Factors Affecting the Early Survival and Growth of Native Tree Seedlings Planted on a Degraded Hillside Grassland in Hong Kong, China

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Abstract

The effects of seasonal drought, belowground competition, and low soil fertility on the survival and growth over 2 years of four native tree species planted on a degraded hillside grassland in Hong Kong were studied in a field transplant experiment using three-way analysis of variance. The tree species were *Schima superba* (Theaceae), *Castanopsis fissa* (Fagaceae), *Schefflera octophylla* (Araliaceae), and *Sapium discolor* (Euphorbiaceae), and the treatments were dry season irrigation, herbicide, and fertilizer. Each species responded differently to the treatments. *Sapium* had a very low survival rate as a result of wind damage at the exposed study site. All three treatments significantly reduced the survival rate of *Castanopsis* seedlings, whereas herbicide reduced it for *Sapium* but increased it for *Schefflera*. The significant effects on seedling growth were all positive, except for a strong negative effect of herbicide on *Castanopsis* growth. Overall, the results suggest that all three factors—seasonal drought, belowground competition, and low soil nutrients—can significantly impair seedling growth on a degraded hillside site in Hong Kong but that their relative importance differs among species. The growth benefits of the three treatments were largest and most consistent for *Schima*, which as a mature forest dominant would be expected to be particularly sensitive to the environmental conditions on degraded open sites. This study highlights the fact that more systematic planting trials are needed to identify suitable native tree species for cost-effective reforestation on degraded hillsides in Hong Kong and South China.

Key words: forest restoration, native tree species, seasonal drought, soil fertility, South China, weed competition.

Introduction

In those parts of the humid tropics with a regular dry season deforestation is relatively easy: a matter of cutting and burning at the appropriate time of the year. Reversing the process, in contrast, is proving to be very difficult, and the area of abandoned, but still treeless, former forest land increases year by year. Recurrent human disturbance by burning or cutting inhibits tree invasion in many areas, but the cessation of disturbance does not necessarily lead to rapid forest recovery. In general, the rate at which woody vegetation develops on deforested sites appears to be inversely related to the duration and intensity of past disturbance and positively related to rainfall (Corlett 2002). The barriers to forest regeneration are higher on dry and/or highly degraded sites. Even on the most favorable sites, however, forest succession is better at restoring biomass than biodiversity, with only a small subset of the forest flora involved, at least in the early stages (e.g., Cubina & Aide 2001). Most studies of forest succession on degraded land have been descriptive, but an understanding of the underlying biological processes is likely to be essential for the design of effective restoration strategies (Holl et al. 2000; Duncan & Chapman 2002). Studies of these processes have been few and confined to the Neotropics (e.g., Nepstad et al. 1990; Holl et al. 2000; Zimmerman et al. 2000) and a single site in Africa (Duncan & Chapman 2002).

The study reported here forms part of a long-term investigation of forest recovery in degraded upland grasslands in tropical South China (Zhuang & Corlett 1997; Hau 1999). The major aims are, first, to understand the processes that control the slow and highly selective invasion of woody species into these grasslands and, second, to design cost-effective strategies for the large-scale restoration of diverse tropical forests. Urbanization in Hong Kong is largely confined to flatland at low altitudes, and much of the remaining land area consists of degraded hillsides for which there is no competing use. There has been a long history of plantation forestry in Hong Kong, largely based on exotic species (Corlett 1999). More recently, an increasing number of native tree species have been planted, albeit in the same way as the exotics were, with little attempt to allow for the particular ecological characteristics of the species used. Most of these planting trials using native tree species have so far gained little success.

Neotropical studies suggest that the major "filter barriers" to forest recovery are the low rate of seed dispersal from forest into open sites (e.g., Cubina & Aide 2001), the high rate of seed predation in grassland (e.g., Nepstad et al. 1990), low rates of seed germination and seedling establishment (Holl et al. 2000), and very slow rates of seedling

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growth (Aide & Cavelier 1994). Seed dispersal and seed predation are the subject of ongoing studies in Hong Kong, but preliminary results suggest that these factors are as important here as elsewhere (Hau 1997; Corlett 2002). Even when protected from predators seeds placed in grassland sites show very low establishment success (Hau 1999). Here we look at the next stage, using planted seedlings to investigate experimentally the postestablishment barriers to seedling survival and growth. The results are not only relevant to understanding forest succession, but also have a direct application in improving methods of reforestation by planting native trees.

