SITE EFFECTS ON SURVIVAL AND GROWTH OF PLANTED SHOREA CURTISII IN A LOGGED-OVER HILL FOREST IN PENINSULAR MALAYSIA

D Hoshino^{1, 2, *}, N Tani^{1, 2}, K Niiyama³, T Otani⁴, D Aida⁵, M Shamsuri⁶, R Azizi⁷, K Abd Rahman², ZS Nur Hajar² & H Ismail²

¹Japan International Research Center for Agricultural Sciences, 1-1 Ohwashi, Tsukuba, Ibaraki 305-8686, Japan ²Forest Research Institute Malaysia, 52109 Kepong, Selangor, Malaysia

³Forestry and Forest Products Research Institute, 1 Matsunosato, Tsukuba, Ibaraki 305-8687, Japan ⁴Shikoku Research Center, Forestry and Forest Products Research Institute, 2-915, Asakura-Nishi, Kochi 780-8077, Japan ⁵Perak State Forestry Department, Persiaran Meru Utama, 30020 Ipoh, Perak, Malaysia

⁶Bidor District Forest Office, Forestry Department Peninsular Malaysia, Perak, Malaysia

⁷Green Forest Resources, 48300 Rawang, Selangor, Malaysia

*dhoshi@affrc.go.jp

HOSHINO D, TANI N, NIIYAMA K, OTANI T, AIDA D, SHAMSURI M, AZIZI R, ABD RAHMAN K, NUR HAJAR ZS & ISMAIL H. 2016. Site effects on survival and growth of planted *Shorea curtisii* in a logged-over hill forest in Peninsular Malaysia. We investigated three site effects on the survival and growth of *Shorea curtisii* trees in an 18-year-old plantation in Bukit Kinta Forest Reserve, Peninsular Malaysia. Past studies of enrichment planting of *S. curtisii* indicated poor survival and growth in logged-over hill forests. To improve the planting technique, three site effects, i.e. slope angle, plot size and total basal area of surrounding trees (TBS), were analysed using a general linear mixed model with Bayesian parameter estimation. Plot size (25–900 m²) showed a major effect on survival and diameter at breast height (dbh), subsequently slope angle was supported as a secondary effect by model selection. TBS was shown to have a major effect on total tree height. Slope angle and plot size consistently showed negative and positive effects on all explanatory variables such as survival rate, dbh and total height. In contrast, TBS showed a positive effect on survival rate but a negative effect on dbh and total height. This result suggested that the amount of surrounding trees improved the survival of planted *S. curtisii* in the seedling stage and then inhibited growth of planted trees during the seedling and subsequent tree stages. We concluded that 30 m × 30 m plots with few surrounding trees on a gentle slope were effective for enhancing the growth of planted *S. curtisii*.

Keywords: Enrichment planting, dipterocarps, seraya, topography, shelterwood, weeding treatment

INTRODUCTION

Shorea curtisii (Dipterocarpaceae), the most dominant tree species found in the hill dipterocarp forests of Peninsular Malaysia, is an important commercial timber species in South-East Asia (Symington 1943). To supplement natural regeneration of logged-over forests, enrichment planting of seedlings of commercial tree species, including S. curtisii, has been carried out on skid trails and in logging gaps (Wan Shukri et al. 2008). Enrichment planting of S. curtisii in logged-over forests has shown poor survival and growth rates (e.g. Lok et al. 1996, Abd Rahman 2008). Failure of enrichment plantings has been attributed to factors including low survival due to inadequate post-planting treatments and high mortality due to poor planting stock (Tang & Wadley 1976). Further improvement of enrichment planting practices of this important

species is required to enhance timber stock recovery in logged-over hill forests.

