophytes would be desirable. In order to accelerate the restoration process of Nan'ao Island and similar islands and ecosystems in south China, we should conserve the existing secondary forest patches because these patches serve as banks and dispersal sources of native species. Finally, introducing native tree seedlings that are suited to the plantation environment is pivotal in improving artificial plantations.

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REFERENCES

Albrecht MA & McCarthy BC. 2009. Seedling establishment shapes the distribution of shade-adapted forest herbs across a topographical moisture gradient. *Journal of Ecology* 97: 1037–1049.

Clarke PJ & Davison EA. 2004. Emergence and survival of herbaceous seedlings in temperate grassy woodlands: recruitment limitations and regeneration niche. *Austral Ecology* 29: 320–331.

Chinese Academy of Sciences. 1978. *Soil Physical and Chemical Analysis.* Shanghai Technology Press, Shanghai.

Facelli JM. 1994. Multiple indirect effects of plant litter affect the establishment of woody seedlings in old fields. *Ecology* 75: 1727–1735.

Graae BJ, Hansen T & Sunde PB. 2004. The importance of recruitment limitation in forest plant species colonization: a seed sowing experiment. *Flora* 199: 263–270.

Group of Comprehensive Investigation of Island Resources in Guangdong. 1995. *The Report of Island Resources of Guangdong*. Guangdong Science and Technology Press, Guangzhou.

Lugo AE. 1988. Ecological aspects of catastrophes in Caribbean islands. *Acta Cientifica Venezolana* 2: 24–31.

MEWAM. 1986. Nitrogen concentration and available phosphorus. In *Methods for the Examination of Waters and Associated Materials*. Her Majesty's Stationery Office, London.

Munzbergova Z & Herben T. 2005. Seed, dispersal, microsite, habitat and recruitment limitation: identification of terms and concepts in studies of limitation. *Oecologia* 145: 1–8.

Olsen SR, Cole CV & Watanabe FS. 1954. *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate*. USDA, Washington DC.

Onyekwelu JC, Mosandl R & Stimm B. 2008. Tree species diversity and soil status of primary and degraded tropical rainforest ecosystems in south-western Nigeria. *Journal of Tropical Forest Science* 20: 193–204.

Peng SL. 2003. *Study and Application of Restoration Ecology in Tropical and Subtropical China*. Science Press, Beijing.

Ren H, Li ZA, Shen WJ, Yu ZY, Peng SL, Liao CH, Ding MM & Wu JG. 2006. Changes in biodiversity and ecosystem function during the restoration of a tropical forest in south China. *Science in China* 36: 563–569.

Ren H, Peng SL & Yu ZY. 2002. Species diversity of seven man-made broad-leaved mixed forests in south China. *Journal of Tropical Forest Science* 14: 16–25.

Ren H, Peng SL & Yu ZY. 1998. The litter and its ecological effects of plantations in Xiaoliang. *Chinese Journal of Applied Ecology* 9: 458–462.

Ren H, Shen WJ, Lu HF, Wen XY & Jiang SG. 2007. Degraded ecosystems in China: status, causes, and restoration efforts. *Landscape and Ecological Engineering* 3: 1–13.

Wang J, Li DY, Ren H & Yang L. 2010. Seed supply and the regeneration potential for plantations and shrubland in southern China. *Forest Ecology and Management* 259: 2390–2398.

Wang J, Ren H, Yang L & Duan WJ. 2009a. Establishment and early growth of introduced indigenous tree species in typical plantations and shrubland in South China. *Forest Ecology and Management* 258: 1293–1300.

Wang J, Ren H, Yang L, Li DY & Guo QF. 2009b. Soil seed banks in four 22-year-old plantations in South China: implications for restoration. *Forest Ecology and Management* 258: 2000–2006.

Xiang YC, Peng SL & Ren H. 2002. The influences of gaps in different forest communities tree seedlings on Nan'ao Island. *Journal of Tropical and Subtropical Botany* 10: 340–347.

Zhou HC, Ren H & Peng SL. 2001. The community dynamics during the process of vegetation restoration on Nan'ao island, Guangdong. *Journal of Plant Ecology* 25: 298–305.