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# Artificial canopy gaps in a *Macaranga* spp. dominated secondary tropical rain forest—Effects on survival and above ground increment of four under-planted dipterocarp species

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**Abstract**

Enrichment planting is a technique used to accelerate the natural recovery of species such as dipterocarps (non-pioneer species of the Dipterocarpaceae family), in situations where natural regeneration is insufficient for satisfactory regeneration in secondary tropical rain forests. Such planting can be done either in artificially created gaps or lines. The fundamental issues to address when creating artificial gaps are the effects of gap creation on seedling survival, height and biomass. The study presented here was performed in secondary forests of Northern Borneo dominated by pioneer species of the genus *Macaranga* established after selective logging and fire. In a randomized split plot block design, three methods of canopy treatment (selective felling, selective girdling and untreated control) were combined with two methods of sub-canopy treatment (slashing woody stems or untreated control) and seedlings from four dipterocarp species were used for under-planting. The survival rates and height of the seedlings were regularly recorded throughout a 30-month study period. Above ground biomass functions were constructed for each species using data from a selection of individuals which were destructively sampled after 30 months.

Reductions in the sub-canopy were found to promote seedling survival for three of the four species. The survival rates of the different species also differed significantly, from 72.6 to 86.0% after 2.5 years. However, the canopy treatments did not affect their survival rates. Both canopy treatments (felling and girdling) and the sub-canopy treatment (slashing) significantly increased the seedling increment. Felling pioneer canopy trees resulted in the highest initial relative height growth rates, but the effect of this treatment gradually declined, while the effects of girdling and especially sub-canopy slashing were more prolonged. Felling and slashing resulted in the highest relative biomass increments during the study period. Seedling height and biomass growth also varied significantly amongst the species.


*Keywords:* Biomass estimation; *Dipterocarpus*; Enrichment planting; Fire; Felling; Girdling; Height increment; Logging; Seedling survival; *Shorea*; Slashing

## 1. Introduction

The continued loss of primary tropical rain forests (FAO, 2001) has led to growing interest in the development of silvicultural measures to restore the remaining secondary forests (Kammesheidt, 2002; Ashton et al., 2001). In the tropical rainforests of Sabah, Borneo, selective logging and wild-fires have reduced the natural regeneration capacity of many non-pioneer species, most notably members of the Dipterocarpaceae family (dipterocarps), the most characteristic indigenous tree family (Meijer and Wood, 1964; Slik et al., 2003).

Appanah and Weinland (1993) proposed that enrichment planting of degraded forests formerly dominated by dipterocarps could be used to accelerate their recovery. Briefly, enrichment planting involves planting nursery-raised seedlings in cleared lines or in either artificially created or naturally occurring gaps (Wyatt-Smith, 1963). Line planting, which has been applied most frequently (c.f. Lamb, 1969; Montagnini et al., 1997; Peña-Claros et al., 2002), results in stands with a geometric pattern. Contrary to planting in regularly spaced lines, gap planting has some resemblance to natural gap dynamics (Denslow, 1987) which could be considered an advantage in restoration programs.

Current knowledge about the factors affecting the results of enrichment planting and the performance of seedlings planted in secondary tropical rain forests is limited (Ramos and del

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Amo, 1992; Ådjers et al., 1995). Thus, there are a number of uncertainties regarding the likely success of a gap planting program. However, key aspects to decide when planning such programs are the layout of the gaps and the methods that should be used to create the gaps in order to promote the survival and growth of selected species of nursery-reared seedlings.

Canopy openness (c.f. Jennings et al., 1999) and quality of light (c.f. Chazdon and Pearcy, 1991; Rijkers et al., 2000a; Leakey et al., 2003) appear to be major determinants of the survival rates (c.f. Peña-Claros et al., 2002) and growth of seedlings (c.f. Denslow, 1987; Tuomela et al., 1996). In artificial shade experiments with various species of potted seedlings of the genus *Shorea* (Dipterocarpaceae) Ashton (1995) and Tennakoon et al. (2005) demonstrated that partial shade often provides the best growth environments and also found differences in shade responses between species. Ramos and del Amo (1992) emphasize that the intensity of pre-planting canopy reduction should be matched with species-specific light requirements to promote high survival and growth rates among under-planted seedlings.

