New Forests **19:** 51–68, 2000.

Early development of three planted indigenous tree species and natural understorey vegetation in artificial gaps in an *Acacia mangium* stand on an *Imperata cylindrica* grassland site in South Kalimantan, Indonesia

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Accepted 5 May 1999

Key words: alang-alang, dipterocarps, *Peronema canescens*, plantations, reforestation, rehabilitation

Abstract. Early performance of two dipterocarp species *Anisoptera marginata* and *Shorea parvifolia*, and a long-living pioneer species *Peronema canescens* (Verbenaceae) planted in artificial gaps (size 260 m^2) and surrounding untreated stands was studied in a fast-growing plantation of *Acacia mangium* on an *Imperata cylindrica* grassland site in South Kalimantan, Indonesia. Forty seedlings of each species were planted at one-meter intervals in lines across each of the five gaps, starting and ending under closed stand. Survival, height and diameter ($d_{0.05}$) increments were measured, and the effect of gap opening on the composition and abundance of understorey vegetation (grass, shrub and native tree seedlings and saplings) was studied. 19 months after planting, average survival rates were 97% for *A. marginata*, 94% for *P. canescens* and 71% for *S. parvifolia*, with no statistical differences between gap and closed stand. Substantial mortality and damage of dipterocarps were caused by wild boars; minor damage by dieback (for *S. parvifolia*) and insect pests (for *A. marginata*). Early growth was clearly influenced by distance from gap centre and light conditions; the growth of seedlings was greater the nearer the seedlings were situated to centre and the higher the level of daily photosynthetic photon flux density (PPFD) was. Gap opening increased the growth of shrub species *Chromolaena odorata*, but not that of *Imperata* grass. It also increased the density and height growth of saplings of native pioneer and secondary tree species. Seedling density increased both in closed stand and actual gaps, but was higher inside gaps. Results indicate good prospects for diversifying the composition of fast-growing forest plantations on severely degraded former forest lands and integrating slow-growing valuable species in plantation programs. Both in-depth ecophysiological studies on species-specific growth requirements, and practical oriented research on silvicultural options and economics need further studies.

Introduction

Imperata cylindrica (L.) Beauv. (alang-alang) dominated grasslands have developed after forest clearing and the subsequent fire-based land-utilisation systems, and they cover large areas of former forest lands throughout moist tropical regions. In Southeast Asia, the recent estimate of the continuous sheet grasslands (mega-grasslands) is 25 million ha; Indonesia has the largest area of 8.5 million ha (Garrity et al. 1997). *Imperata* grasslands occur as a fire climax vegetation type in areas where annual fires prevent the natural secondary succession of forest (Eussen and Wirjahardja 1973). They are associated with harsh environmental conditions, grass competition and allelopathy, fire susceptibility of the grass, as well as soil degradation and compaction (Soerianegara 1980; Dela Cruz 1986; Ohta 1990). The large sheet grasslands are considered under-utilized resource and their reclamation by means of reforestation are widely acknowledged.

The utilisation of *Imperata* grasslands for short rotation wood production has been found promising in Southeast Asia (Turvey 1996; Otsamo et al. 1997). With proper species and provenance selection as well as intensive site preparation and fertilization, mean annual increments of 25–35 m^3 ha a^{-1} have been achieved in research sites (Otsamo et al. 1995, 1997; Turvey 1996). The best species in grassland reforestation have proven to be the fast-growing exotics such as tropical acacias, which have fast early growth and ability to suppress the grass (Otsamo et al. 1997; Turvey 1996). *Acacia mangium* Willd., an evergreen nitrogen-fixing legume, is one of the species with great potential and has been selected to be the main species in several plantation programs in the region (e.g., Awang and Taylor 1993; Otsamo et al. 1997). In Indonesia, A. mangium plantations cover an area of 426 000 ha (Turnbull et al. 1998) of which less than half has been established on grasslands. Direct reforestation with dipterocarps or other indigenous tree species is difficult due to their slow growth and shade requirements (Appanah and Weinland 1993; Otsamo et al. 1997).

