THE USE OF GIS TO STUDY THE INFLUENCE OF SITE FACTORS IN ENRICHMENT PLANTING WITH DIPTEROCARPS[1]

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ABSTRACT

A geographical information system (GIS) was used to investigate the influence of different site factors on growth and mortality of dipterocarp seedlings in an enrichment planting project. The study was conducted in three logged forest sites of contrasting characteristics, which were enrichment planted with seedlings of different species of dipterocarp. Field surveys were carried out in order to produce detailed maps of topography, remaining vegetation (trees, vines, bamboo and weeds), hydrology (rivers and streams) and skid trails. Individual measurements of site leaf area index were taken above all planted seedlings. Coverages (digital maps) were produced in GIS and used to study the effects of these factors on growth and mortality of planted seedlings, using the various GIS commands such as creation of buffer zones, overlaying and merging of data and maps. It was found that seedling growth rates were negatively correlated to leaf area index of the site where they were planted, and therefore all factors which were related to reduced light (ie. tree canopies and vine tunnels) also caused a negative effect on growth rates of planted seedlings. High mortality and low growth rates were observed on skid trails, possibly because of the high compaction and low nutrient concentration of the soil. Planting sites with little remnant vegetation showed higher growth rates, probably due to the higher mean light intensity reaching planted seedlings. Among the dipterocarp species studied, *Shorea leprosula* exhibited the fastest growth rates and low mortality. *Dipterocarpus* spp. performed worst, with slowest growth rates and highest mortality. *Dryobalanops lanceolata* suffered the lowest mortality rates among the dipterocarps studied. *Agathis dammara*, the only non-dipterocarp species studied, had higher mortality and lower growth rates than any dipterocarp.

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INTRODUCTION

Timber from dipterocarp forests are an important source of revenue for many South East Asian countries (Poore 1989). The decrease in the productivity of natural forests following initial logging (Chin 1989) has created an interest in planting timber trees in logged forests (Pinso and Moura Costa, 1993). Enrichment planting is a technique for promoting artificial regeneration in which seedlings of preferred timber trees are planted in the under-storey of existing logged-over forests and then given preferential treatment to encourage their growth (Lamprecht 1986). While for mono-specific natural forests or plantations this technique may be relatively simple, enrichment planting of tropical forests is a very complex forestry practice. The wide variety of plant species in the forest, with trees of different sizes, growth rates and canopy shapes pose difficulties to planning spacing, line width, light management and selective thinning required for planting. Enrichment planting of logged forests is even more complex, since logging creates a mosaic of patches of forest with different disturbance levels (Nussbaum *et al.*, 1993). The distribution of remnant trees is very heterogeneous, the soils are disturbed due to erosion or compaction, and the forest is invaded by light-demanding plants such as pioneer trees, vines, climbers, bamboo and grasses.

In order to decide which silvicultural practices to prescribe for enrichment planting, it is necessary to understand the effect of these various factors on planted seedlings. Ideally, this type of study should take into account the spatial distribution of the factors involved. The Geographic Information System (GIS) is a tool for storing, processing and analyzing geographically-related data (van der Knaap & van der Meer, 1993), with potential for studies of complex, heterogeneous systems such as rain forests (Buhmann 1989). GIS works by super-imposition of layers of maps containing different information, and enables data bases to be linked to specific geographical locations (Bayer 1991). This study investigated the effects of different site factors on growth and mortality of dipterocarp seedlings using a GIS.

MATERIALS AND METHODS

Study sites

This study was conducted in the Ulu Segama Forest Reserve, Sabah (Malaysia), 5° N, 117° E, near the Danum Valley Field Centre. Mean annual rainfall is 2,600 mm, and mean annual temperature is 26.7°C. The geology, soils and topography of the region are very variable (Marsh and Greer 1992). Three plots (*ca.* 5 ha each) were established within sites which were enrichment planted by the Innoprise-Face Foundation Rainforest Rehabilitation Project (Infapro, Moura-Costa 1993a, Moura-Costa *et al*. this volume). A description of the sites chosen is given below.

Plot 78 was located in a site logged in 1978, and was covered by a homogeneous canopy formed predominantly of the pioneer tree species *Macaranga*. Few remnant trees or natural regeneration of hardwood species were found in this site. Few vine tunnels were observed, since most of the climbers were above the branches of the *Macaranga* trees. The relief was flat. Timber harvesting was done by tractors, but no signs of skid trails were identified. Timber volume extracted from this site was 152 m^3 ha^{-1}. Less than 8 % of the seedlings in this plot were planted outside any canopy cover.