In hill dipterocarp forests, mature *S. curtisii* trees are usually limited to ridge crests (Wyatt-Smith 1963, Niiyama et al. 1999). This species is likely specialised and restricted to dry sites (Burgess 1969). In contrast, the difference in the density of seedlings and saplings between gentle slopes of ridges and steep slopes is insignificant (Kominami et al. 2000, Yagihashi et al. 2010). Accordingly, the decline in numbers of *S. curtisii* on steep slopes is expected to increase from the seedling to the tree stage but evidence for this is still lacking.

Light conditions also represent a complex site effect for *S. curtisii*. The difference in sapling density between canopy gaps and locations under closed canopy in primary hill forest was found to be insignificant (Kominami et al. 2000). Seedlings of *S. curtisii* transferred from shade to direct sunlight underwent leaf scorching often resulting in mortality (Turner 1989) because *Shorea* species suffer leaf damage from high temperature or strong light irradiance in large gaps (Turner & Newton 1990). In contrast, the growth of naturally-regenerated *S. curtisii* seedlings appears to require relatively high photosynthetically active radiation (23%; Turner 1989). Seedlings of this species may need moderate shading for survival and growth from seedling to tree stage.

Surrounding trees that provide moderate shade to planted trees are known as 'shelterwood' (Paquette et al. 2006). However, shading effects on growth or mortality from intercropping with other fast-growing species were not detected in *S. curtisii* trees 12 years after planting (Lok et al. 1996). More evidence based on long-term observation may be required to determine the effect of shelterwood on the species.

Maintenance treatment such as weeding and climber cutting is also important in enrichment planting (Wan Shukri et al. 2008). Ådjers et al. (1995) suggested that horizontal tending was more effective for the growth of *Shorea* species than vertical tending using line planting. The effect of horizontal tending was thought to depend on treatment area size (i.e. width and length).

At planting sites after logging, foresters must judge appropriate site selection from few visible signs. Topographic position, treatment area size and amount of shelterwood could be simple and useful information for enrichment planting of various timber tree species. Therefore, for this study, we focused on slope angle as topographic position, plot size as treatment area size and basal area of surrounding trees as the amount of shelterwood. We clarified site effects on the survival and growth of the planted S. curtisii. Our objectives in this study are to: (1) rank the site effects by order of importance and (2) determine whether site effects are negatively or positively correlated to survival and growth of planted S. curtisii trees.

MATERIALS AND METHODS

Study site

The study was conducted in Compartment 146 (4°32' 41" N, 101°13' 38" E) within the 500-ha Bukit Kinta Forest Reserve, Perak, Peninsular

Malaysia. The altitude ranges from 300–600 m above sea level, with a mean annual precipitation of 2417 mm and monthly mean temperature of 24.5 °C (range 22.6–28.4 °C; Anon et al. 1999). The topography at the study site comprises gentle and steep slopes and narrow ridges (Aizawa 1993). The geology is formed by acid intrusive rock and the soils in this site are Acrisols (FAO 1974). The soil profile is characterized by an A horizon that is thin (5–10 cm) on ridges and upper slopes and relatively thick (ca. 20 cm) on gentle slopes, and hard-clay-accumulated B horizons in most areas (Aizawa 1993).

Bukit Kinta Forest Reserve was selectively logged from 1990 to 1992, with 32.59 m³ ha⁻¹ of dipterocarp timbers extracted from Compartment 146 and the adjacent Compartment 147 (Anon 1999). The present study site was established in 1996 as part of an international collaborative research project that evaluated the growth performance of selected dipterocarp species under different line and gap planting techniques (Anon 1999).