Studies elsewhere in broadly comparable climates suggest three major factors that may limit the growth and survival of established seedlings in degraded hillside grasslands in Hong Kong: soil nutrient supply, competition with grasses, and the stresses imposed by seasonal drought (Nepstad et al. 1990, 1996; Holl et al. 2000). At some Neotropical sites herbivory by leaf-cutter ants (e.g., Nepstad et al. 1996) or vertebrates (e.g., Holl et al. 2000) is also an important factor, but leaf-cutter ants are absent from the Old World and vertebrate herbivores are not a major problem in the study site. The purpose of this study is to test if poor soil nutrient, competition with grass, and seasonal drought are limiting factors to tree seedling growth and survival on degraded hillsides in Hong Kong.

Methods

Study Site

The Hong Kong Special Administrative Region of the People's Republic of China (hereafter, Hong Kong) consists of a section of the Chinese mainland (Kowloon and the New Territories) and numerous islands, with a total land area of 1,100 km^2. The topography is mostly rugged, with the highest point at Tai Mo Shan (957 m above sea level) in the New Territories. The climate is subtropical monsoon (the mean annual temperature is 23°C, the mean temperature of the warmest month is 28.8°C, and the mean temperature of the coldest month is 15.8°C) with a hot wet summer and cool dry winter. The mean annual total rainfall is 2,214 mm. This climate would support tall, evergreen, fire-excluding forest, but this has been largely cleared within the last 1,000 years (Dudgeon & Corlett 1994). There is no large primary forest remnant surviving in Hong Kong or in adjacent parts of mainland China. However, the dominant tree families were likely Lauraceae (e.g., *Machilus*) and Fagaceae (e.g., *Castanopsis*, *Lithocarpus*, and *Cyclobalanopsis*) because of their prominence in the regional flora (Dudgeon & Corlett 1994). Today all flatland is urbanized, cultivated, or abandoned cultivation. The remaining 80% of the land area is mostly steep hillsides covered with secondary grasslands and shrublands, maintained by anthropogenic fires, with an increasing area of secondary forest that has largely developed since 1945 (Zhuang & Corlett 1997). Some sites at high altitude may have escaped from complete deforestation, although all forest patches have been disturbed.

The study was conducted on a steeply sloping grassland site at 550 m on the northeast side of Tai Mo Shan, within the Kadoorie Farm and Botanic Garden (22°26′N, 114°07′E). The anthropogenic fire frequency is one per 5 to 7 years. Ecological succession is arrested at the grassland stage. The site is dominated by species in the family Poaceae (Gramineae), including *Arundinella*, *Ischaemum*, *Eulalia*, *Eragrostis*, *Cymbopogon*, and *Miscanthus*, with some small trees and shrubs ($<$1 m in height) in less exposed areas. Tai Mo Shan is underlain entirely by volcanic rocks, and red-yellow podzol is the dominant soil type above 500 m (Grant 1960). Short grasslands on Tai Mo Shan with similar grass species cover to the study site were found to have large amounts of herbaceous litters on the ground surface and have a distinct O horizon of about 5 cm in depth with a very dark gray color (Marafa & Chau 1999a). The A horizon is 16 cm in depth with a very dark grayish brown color, and the B horizon is 17 cm in depth with a dark yellowish brown color. The last fire recorded at this site was in 1989, and it was burned again in 1999 after the experiment was completed. This grassland is typical of degraded hillsides in Hong Kong where natural colonization by trees is slow or absent.