Plot 81 was logged in 1981 using a combination of tractor and high-lead harvesting methods, and was located in the most disturbed forest among the sites selected. There were few remaining trees and a large proportion of the area was extremely open (29 % of seedlings were planted outside canopy cover), with large numbers of grasses, weeds, shrubs, vines and bamboos. Few skid trails were identified. The area was fairly steep, with slopes up to 36°. The timber volume extracted was 92 m^3 ha^{-1}.

Plot 88 was tractor-logged in 1988. Skid trails were obvious and abundant. The volume of timber extracted from this site (73 m^3 ha^{-1}) was lower than from the other sites. Possibly for this reason, it had a combination of patches of undisturbed forest with large trees and dense canopy cover, together with areas with little original vegetation dominated by pioneer trees and lianas. There were many tunnels of vines and climbers. 14 % of the seedlings in this plot were planted outside canopy cover.

Enrichment planting system

The method of enrichment planting used consisted of opening 2 m-wide parallel lines every 10 m through the logged forest matrix and planting seedlings every 3 m along the lines. Lines were opened in an East-West direction. During line opening, most vegetation was removed except for remnant trees or natural regeneration of dipterocarps and fruit species. Planting holes were approximately 10 cm diameter and 20 cm deep. Rock phosphate fertiliser was applied in each planting hole (100 g per plant). Four rounds of weeding were carried out during the experimental period.

Species and plant material used

A combination of species was planted in the different plots (Table 1), each species in a separate line. Lines were approximately 450 m long, and contained *ca.* 150 seedlings each. All species belong to the family Dipterocarpaceae, with exception of *Agathis dammara* (Araucariaceae). A mixture of *Dipterocarpus* species were planted together, since there were few plants available of each individual species of this genus. Seedlings were raised from either seeds or wildings, planted in poly-bags (7 x 21 cm) and raised in the large scale nursery of the Infapro project. A description of the propagation methods used is given in Moura-Costa *et al.* (1993) and Moura-Costa (1993b). Seedlings were planted in the forest after at least four months in the nursery, and had average height between 30 and 60 cm.

Table 1. List of species planted in each plot. (n = number of seedlings per plot). The species are listed according to the position of their lines in the plots, the uppermost corresponding to the northern lines.

78	n	81	n	88	n
Agathis dammara	75	*S. leprosula*	180	*D. lanceolata*	139
Dryobalanops lanceolata	79	*D. lanceolata*	186	*A. dammara*	139
Parashorea malaanonan	100	*P. malaanonan*	190	*Dipterocarpus spp*	129
Shorea johorensis	104	*S. ovalis*	163	*S. ovalis*	132
Shorea leprosula	75	*S. johorensis*	162	*S. parvifolia*	138
				S. leprosula	142

Measurements of survival and growth

Height measurements were taken for each seedling two months after planting and again after one year. At the same time, other data was collected for mapping. Seedling mortality was also recorded during the two rounds of measurements. In order to compensate for the different sizes of seedlings at the beginning of the experimental period, growth rates were expressed as relative height increment (RHI), calculated as follows:

$$\text{RHI} = \frac{\text{Final height - Initial height}}{\text{Initial height}} \times 100$$

Measurements of leaf area index

Measurements of leaf area index (LAI, m^2 foliage area per m^2 ground area) of the forest surrounding planted seedlings were taken using two Li-Cor LAI-2000 Plant Canopy Analyzers (Li-Cor, USA). LAI is inversely correlated to canopy gap fraction (which is also measured with the Li-Cor LAI-2000; Welles 1990) but it was chosen for this study because it was found that it correlates better with seedling growth rates. One canopy analyzer was located in a large clearing and recorded automatically while another was used to manually collect below-canopy readings above each panted seedling. In a second stage, the two LAI-2000 units were connected, so that each below-canopy reading was matched to the correspondent outside-canopy reading. LAI was automatically calculated with the internal software of the LAI-2000, by comparing the relative amount of light reaching the below-canopy sensor with the light reaching the sensor located outside the canopy.

One single measurement was taken for each planted seedling, without using any of the view-masks provided with the LAI-2000, so that a 360° reading was done. The LAI-2000 measures the attenuation of diffuse sky radiation with a set of five optical sensors, arranged as concentric rings (Welles and Norman 1991). Our measurements ignored the two outermost rings, since they measure incident light from a low angle, close to the ground, and there was substantial interference from tree stems and rocks.