In the present study, one-year-old nurseryraised S. curtisii seedlings were planted in square plots of four different sizes, on the ridge and upper slope of the north-east-facing hillside (Figure 1; Emori et al. 2002). Plot sizes were $5 \text{ m} \times 5 \text{ m}$, $10 \text{ m} \times 10 \text{ m}$, $20 \text{ m} \times 20 \text{ m}$ and $30 \text{ m} \times 10 \text{ m}$ 30 m, with a 5 m wide buffer zone around each plot (Figure 2). Plant spacing was $2 \text{ m} \times 2 \text{ m}$ in the plots, and no seedlings were planted in the buffer zone. In the plots, residual trees of commercial value that had a diameter at breast height (dbh) ≥ 10 cm were kept, while all other vegetation (e.g. trees, bamboo, palms, climbers and grasses) was cleared before planting. Vegetation in the buffer zone was not cleared. A total of 54 plots were established: 30, 14, 6 and 4 plots, for the $5 \text{ m} \times 5 \text{ m}$, $10 \text{ m} \times 10 \text{ m}$, $20 \text{ m} \times 20 \text{ m}$ and $30 \text{ m} \times 10 \text{ m}$ 30 m plot treatments respectively. A total of 2000 seedlings were planted over 0.82 ha and total area under the buffer zone was 1.60 ha. In the plots, weeding and cutting of climbers was carried out 8 times in the first 5 years after planting. Over the remaining 13 years of the study period, the plots received no additional tending.

Field survey

At the end of the 18-year study period (in March 2014), a complete tree census was conducted for the plots and buffer zones. Plots and buffer zones were divided into $5 \text{ m} \times 5 \text{ m}$ quadrats. For each



Figure 1 Location of study site in Compartment 146 showing the layout of plots of four sizes where *Shorea curtisii* seedlings were planted

quadrat, the following parameters were recorded: number of surviving *S. curtisii* trees, dbh (in cm) and total stem height (in m) of all *S. curtisii* trees, dbh of other tree species with dbh > 5 cm, and slope angle (using a clinometer).

To understand tree species composition in the plots and the buffer area, a separate census of a $10 \text{ m} \times 50 \text{ m}$ plot on the ridge next to the study site recorded the following for all trees with dbh > 5 cm: dbh, total height and tree species (Figure 1). Basal area and stem density were calculated for each tree family.

At 18 years after planting, in addition to the surviving *S. curtisii* trees and the preserved residual trees (dbh > 10 cm at the start of the study), the study site had some natural regeneration from seeds that germinated after the study site was established. Canopy cover was therefore greater than at the start of the study. For each 'target' quadrat, the amount of canopy cover (as a proxy for light penetration to the understory) was estimated by obtaining total basal area of surrounding trees (TBS) (adapted from Cade 1997). Here, it was calculated as the total basal area of other tree species with dbh > 5 cm in the target quadrat and in the adjacent eight quadrats (a 15 m \times 15 m area).

To estimate stand volume, we measured stem height up to the first living branch (HB, in m) and total stem height (HT, in m). A total of 138 *S. curtisii* trees were sampled from the four plot sizes for these measurements. A linear regression was fitted to the data as follows:

$$HB = aHT$$

where the constant a was assigned as the value 0.624 (r² = 0.62). The stem height up to the first living branch of all planted trees in all plots was estimated using this regression.

The merchantable height of a single tree was estimated as follows:

$$L = HB - HC$$



Figure 2 The four plot sizes planted with *Shorea curtisii* seedlings after logging and the 5-m buffer zone surrounding each plot

where L and HC are merchantable height and cutting height respectively. The cutting height was assigned as 0.3 m, the probable stump height.

The merchantable volume of a single tree was estimated as follows (FDPM 1997):

$$V = \frac{\pi f d^2 L}{40000}$$

where V and d are merchantable volume (m^3) and dbh (cm) respectively. The form factor f takes the value 0.65 (after FDPM 1997). Total merchantable volume of *S. curtisii* trees was calculated for each quadrat as a representation of stand volume $(m^3 ha^{-1})$.