In addition to direct effects on light conditions at the forest floor, the methods used to create gaps, and their design, also probably affect other factors that influence seedling survival and their early growth parameters, e.g. soil moisture, nutrient availability and the occurrence and degree of stresses and potentially damaging agents. Furthermore, the significance of different growth factors and hazards for seedling establishment in an artificial gap changes with time as the local vegetation recovers and the planted seedlings develop.

The present study considers different approaches to artificial gap creation in secondary tropical rain forests and compares gap effects on survival, height and biomass increments of under-planted dipterocarp seedlings. The specific objectives were to determine seedling establishment responses to pre-planting gap creation involving two canopy treatments (felling and girdling) and one sub-canopy treatment (slashing), together with controls, in a *Macaranga*-dominated tropical secondary forest.

## 2. Material and methods

### 2.1. Study site

The study was conducted at four sites in the Kalabakan Forest Reserve (latitude 4°36′N, longitude 117°14′E), 25 km west of Luasong Forestry Centre (LFC) in Tawau district, Sabah, Malaysia. The natural vegetation is lowland tropical rain forest (Whitmore, 1998) in a landscape with undulating terrain (300–700 m a.s.l.) on sedimentary bedrock (Acres et al., 1975). The climate is tropical humid with diurnal temperatures ranging between 22.0 and 32.7 °C and the mean precipitation throughout the study period was 2890 mm year$^{-1}$ (Climate records from LFC, unpublished).

Commercial tree species were selectively logged between the years 1975 and 1985 (according to local foresters). The area was affected by an El Niño Southern Oscillation induced dry spell (Walsh, 1996), which was followed by forest fires in 1983 (Garcia personal observation, Woods, 1989; Nykvist, 1996). After these large-scale disturbances a secondary forest dominated by pioneer tree species of the Euphorbiaceae family covered the experimental area. At the study sites, trees regarded as pioneer species averaged 97% of the mean basal area (34.7 m$^2$ ha$^{-1}$). *Macaranga* spp. were the dominant genera and accounted for 87% of trees $\geq$10 cm in diameter at breast height (DBH) (Romell et al., in press). The dominant canopy (hereafter referred to as ‘‘canopy’’) consisted of trees with an average height of 20–35 m. The sub-canopy (2–20 m height) comprised saplings and pole-sized trees (c.f. Barker et al., 2006) of pioneer and non-pioneer species. Seedlings, ferns and herbs (mainly ginger, Zingiberaceae), occupied the forest floor and under-storey. The experimental sites were distributed on four localities, all situated within 7 km range.

### 2.2. Experimental design

Three canopy treatments (selective girdling, selective felling and untreated control) were combined with two sub-canopy treatments (slashing woody stems, or untreated control) in a randomized split-plot block design (Stehman and Meredith, 1995). The seven blocks, each included all canopy and sub-canopy treatment combinations. The blocks were divided into main plots and the main plots were split into subplots (Fig. 1).

Canopy treatments were randomly assigned to 1600 m$^2$ main plots, and the main plots were divided into 16 square subplots (10 m × 10 m) arranged as a connected unit. The sub-canopy treatments were randomly applied to the subplots within each main plot, resulting in eight replicates (8 subplots) of each sub-canopy treatment per main plot (Fig. 1). To limit potential edge effects, each main plot was surrounded by a buffer zone of equally sized subplots subjected to the same canopy treatment (Fig. 1). Each main plot, including its buffer zone, required an unbroken canopy of pioneer trees, occasionally necessitating slight modification of the subplot configuration.

Canopy treatments (felling and girdling) were applied to a circular area (radius, 5 m) in each designated subplot of the main plot (Fig. 1), while subplots in control main plots were left untreated. *Macaranga* spp., and trees of other pioneer species with stems exceeding 10 cm in DBH, were selected for treatment according to a plotted mathematical function – $Y = (0.05x)^3 - 4.2(0.05x)^2 + 5.8(0.05x)$ – using stem DBH ($x$) and distance from the plot centre ($Y$) as coordinates (Romell et al., in press). All non-pioneers were excluded from treatment. The function was intended to provide standardised, unambiguous selection criteria that were simple to apply to all plots regardless of the assigned canopy treatment and to concentrate the stems selected for treatment towards the centre of the plot unless they had a large DBH, in which cases trees within 3–5 m of the centre of the gap were also treated.

Trees selected for felling were cut with a chain-saw at the stem base. The stems were left on site, but cut as needed to clear the planting spots. Girdling involved stripping away the outer and inner bark of the trunk 50–100 cm above ground using a parang (a long, sharp jungle-knife). The average basal area per