Collection of field data for mapping

Detailed maps were made by surveying along each line and locating accurately each planted seedling. Other features were also mapped, including all trees with dbh greater than 10 cm; clusters of vines, bamboo and weeds; rivers and streams; and any skid trails which were still identifiable. Trees were divided into 3 classes, ie. small (dbh between 10 and 25cm), medium (dbh between 26 and 45 cm) and large (dbh > 45 cm).

Input and handling of field data in GIS

The geographical information system (GIS) package used for this project was PC-ArcInfo running in a 486 IBM-compatible personal computer. Digitization was done using a Summasketch III Professional (Summagraphics, USA) A3 digitiser tablet. The coordinates of the planted seedlings collected from field surveys were used to generate base coverages (digital maps) for each plot. Data bases were created containing the growth rates, survival status (dead or alive) and LAI values for each seedling. The data were attached to the seedlings by using their corresponding coordinates. Rivers, streams, skid trails, rock outcrops, and patches of vines, bamboo and weeds were digitized in ArcInfo as polygons. Trees were digitised as point data and different buffers were created according to their size-classes in order to simulate canopy cover. Coverages were created for each of these factors. See Figure 1 for a description of the GIS processes.

To analyze the data, overlays of the different coverages were produced to study the influence of the various factors on growth and survival of planted seedlings. Another analytical procedure used was to generate buffers surrounding certain physical features in order to study the extent of their zone of influence on seedling growth and survival. After patterns were identified from the maps generated from the overlays, data were extracted and statistically analyzed. The GIS was used to perform the following analyses:

a) Effect of trees and their zone of influence

The differences in growth rates of seedlings planted at different distances from the stem of remnant trees were investigated by using the buffer feature of ArcInfo. Buffer zones of different diameters were created around trees according to their size classes, in order to simulate a zone of dense shade and root competition. A second, larger, buffer was created around the same trees to simulate their canopies (Table 2). Growth data from seedlings in these buffer zones were selected and compared with data from seedlings outside the 'zone of influence' of the trees.

Table 2. Buffer zones created to study the zones of influence of tree crowns and root competition.

Tree size-classes	Buffer size (radius, in m)	
	Outer ring (crown cover)	Inner ring (competition zone)
Small	2.5	1.5
Medium	5.0	2.5
Large	11.5	4.0

b) Effects of competing vegetation: vines, bamboo and weeds

By using the overlaying feature of ArcInfo, data were selected from all plants under vines tunnels, bamboo clusters and patches of weeds and compared to data from plants away from them.

c) Effects of streams, riverine areas and skid trails

In order to study the effect of riverine conditions on development of seedlings, a 10 m buffer zone was created from the margin of each stream, and data from seedlings located there were selected and compared to seedlings planted elsewhere. Similarly, 3 m buffers were created on each side of skid trails, and the growth and survival of seedlings in these areas were compared with those planted elsewhere.