Experimental Design

Twenty 0- to 20-cm soil samples were collected in December 1997 at random intervals along a 50-m transect placed haphazardly across the study site. Total nitrogen was determined using the Kjeldahl method and available phosphorus by the Mehlich no.1 (double acid) extraction (Anonymous 1992). During the dry seasons soil suction at 20 cm depth was determined with a tensiometer (model 2900F Quickdraw Soil Moisture Probe, Soilmoisture Equipment Corporation, CA, U.S.A.) three times a month, after at least 2 consecutive rainless days, at five haphazardly selected points. Q1

The seedling experiment used a three-factor analysis of variance design with fixed effects, comprising a total of seven treatments and one control (eight plots) with five replications (five blocks) and four native tree species. The factors were irrigation in the dry seasons, herbicide application, and fertilization. All three factors had two levels, the presence and absence of the factor. In each planting plot ten 18-month-old container-grown seedlings of each species were planted randomly with 1.2–1.5 m spacing to form a rectangular grid with five rows and eight columns between 6 June and 6 July 1995. The eight treatments (plots) in each block were arranged randomly, except that the irrigated plots were grouped together for ease of management. A 3-m vegetated gap was left between the irrigated and nonirrigated plots in each block to avoid contamination. A total of 1,600 seedlings was planted.

The four native tree species used in this study were *Schima superba* Gardner & Champ. (Theaceae), *Castanopsis fissa*

Table 1. Overall means across all treatments of initial, final, increase, and percentage increase of stem height and basal diameter of the seedlings.

	Species			
	Schima	*Schefflera*	*Castanopsis*	*Sapium*
Height				
Initial (cm)	51.2 ± 7.2	12.5 ± 4.7	36.9 ± 13.3	73.1 ± 19.5
Final (cm)	94.3 ± 27.6	42.9 ± 16.3	63.9 ± 21.2	—
Increase (cm)	43.2 ± 27.0	30.3 ± 15.7	29.9 ± 24.8	—
% increase	86.3 ± 56.0	274.0 ± 176.6	100.4 ± 94.7	—
Diameter				
Initial (mm)	6.8 ± 1.4	6.9 ± 1.7	5.2 ± 2.5	7.9 ± 2.0
Final (mm)	16.7 ± 8.3	15.4 ± 7.4	9.6 ± 4.0	—
Increase (mm)	9.9 ± 7.8	8.4 ± 6.9	4.5 ± 3.6	—
% increase	145.5 ± 133.1	120.3 ± 121.7	93.1 ± 72.8	—

Because of low survival rate and therefore small sample size, growth data for *Sapium* were not available. Sample sizes are more than 150 to 400 for height and diameter.

(Champ. ex Benth.) Rehder & E. H. Wilson (Fagaceae), *Schefflera octophylla* (Lour.) Harms (Araliaceae), and *Sapium discolor* (Champ. ex Benth.) Müll. Arg. (Euphorbiaceae). *Schima* is a common canopy dominant in the oldest forests in the Hong Kong region. *Castanopsis* has intermediate characteristics: It grows well in open sites but has shade-tolerant seedlings. *Sapium* and *Schefflera* are common pioneer trees in Hong Kong, with *Schefflera* exhibiting more shade tolerance than *Sapium*. All seedlings were about 18 months old and obtained from a commercial nursery supplier in the adjacent Guangdong Province, China. According to the supplier, seeds were collected from the natural hillside secondary forests (<500 m in altitude) nearby the nursery and sown immediately after collection in nursery seed bed. Saplings were transplanted into polystyrene tubes (8 cm in diameter and 12 cm in height) and grown for 18 months in the nursery. Any seedlings that were damaged during transportation were discarded, and the remainder were hardened on site before planting. Seedlings planted on dry days were watered to reduce transplantation losses. Initial seedling sizes differed among species (Table 1).