Statistical analysis

We used a generalised linear mixed-effects model (GLMM) to determine whether some surrounding environments influenced survival and growth of the planted seedlings. The site effects (slope angle, plot size and TBS) were used as explanatory variables with fixed effect. Dummy variables were used to express different combinations of plot sizes: 5 m × 5 m plots vs 10 m × 10 m, 20 m × 20 m and 30 m × 30 m plots (PC1); 5 m × 5 m and 10 m × 10 m plots vs 20 m × 20 m and 30 m × 30 m plots (PC2) and 5 m × 5 m, 10 m × 10 m and 20 m × 20 m plots vs $30 \text{ m} \times 30 \text{ m}$ plots (PC3). Values of zero for slope angle and/or TBS, were substituted with 0.1 for the purpose of fitting GLMM for the analysis. No correlation was detected between any pair of explanatory variables.

As survival rate, which was calculated for each 5 m \times 5 m quadrat as the numbers of surviving seedlings from those planted, has a discrete probability distribution with numbers of planted and surviving seedlings censused, GLMM using binomially distributed response variables (a survival model) was fitted to the explanatory variables with a random intercept for each quadrat. As growth is a positive continuous variable, primary (dbh) and secondary (total height) growth of individual planted trees was evaluated by GLMM using a gamma distribution with random intercept of each tree (a growth model). We did not fit interactions between the explanatory variables. Uninformative priors were used for initial parameter distributions, which were then re-parameterised with a Hamiltonian Monte Carlo sampler using the No-U-Turns sampler. These models were implemented in RStan version 2.5 (2014) using the package RStan in R version 3.1.1 (2014). Three chains were run for each survival and growth model with explanatory variables. All models were run for 150,000 iterations, discarding the first 30,000 as a burn-in period. We used the Rhat statistic together with the visual inspection of the chains to assess convergence (Gelman & Rubin 1992). For both survival and growth models, we separately analysed explanatory variables and then combinations of two and three of the explanatory variables. We evaluated model fit by the Watanabe-Akaike information criterion (WAIC). To evaluate the significance of posterior distribution of the parameters, we used a 95% Bayesian credibility interval. When the 95%Bayesian credibility interval of each parameter contained zero, we recognised the parameter as insignificant. In contrast, when the 95% Bayesian credibility interval of each parameter was located below or above zero, we recognised the parameter as negatively or positively significant respectively.

RESULTS

Species composition in the logged-over forest

In the 10 m \times 50 m logged-over forest plot adjacent to the replanted plots, mean dbh,

maximum dbh, mean total height and maximum total height of stems were 14.7 cm, 43.5 cm, 11.6 m and 29.6 m respectively. Total basal area and stem density were 27.2 m² ha⁻¹ and 1200 ha⁻¹ respectively. The most common families based on stem density were Dipterocarpaceae (20%), Lauraceae (14%) and Anacardiaceae (6%). This logged-over hill forest was dominated by commercial trees such as *Shorea acuminata* and *S. macroptera*. On the other hand, some pioneers such as *Macaranga* spp. and *Porterandia anisophylla* were present.

Survival rate, stand volume and growth

Except for one incident where fallen trees covered a fifth of one 20 m \times 20 m plot, killing some planted trees and surrounding trees, no other major disturbances were noted in the plots and buffer zones. Mean slope angle and TBS were in the ranges of 20–29° and 33–41 m² ha⁻¹ respectively (Table 1).

A total of 683 planted S. curtisii survived in plots from the initial planting of 2000. Mean survival rate, mean total height and mean stand volume tended to increase with plot size (Table 1). In contrast, mean dbh was limited to a narrow range (6.2-7.9 cm). The largest values for stand volume and total height were observed in the 30 m \times 30 m plots: 384 m³ ha⁻¹ and 22.9 m respectively. The largest value for dbh (25.6 cm) was observed in the 10 m \times 10 m plots. Mean annual increment (MAI) of dbh and total height were in the ranges of 0.34–0.44 cm year⁻¹ and 0.35–0.48 m year⁻¹ respectively. Stand volume was likely to be affected by three site effects (Figure 3). Stand volume decreased with increasing slope angle and TBS but increased with plot size.