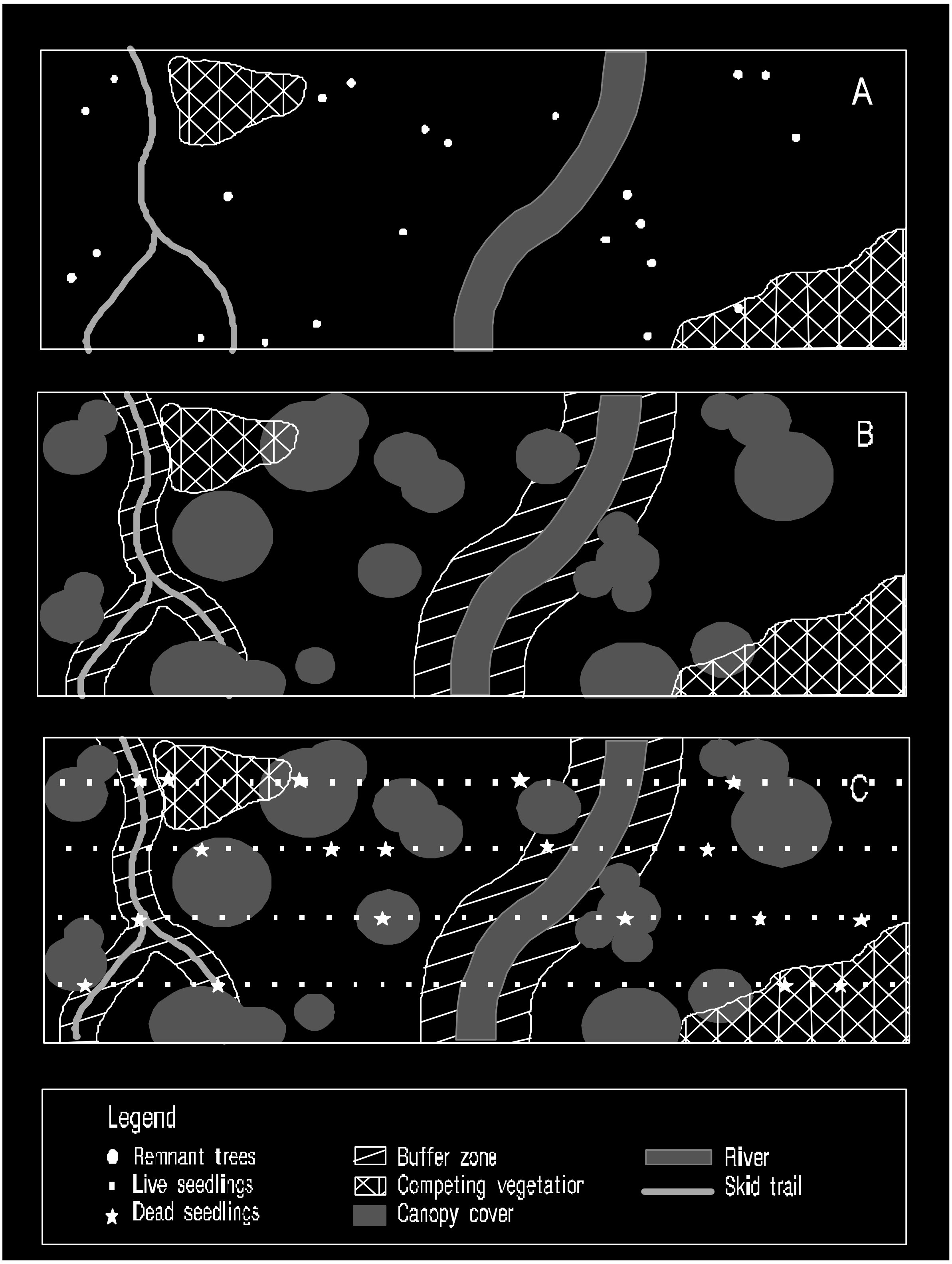

Figure 1. Process of GIS analysis. A = site features were mapped and digitized in Arc-Info. B = buffer zones were created around rivers, skid trails and trees. C = an overlay was created with data from planted seedlings.

RESULTS

General performance of the different species in different plots

Table 3 gives the growth rates and mortality for the different species grown in the three sites. In general, seedlings grown in Plot 81 had the highest growth rates, although they suffered the highest mortality. Conversely, Plot 88 showed the lowest growth rates but also the lowest mortality.

Table 3. Mean relative height increment (RHI, in %) and mortality (%) of different tree species planted at different sites, one year after planting.

Species	78		81		88		Mean	
	Mort	RHI	Mort	RHI	Mort	RHI	Mort	RHI
Dipterocarpus	-	-	-	-	47.3	60.5	47.3	60.5
D. lanceolata	28.4	77.9	33.9	86.1	18.0	70.3	27.4	78.5
P. malaanonan	35.6	97.4	54.0	45.2	-	-	47.6	67.5
S. johorensis S.	29.7	97.4	60.7	87.2	-	-	49.3	92.4
leprosula	33.0	141.8	32.1	162.6	31.0	200.7	32.0	169.
S. ovalis	-	-	52.5	129.8	25.8	60.2	41.1	92.3
S. parvifolia	-	-	-	-	34.1	96.0	34.1	96.0
A. dammara	44.8	68.4	-	-	25.9	17.7	32.0	31.1
Mean (weighted)	33.8	101.1	46.2	106.9	30.2	84.4	37.6	96.2

Effects of light

Correlations between forest canopy LAI and relative height increments were calculated for each species and the correlation table is shown below (Table 4). There was a negative correlation between LAI and growth, which is understandable since LAI is inversely related to incident light.

Influence of trees

It was found that seedlings planted in the inner buffer zone ring, *ie.* in the close vicinity of trees, suffered a strong reduction in growth rates (Table 5). Seedlings in the outer ring had faster growth than those close to the tree stems, but still slower than those planted outside. It is interesting to notice that among the range of dipterocarp species studied, *Dipterocarpus* spp. did not exhibit any site preference in relation to proximity to trees. Conversely, the *Shorea* spp. suffered strong reduction in growth rates when under competition for light and nutrients.