For the irrigation treatment approximately 0.75 L of water was given to each seedling once a week in the 1995–1996 dry season and 1.5 L per week in the 1996–1997 dry season. No water was given when it rained on the scheduled irrigation day. In the 1995–1996 dry season each plant was irrigated 19 times with a total of 14.25 L of water. In the 1996–1997 dry season each plant was irrigated 14 times with a total of 21 L of water. For the herbicide treatment the grass was clipped and removed manually before application of the postemergence nonselective herbicide Roundup
Q3 (Monsanto Company, MO, U.S.A.). Herbicide was applied in April 1995, 1996, and 1997, with the first application 2 months before the seedlings were planted. For the second and third applications a plastic shield was used to protect the seedlings from direct contact with the spray, and the area within a 20-cm radius from each seedling was not sprayed but weeds were pulled up by hand. For the fertilizer treatment 12 g of a slow release NPK complex fertilizer
(Nitrophoska Permanent 15-9-15, BASF, Germany) was Q3
buried 5 cm below the soil surface 10 cm up slope of each seedling in July 1995, soon after all seedlings were planted. An additional 25 g of Nitrophoska was applied in a similar manner in March 1996 and 1997, respectively.

Transplantation losses (i.e., seedling mortality due to stress in delivery and transplantation) were assessed in July/August 1995, 1 month after planting. Survival was recorded again in October 1995, March and October 1996, and June/July 1997. The basal diameter (i.e., stem diameter on the ground surface) and stem height (i.e., the height of the apical meristem from the ground surface) of each seedling were recorded 1 month after planting, which were taken as the baselines for determining the growth rate. The same measurements were repeated in October 1995, March and October 1996, and June/July 1997. The relative height increment per year (RHI) was calculated using RHI = [ln (H_2) − ln (H_1)] / time in years, where H_1 and H_2 were seedling heights in July 1995 and 1997, respectively (Coomes & Grubb 1998). The relative basal diameter increment per year was calculated in the same way.

The mean percentage seedling survival and growth rate of each species in each treatment were compared by three-way analysis of variance (ANOVA) using Minitab Release
13.1 (Minitab Inc., PA, U.S.A.). Percentage seedling sur- Q4
vival data were arcsine transformed following standard practice. Seedling growth data were transformed according to Taylor's power law (Fry 1993). In all ANOVA the homogeneity of variance was checked by manually calculating Hartley's F_{max} and Cochran's C. Normal probability plots produced by Minitab Release 13.1 were used to check the residuals for normality (Fry 1993). When the assumptions of an ANOVA did not hold outliers were removed. A new power of transformation was determined and a new ANOVA was conducted. These steps were repeated until the assumptions of the ANOVA were main-

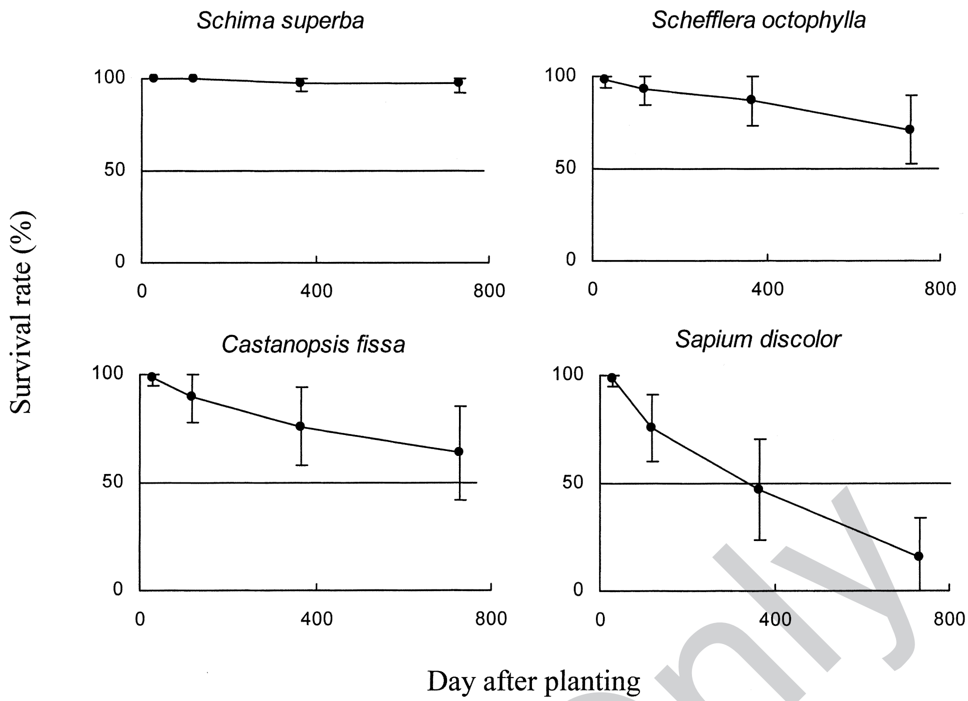

Figure 1. Mean percentage survival of the four seedling species over 2 years in the field.

tained. The Newman-Keuls multiple range (SNK) test was used for multiple comparisons.