Site effects on survival and growth

In survival models with a single explanatory variable, WAIC was the lowest in PC2 (1.651) followed by slope angle (1.654) corresponding to the best and second-best fit models (Table 2). WAIC of the survival model with two variables showed the lowest value for the combination of slope angle and PC2 (1.646). WAIC of the survival model with three variables showed the lowest value for the combination of slope angle (1.645) and was the best of all models for explaining survival rate. However, the difference in WAIC between the best-fitting models with two variables and with three variables

Table 1	Survival and growth of <i>Shorea curtish</i> seedlings planted in plots of four different sizes in relation to
	slope angle and the total basal area of surrounding trees (TBS)

Plot size	No. of	Planted	Surviving	Mean values (± SD) for:						No. of
	plots	trees	trees	Survival	Stand	Dbh	Total	Slope	TBS	quadrats
				rate	volume	(cm)	height	angle	$(m^2 ha^{-1})$	
				(%)	$(m^3 ha^{-1})$		(m)	(°)		
$5 \mathrm{m} \times 5 \mathrm{m}$	30	150	38	25 (33)	10 (22)	6.2 (4.0)	6.3 (3.4)	29 (7)	41 (35)	30
$10~\mathrm{m}\times10~\mathrm{m}$	14	350	76	22 (23)	17 (43)	7.1 (5.3)	6.5(3.6)	31 (5)	33 (16)	56
$20~\mathrm{m}\times20~\mathrm{m}$	6	600	205	34 (26)	20 (35)	6.4(3.9)	7.1 (3.7)	28 (8)	42 (23)	96
$30 \text{ m} \times 30 \text{ m}$	4	900	364	40 (23)	46 (71)	7.9 (5.1)	8.7 (4.7)	20 (9)	43 (22)	144

SD = standard deviation



Figure 3 Stand volume of *Shorea curtisii* planted in logged-over plots of four sizes in relation to (a) slope angle, (b) total basal area of surrounding trees (TBS) and (c) plot size

was only 0.1, indicating that PC2 and slope angle affected survival rate more strongly than TBS.

For dbh models with a single explanatory variable, the lowest WAIC was PC3, followed by TBS (Table 2). In dbh models with two variables, WAIC of the model combining PC3 and TBS was lowest (2.756). However, WAIC of the best-fitting model with three variables (2.756) was similar to that of the model with two variables, indicating that both PC3 and TBS affected dbh of *S. curtisii* while slope angle had almost no effect.

In the height models with a single explanatory variable, WAIC in ascending order was TBS, slope angle and PC3 (Table 2). However, the lowest WAIC of models with two variables was shown in the model combining PC3 and TBS. The lowest WAIC was derived when three variables combining slope angle, PC3 and TBS were applied.

For all response variables, GLMMs with three explanatory variables yielded lower WAIC values than other combinations (Table 2). Table 3 and Figure 4 show the convergence and posterior probabilities of coefficients of models with three explanatory variables. Their 95% Bayesian credibility intervals of coefficient estimates of the explanatory variables indicated significant association with all explanatory variables. Slope angle showed a negative effect on all response variables. Plot size showed a positive effect on all response variables. TBS showed a positive effect on survival rate and a negative effect on dbh and total height.

DISCUSSION

At 22–40%, survival rates of *S. curtisii* in this study were similar to those reported for previous studies i.e. 15-36% 12 years after planting (Lok et al. 1996) and 26% 17 years after planting (Abd Rahman 2008). In contrast, mean growth rate of 0.34–0.44 cm year⁻¹ MAI of dbh in the present study was clearly poorer than the 0.85–1.16 and 0.85 cm year⁻¹ MAI of dbh reported by Lok et al. (1996) and Abd Rahman (2008) respectively. Such discrepancies between the present and

Table 2Explanatory variables, Watanabe–Akaike information criterion (WAIC) and convergence
of mixed models to fit survival and growth of planted S. curtisii in 5 m × 5 m quadrats and
individually