Generally, the greatest effects of competition with trees were observed in the Plot 78. No reduction in growth rates was observed from tree competition in Plot 81.

Table 4. Pearson product-moment coefficients of correlation (r) between forest canopy LAI and relative height increment (RHI) of seedlings of different tree species in the plots 78 and 88. P = level of significance, n = number of replicates.

Species	Mean RHI (%)	Mean LAI	r	P	n
Dipterocarpus	69.7	5.32	-0.459	0.000	59
D. lanceolata	87.1	5.09	-0.557	0.000	144
P. malaanonan	103.6	4.9	-0.267	0.037	61
S. johorensis	100.1	4.63	-0.358	0.002	69
S. leprosula	179.2	4.79	-0.486	0.000	169
S. ovalis	70.2	5.10	-0.459	0.000	84
S.parvifolia	110.6	5.29	-0.486	0.000	79
A. dammara	44.8	5.32	-0.246	0.015	97
Total	103.9	5.05	-0.433	0.000	762

Table 5. Relative height increment (%) of seedlings in relation to proximity to trees. (diameters of the inner and outer rings are related to the size class of trees (see Table 2).

Sp	Plot 78			Plot 81			Plot 88			Mean		
	inner ring	outer ring	open	inner ring	outer ring	open	inner ring	outer ring	open	inner ring	outer ring	open
D.	-	-	-	-	-	-	65.1	54.2	65.3	65.1	54.2	65.3
Dl	13.7	96.4	73.4	61.7	80.4	95.5	63.2	68.1	90.0	57.8	77.5	90.0
Pm	73.2	102.2	120.2	25.2	52.0	43.8	-	-	-	58.2	71.9	67.9
Sj	68.0	163.5	71.2	79.2	90.0	89.2	-	-	-	72.3	81.0	125.9
Sl	122.6	141.7	154.5	208.7	151.3	155.6	159.7	203.2	254.3	168.5	170.1	169.8
So	-	-	-	120.1	121.7	142.1	32.6	71.9	57.4	60.8	92.9	108.8
Sp	-	-	-	-	-	-	104.5	87.4	125.8	104.5	87.4	125.8
Ad	78.3	69.6	60.9	-	-	-	15.2	17.2	20.9	26.4	32.2	32.4
Mn	77.2	100.6	119.5	108.2	104.8	108.2	73.9	88.4	86.7	83.9	95.8	105.4

D = Dipterocarpus; Dl = Dryobalanops lanceolata; Pm = Parashorea malaanonan; Sj = Shorea johorensis; Sl = S. leprosula; So = S.ovalis; Sp = S.parvifolia; Ad = Agathis dammara; Mn = means.

Effects of competing vegetation

Vine tunnels caused a reduction in growth rates of seedlings of some species (Table 6). No consistent pattern of mortality was observed, although in some cases these tunnels caused death of seedlings when they collapsed. In a natural situation, vines can also strangle seedlings, but in this enrichment planting project vines are removed from seedlings every three months during the weeding operations. Although it was expected that bamboo clusters would cause mortality of planted seedlings due to climbing (REF), this was not observed. High seedling mortality was observed within patches of grasses (Table 6).

Influence of riverine areas and skid trails

Although it was expected that seedlings grown in riverine areas would grow faster than those elsewhere, because of the presence of alluvial soil and high water availability in these sites, this was only true in plot 88. All the plots studied had many zero order streams (ie. streams that only appear after rainfall) and seedlings planted in these sites suffered high mortality (Table 6). This is possibly because the underlying soil is frequently saturated and anaerobic, killing roots through lack of oxygen. Seedlings of all species showed higher mortality rates when planted in skid trails. A reduction in growth rates was observed in seedlings planted in skid trails in plot 88, but not in 81.

Table 6. Relative height increment (RHI, %) and mortality (%) of seedlings grown under the influence of different site features or competing vegetation.