Results

The total nitrogen content of the soil at the study site ranged from 0.007 to 0.043% (mean, 0.0204 ± 0.0084%, $n = 20$) and the available soil phosphorus content ranged from 0.0010 to 0.0040% (0.00225 ± 0.00079%, $n = 20$). The soil suction never reached the lethal value of −80 kPa, with a maximum reading of −72 kPa on 19 November 1996.

Transplantation losses were less than 2% in all species, and survival remained over 75% before the onset of the first dry season in November 1995. Overall 2-year seedling survival rates ranged from a high of 97.8% in *Schima* to 15.8% in *Sapium* (Fig. 1). All seedling mortality did not appear to be due to pest or herbicide damage. Herbicide, however, had a large significant negative effect on the survival of *Castanopsis* and *Sapium* seedlings but a significant positive effect on *Schefflera* (Table 2). Irrigation and fertilizer had significant negative effects on the survival of *Castanopsis* only.

Sapium growth was not analyzed because its survival rate was zero in 40% of the plots. Most of the surviving seedlings of this species decreased in height due to wind damage. Mean height and diameter increments over 2 years were highest for *Schima* and lowest for *Castanopsis*, but *Schefflera* showed the highest percentage increase (Table 1). Irrigation had a strong significant positive effect

Table 2. Summary of the three-way ANOVAs to investigate the effects of irrigation, herbicide, and fertilizer on the survival and growth of tree seedlings.

Species		*Schefflera*			*Castanopsis*			*Sapium*			
Measure	*Schima*	*S*	*H*	*D*	*S*	*H*	*D*	*S*	*H*	*D*	*S*
Irrigation	+	98	<u>113</u>	<u>206</u>	74	290	119	<u>57</u>	100	<u>92</u>	15
	−	87	<u>82</u>*	<u>135</u>**	57	257	122	<u>71</u>**	100	<u>66</u>**	17
Herbicide	+	99	<u>444</u>	<u>195</u>	<u>76</u>	287	<u>169</u>	<u>53</u>	<u>66</u>	78	<u>7</u>
	−	86	<u>60</u>***	<u>98</u>***	<u>66</u>*	266	<u>62</u>**	<u>75</u>***	<u>111</u>*	77	<u>25</u>**
Fertilizer	+	85	<u>104</u>	<u>165</u>	66	<u>310</u>	135	<u>58</u>	<u>124</u>	<u>93</u>	16
	−	88	<u>68</u>***	<u>131</u>***	76	<u>243</u>***	108	<u>69</u>*	<u>78</u>***	<u>65</u>**	12

The mean survival (% in 2 years) and growth rates (% increment in 2 years) of the seedling species under each treatment are listed (the underlined are found significantly different). S, % seedling survival in 2 years; H, relative stem height increment per year; D, relative basal diameter increment per year. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Table 3. Newman-Keuls multiple range test results of the significant higher order interactions.

Schima (relative basal diameter increment per year)							
Treatment:	+ herbicide + fertilizer		+ herbicide − fertilizer		− herbicide + fertilizer		− herbicide − fertilizer
Sample mean:	19.77	>	17.49	>	12.13	>	8.32
Schefflera (relative stem height increment per year)							
Treatment:	− herbicide + fertilizer		+ herbicide + fertilizer		+ herbicide − fertilizer		− herbicide − fertilizer
Sample mean:	352.67	=	320.09	=	279.10	=	238.38

Both cases have $p < 0.05$.

on the height (relative height increment per year) and diameter growth (relative basal diameter increment per year) of *Schima* and the diameter growth of *Castanopsis* (Table 2). Herbicide had a significant positive effect on the height growth of *Schima* and diameter growth of *Schefflera* but a strong significant negative effect on the height growth of *Castanopsis* (Table 2). Fertilizer had a significant positive effect on the height growth of *Schima* and on the height and diameter growth of *Castanopsis*.