It has been widely hypothesized that indigenous species could be introduced into industrial fast-growing plantations after the first rotation of fast-growing species (ITTO 1993; Lamb and Tomlinson 1994; Appanah and Weinland 1996; Ashton et al. 1997). Species like *A. mangium* are able to ameliorate microclimatic conditions, increase soil biological activity and improve soil physical and chemical properties on *Imperata* grasslands (Ohta 1990; Fisher 1995), thus modifying conditions more suitable for slower growing primary forest species. Integration of valuable timber species would also be a convenient way to speed up the gradual restoration process. Using fast-growing plantations as foster ecosystems in the rehabilitation of degraded former forest lands back to native forests has recently gained much attention in *Imperata* grasslands (Kuusipalo et al. 1995) and other plantation ecosystems in the tropics (e.g., Parrotta et al. 1997). So far, results concerning planting indigenous species in fast-growing plantations in Southeast Asia are limited and mainly from cleared rain forest lands with better initial soil conditions than those on grasslands (e.g., Priasukmana 1991; Appanah and Weinland 1993, 1996). In Sri Lanka, several indigenous dipterocarp species have successfully been planted in a *Pinus caribaea* plantation (Ashton et al. 1997).

Dipterocarps are economically and ecologically the most important tree species in Southeast Asia. Their potential and constraints in plantations have been evaluated by Appanah and Weinland (1993, 1996). Although dipterocarps are generally classified as shade-demanding and slow-growing climax rain forest trees, several commercially important species from the light-hardwood group are fairly fast-growing and light-demanding after establishment (Appanah and Weinland 1993, 1996). Gap dynamics play an important role in their successful regeneration in natural forests.

The main objective of this study was to explore a silvicultural method for integrating three economically important indigenous tree species *Anisoptera marginata* Korth. (Dipterocarpaceae), *Shorea parvifolia* Dyer (Dipterocarpaceae) and *Peronema canescens* Jack (Verbenaceae) in fast-growing plantations on an *Imperata* grassland site. Earlier experiences with *A. marginata* have shown that seedlings planted under *Acacia mangium* stands with normal planting density did not grow optimally due to excessive shading (Otsamo 1998a), and on the other hand, that the underplanted seedlings responded clearly to the artificial opening of plantation canopy (Otsamo 1998b). In the present study, the possibility to plant seedlings directly in artificial gaps in an *Acacia mangium* stand was investigated. In addition, the effect of gap opening on natural understorey vegetation was studied.

The following hypotheses were formulated and tested:

1. Early survival and health conditions of seedlings differ between gap and closed stand.
2. Early growth of seedlings depends on the distance from gap centre and on the prevailing light conditions.
3. Gap opening affects the composition and abundance of natural understorey vegetation.

Material and methods

Study area

Riam Kiwa trial and demonstration area is located in South Kalimantan, Indonesia (3°30′ S, 115° E, 100–200 m a.s.l.), and lies on the undulating basin of the Riam Kiwa river. The mean annual precipitation is 2113 mm (1988–1996) with a pronounced dry season from May to September. During the study period of 19 months, the total amount of rainfall was 3387 mm with no severe dry period. The soils are deeply weathered, heavily textured acidic soils which have suffered various degrees of degradation. Depending on the classification system they belong to the red-yellow podzolic type (Stace et al. 1968), xanthic ferralsols (FAO-UNESCO 1979) or udic ultisols (USDA 1975), with low pH-values (4.8–5.4 in H_2O) and low levels of nutrients, especially available phosphorus (Simpson 1992). Parent material consists of igneous rocks. Compared with many similar sites in Southeast Asia, the site is considered good for forest plantations (Jusop and Hanif 1992). On undisturbed land, the height of *Imperata* grass varies between 1.0 and 1.5 m and the above ground dry biomass may reach 10–20 t ha^{-1}. The vegetation has been dominated by *Imperata* grass since the late 1800s (Potter 1987). Remnants of natural woody vegetation only exist along the small creeks in and around the area, consisting mainly of secondary and of few emergent trees of primary forest species.