	Plot 78		Plot 81		Plot 88		Mean	
	mort	RHI	mort	RHI	mort	RHI	mort	RHI
Vines	12.5	69.1	44.3	81.1	37.2	50.4	39.7	69.3
Bamboo	-	-	34.7	114.8	27.3	88.8	33.3	109.6
Weeds	75.0	251.8	70.7	99.9	-	-	70.9	107.3
Open	33.8	101.6	37.1	123.7	29.5	87.5	32.2	98.7
Streams	36.0	104.6	49.4	95.2	27.9	125.8	40.7	107.8
No Streams	32.7	100.8	44.3	110.8	30.1	70.6	36.2	91.2
Skids	-	-	53.5	104.4	30.4	74.5	36.8	80.6
No Skids	-	-	45.8	107.0	30.1	85.9	38.8	96.3
Mean	33.8	101.1	46.2	106.9	29.7	84.4	37.6	96.2

DISCUSSION

The analyses carried out in this study were mainly centred on the effects of light on dipterocarp seedlings, and how the various site features contributed to the light status of planted seedlings. In an initial stage, the influence of light on growth of the different species was studied by taking measurements of light (LAI) reaching each individual seedling, and it was found that all species studied benefit from increasing intensities of light. In a second stage, the effects of competing vegetation were investigated, looking primarily at their shading effect, but also trying to address other possible effects such as root competition.

As it would be expected, it was found that seedlings grown under the canopy of remnant trees grew slower than those outside their shade zone. It was also found that the closer to the tree stem the seedlings were planted, the slower their growth rates, possibly because of more intense root competition (Putz 1992) and deeper shade (Sasaki and Mori 1981). On the other hand, seedlings planted in the open had fast growth but suffered high mortality, in accordance with the results of Howlett and Davidson (in this volume), also working in the Ulu Segama Forest Reserve. The silvicultural implications of this is that in some cases liberation thinning is required, but taking the precaution not to remove too many trees. Obviously, the decision of whether or not to carry out liberation thinning depends on the value of the tree species shading the seedlings. The planning of thinning operations could be optimised by simulations carried out in the GIS, testing the effects of different treatments prior to their actual implementation in the field.

A similar pattern of growth suppression was caused by other competing vegetation, particularly dense patches of climbing vines, in accordance with Hutchinson (1981). Given that vine tunnels may have the same effect as shading trees (Fox 1968), and that vines do not have any commercial value, it is highly recommended that they are removed during the early stages of site preparation prior to enrichment planting. No growth suppression or mortality was observed in the vicinity of bamboo clusters, but this may change when seedlings become taller providing a support for the climbing bamboo (Yap *et al*. 1994). High mortality was observed in areas infested with weeds, possibly because of inadvertent cutting of seedlings during weeding operations. This could be avoided if sticks were used to mark the location of young seedlings during their early development. Since weedy grasses tend to occur in extremely open areas (Ipor and Tawan 1992), it is also possible that dipterocarp seedlings in their vicinity actually suffered from the excessive radiation and drought in these sites.

Among the sites studied, the best growth rates were observed in the site with most open canopy, *ie.* Plot 81. Furthermore, no reduction in growth rates from tree competition was observed in this site. This is probably because of higher light intensity in this site. Plot 81 was heavily logged by a combination of tractor and high lead, and very few remnant trees were left standing. Most of the trees left were the large *Koompassia excelsa* which have very long roots (spreading its zone of nutrient uptake over a large area) and have high crowns which result in little shade. Therefore, the canopy in this site is very open, and the higher light intensity allowed better growth rates of the planted seedlings. However, these open sites form a favourable habitat for competing vegetation such as weeds, climbers and bamboos, which can have very serious effects on survival of planted seedlings (*eg*. Abalus *et al.* 1991). The strongest effects of tree competition were observed in the Plot 78, probably because of strong root competition between the abundant *Macaranga* spp. trees at a close proximity to planted seedlings.

In this study, it was found that seedlings planted in skid trails suffered high mortality and had reduced growth rates. It is therefore important, that hardier species are used in these areas, possibly in combination with the application of fertilisers, as suggested by Nussbaum *et al.* (in this volume). The negative effects of skid trails were stronger in plot 88, possibly because soil in the other plots had a longer time to recover from damage caused by tractors.

Among the range of species studied, *Shorea leprosula* performed best, with the fastest growth rates and relatively low mortality. This is in agreement with the findings from other foresters in Malaysia which consider this species as the most promising dipterocarp for planting (*eg.* Appanah and Weinland, 1993). The worst species were the *Dipterocarpus* spp., which showed low growth rates and high mortality. These species did not seem to suffer from competition with remnant trees, possibly because they are generally adapted to low light conditions. *Dryobalanops lanceolata* was found to be the most resilient of the species, with the lowest mortality rates and reasonable growth rates, as reported by Chai (1975). *Agathis dammara* (Araucariaceae) did not perform well and was the only species which suffered from insect predation.

This study tested a new application of GIS for forest research and management. The analyses described here are just a sample of what can be extracted from the information stored in the system. Further studies are required to refine the findings reported here.

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