Model type	Explanatory variables		WAIC			
		Survival rate	Dbh	Total height		
Single variable						
	Slope angle		1.654	2.778	2.759	
	Plot combination	PC1	1.664	2.774	2.772	
		PC2	1.651	2.765	2.769	
		PC3	1.656	2.759	2.761	
	Surrounding trees	TBS	1.663	2.763	2.755	
Two variables						
		Slope angle, PC1	1.654	2.779	2.760	
		Slope angle, PC2	1.646	2.780	2.759	
		Slope angle, PC3	1.652	2.777	2.756	
		Slope angle, TBS	1.654	2.758	2.742	
		PC1, TBS	1.660	2.764	2.756	
		PC2, TBS	1.649	2.760	2.751	
		PC3, TBS	1.654	2.756	2.739	
Three variables						
		Slope angle, PC1, TBS	1.650	2.760	2.744	
		Slope angle, PC2, TBS	1.645	2.760	2.742	
		Slope angle, PC3, TBS	1.649	2.756	2.736	

TBS = total basal area of surrounding trees; PC1–PC3 are different combinations of plot sizes (see text), values in bold are the smallest WAIC value

Response variable	Explanatory variable	Coefficient value	SD	95% lower	95% upper	Site effect
Survival rate	(Intercept)	-0.621	0.326	-1.264	0.010	-
	Slope angle	-0.035	0.009	-0.052	-0.017	Negative
	PC2	0.558	0.190	0.191	0.937	Positive
	TBS	0.297	0.140	0.020	0.573	Positive
Dbh	(Intercept)	2.358	0.101	2.160	2.555	Positive
	Slope angle	-0.009	0.003	-0.015	-0.003	Negative
	PC3	0.120	0.056	0.009	0.232	Positive
	TBS	-0.267	0.045	-0.355	-0.178	Negative
Height	(Intercept)	2.315	0.083	2.151	2.478	Positive
	Slope angle	-0.006	0.003	-0.011	-0.001	Negative
	PC3	0.152	0.048	0.058	0.246	Positive
	TBS	-0.212	0.038	-0.286	-0.136	Negative

Table 3Convergence and posterior probability of coefficients of mixed models when survival or
growth was assigned as a response variable

SD = standard deviation, TBS = total basal area of surrounding trees; PC2 and PC3 are different combinations of plot sizes (see text), values in bold are significant because the 95% Bayesian credibility interval is located below or above zero

previous studies could be due to shading by surrounding trees at our study site whereas the previous study sites were clear-cut before planting.

However, localised survival and growth rates in the present study site showed larger values than those of past records. Maximum diameter size of 25.6 cm 18 years after planting was comparable to the 29.7–35.0 cm measured from the largest of 20 year-old *S. curtisii* trees planted in the Forest Research Institute of Malaysia in Kepong (Ng & Tang 1974). Maximum stand volumes substantially exceeded the past harvesting timber volume in Compartments 146 and 147 in 1990. The heterogeneity of growth among quadrats and plots suggested the existence of favourable sites for this species.

Slope angle was the second significant explanatory variable for survival rate and height growth but not for diameter growth. The negative effect of slope angle indicated that the *S. curtisii* seedlings had an advantage in survival and height growth when they were planted on flat or gently sloped sites on the ridge at the study site. Carbon, nitrogen and available phosphoric acid content have been reported to be high for surface soil on ridges in hill dipterocarp forests (Tange et al. 1998). On the other hand, during a rare drought, the shallow soil on the ridge was much drier than that on the slopes or valley sites (Tange et al. 1998). Shorea curtisii has a relatively high water use efficiency among dipterocarp tree species and tolerates the drier soil conditions on the ridges in hill dipterocarp forests (Maruyama et al. 1997). Further, this species showed poor growth performance under wet conditions (Tange et al. 2000). Flat or gently sloped sites on the ridge, which has better drainage than slopes and valleys, may favour the survival and height growth of *S. curtisii*.