The interactions between herbicide and fertilizer on the diameter growth of *Schima* and height growth of *Schefflera* were significant (Table 3). The Newman-Keuls test results showed that the effects of herbicide and fertilizer treatments on *Schima* were greater in the presence of the other treatment than alone and that herbicide appeared to have a stronger influence than fertilizer (Table 3). For *Schefflera* the SNK test is not powerful enough to differentiate the treatment combinations. Main effects involved in these interactions were not considered separately.

Discussion

Total nitrogen and available phosphorous were lower at the study site than for most other sites with published soil analyses in Hong Kong and Guangdong (Chen et al. 1996; Lay et al. 1999; Marafa & Chau 1999b; Wong 1999). Soil analysis data are very sensitive to the precise methodology used, but this suggests that soil degradation at the study site may be extreme. On the other hand, the soil suction results suggest that dry season water stress was not severe. This is consistent with the largely evergreen phenology of Hong Kong's woody flora, with *Sapium discolor* one of the few common dry-season deciduous species.

Almost 100% seedling survival for all species after 30 days, and the still very high survival rates before the first dry season show that the postnursery care and the precautions during seedling transportation and transplantation were effective in minimizing transplantation loss. Most seedling mortality occurred in the dry seasons, but this was not reduced by irrigation. Indeed, all three treatments reduced survival in *Castanopsis*, and the herbicide treatment, which was expected to reduce belowground competition for water, also reduced survival in *Sapium* but increased it in *Schefflera*. The negative impacts of herbicide treatment on the survival of *Castanopsis* and *Sapium*, which contrasts with the results of similar studies elsewhere in the tropics (e.g., Chapman & Chapman 1997; De Steven 1991), may reflect an effect of removal of grass cover on evaporation from the soil surface, but no data are available. The overall low survival of *S. discolor* in this study, which contrasts with other planting trials with this species in Hong Kong (Lay et al. 1999; Zhuang 1993), appeared to result directly from physical damage by wind at this very exposed site.

The significant effects of the treatments on seedling growth are all in the expected direction, except for the strong negative effect of herbicide on *Castanopsis* growth. *Castanopsis* was known to bear ectomycorrhizas under natural growing conditions in Hong Kong (Tam & Griffiths 1992). The reason for the negative effect of herbicide on *Castanopsis* growth is not known. The interaction between herbicide and fertilizer for *Schima* is in the direction expected if there is underground competition with grasses for nutrients. Overall, the results suggest that all three factors—seasonal drought, belowground competition, and low soil nutrients—can significantly impair seedling growth on a degraded hillside site in Hong Kong but that their relative importance differs among species. The growth benefits from the treatments are largest and most consistent for *Schima*, which as a mature forest dominant would be expected to be particularly sensitive to the environmental conditions on degraded open sites. Fertilizer and herbicide had large and significant effects on growth of *Schefflera*, which spontaneously invades such sites in Hong Kong. The treatment effects on *Castanopsis*, which is widely planted in open sites but does not invade them spontaneously, seem contradictory and are not easily explained.

This study involved only one site and only 4 of the more than 400 native tree species in Hong Kong. Trials of more species and at more sites are needed before definite recommendations to enhance the survival and growth of tree seedlings during reforestation can be made. Because the irrigation treatment is impractical under normal field conditions, these trials only need to investigate the effects of fertilizer and herbicide treatments, which will greatly reduce the numbers of seedlings required. This study was also limited to 2 years, but early survival and growth are the keys to successful reforestation in Hong Kong, because grassland sites are very susceptible to anthropogenic fires and early closure of the woody canopy is essential.

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Queries

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Q2: Provide city
Q3: Provide city
Q4: Provide city