Expansion of treatment area size (plot size) was mainly effective for survival and diameter growth and secondarily effective for height growth. Since study plots included residual commercial trees, vertical treatment was different in each plot and each quadrat. On the other hand, 8 weeding treatments during the first 5 years provided both a safe site and growing space free from competition with understorey vegetation. Outward-facing edges of all quadrats in the smallest plots $(5 \text{ m} \times 5 \text{ m})$ and most quadrats in 10 m × 10 m plots were exposed to competition from understorey vegetation. On the other hand, quadrats in the middle of the larger plots (20 m \times 20 m and 30 m \times 30 m) did not face any understorey vegetation (Figure 2). After the last weeding treatment conducted in 2000, competition with the understorey vegetation in the small plots may have become severe as understorey trees and palms underwent canopy



Figure 4 Linear regression charts for the logged forest site planted with *Shorea curtisii* seedlings showing relationships between: survival rate and (a) slope angle and (b) total basal area of surrounding trees (TBS); diameter at breast height (dbh) and (c) slope angle and (d) TBS; total height and (e) slope angle and (f) TBS; closed circles represent larger plot size and crosses represent smaller plot sizes, bold and grey lines line indicate the fitting curves of the mixed model for larger and smaller plot sizes respectively

expansion and weeds and climbers invaded those plots. Previous reports on line planting have recommended clear-cutting surrounding vegetation to the width of 6 m around planted trees (Ådjers et al 1995, Pena-Claros et al 2002). Although our study did not involve clear-cutting and line planting, our results similarly suggest that horizontal weeding treatment of a wide area aided the survival and diameter growth of *S. curtisii* planted seedlings.

Generally, in tropical forests, canopy gap size affects the growth of naturally-regenerating (Tuomela et al. 1996) or planted trees (Lopes et al. 2008, Schulze 2008) at the seedling stage. In our study, TBS was used as the proxy for light condition measurement because study plots included residual commercial trees and the edge effect from trees in the buffer zone also could be estimated. TBS positively affected survival rate, suggesting the shade of adjacent and buffer zone shelterwood trees in plots enhanced the survival of planted seedlings (Paquette et al. 2006). During the seedling stage, some mid- to late-successional tropical forest species show relatively high shade acclimation but are sensitive to photoinhibition of leaf photosynthesis under strong light irradiance (Turner 1989, Kenzo et al. 2011). Likewise, our results indicate a positive correlation of shade with increased survival rate of planted seedlings.

Shelterwood trees do not always enhance survival and growth and may sometimes harm neighbouring species by competing for limited resources including light, growing space, water and nutrients (Franco & Novel 1988, Padilla & Pungnaire 2006). Based on its natural distribution, S. curtisii is considered a shade-tolerant species (Kominami et al. 2000) and its growth increases under moderate light conditions in the seedling stage (Turner 1990). In a previous study at Bukit Kinta Forest Reserve, height and dbh growth of Shorea parvifolia seedlings planted in plots with few residual trees was better than in plots with many residual trees (Ito et al. 2002). Our results suggest that the presence of many surrounding trees eventually inhibited both diameter and height growth of the planted seedlings beyond the seedling stage.

To conclude, our findings suggest that a 30 m \times 30 m plot with few surrounding trees on a flat or gently sloping site may favour the growth of planted *S. curtisii*. However, the large difference found in survival rate between the 5 m \times 5 and 10 m \times 10 m vs 20 m \times 20 and 30 m \times 30 m

treatment area size (PC2) implies that very large gaps with no shelterwood may decrease survival in planted seedlings. Increasing amounts of solar radiation has been reported to cause photoinhibition and suppress growth of seedlings (Turner 1989). Appropriate site selection may enhance the productivity of planting sites and decrease the cost of enrichment planting in logged-over hill forests.

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