Species description

Anisoptera marginata belongs to the light-hardwood group and is widespread but rarely common growing in mixed peatswamp and heath forests on podzols up to 1200 m altitude (Soerianegara and Lemmens 1994). Also *Shorea parvifolia* belongs to the light-hardwood group. It is widespread from lowlands to upper hills on well-drained clay soils (Soerianegara and Lemmens 1994). *Peronema canescens* is a long-living pioneer, which is common in secondary forests, forest clearings and river banks, but rarely in primary forests (Soerianegara and Lemmens 1994). It has shown high survival and reasonable growth even on open grasslands (Otsamo et al. 1997). All species are high-quality timber species important for large- and small-scale industry.

Planting material

The seeds of *A. marginata* and *S. parvifolia* were collected locally from a hill-dipterocarp and a logged-over lowland dipterocarp forest, respectively. The seeds were sown in sand and transplanted into Enso pot-trays with peat and rice husk (70:30%) as substrate for *A. marginata* and into black polythene tubes (8×15 cm, volume 750 cm^3) with forest top soil for *S. parvifolia*. Transplants of *P. canescens* were produced as cuttings in peat and rice husk substrate. Cuttings were collected locally from different plantation stands. The seedlings were watered according to normal nursery practices and fertilized with NPK-fertilizer (15:15:15) twice weekly for two to four months with a dose of 10 g m^{-2}. At the time of planting, the seedlings were 12, 9 and 4 months old, and the mean heights were 57, 27 and 16 cm for *A. marginata*, *S. parvifolia* and *P. canescens*, respectively.

Experimental design

The experimental site was located inside a four-year-old *Acacia mangium* stand of 10 ha in size. The stand was originally established in January 1990 on a grassland site following the normal reforestation procedure on *Imperata* dominated grasslands, including mechanical soil preparation, initial fertilization with NPK and manual weeding (Otsamo et al. 1995). *A. mangium* had a spacing of 3×3 m, mean diameter at breast height (1.3 m) of 16 cm, mean height of 18 m and stand volume of 178.0 m^3 ha^{-1} at the time of opening the gaps.

Five gaps were opened in the *A. mangium* stand in November 1994. Felled stems and major branches were removed from the gaps but small branches and leaves were left on the site. The mean diameter of the gaps was 18 m (260 m^2) measured from stem to stem (“actual gap”) and 15 m (174 m^2) from canopy border to canopy border (“canopy gap”). In May 1996, stems along the gap border were girdled in order to maintain the gap size.

The seedlings were planted in December 1994 in lines of 40 seedlings at one meter intervals across the gaps, starting and ending under the closed canopy of *A. mangium*. Thus every replication included both the area of the actual gap and the close vicinity around it in the closed stand, with a total area of 1257 m^2. Each species had one line of 40 seedlings in each of the five gaps. Orientations of the planting lines were randomized. The planting spots were mulched with *A. mangium* leaf litter. Weeds and climbing vines were cut manually every fourth months within a radius of 1.0 m around the planted seedlings. At the time of planting, the stand was characterized by a weakly-developed forest floor: litter was abundant, but the undergrowth of small-sized grasses and shrubs as well as seedlings and saplings of naturally regenerated pioneer and secondary tree species was poorly developed.

Field assessments

Light availability
Light, measured as photosynthetic photon flux density (PPFD: 400–700 nm), was sampled during a partly cloudy day in April 1995 in one of the five gaps. PPFD was recorded above each seedling at one meter intervals (40 spots per line) with a Li-189 light radiometer (LI-COR, Lincoln, NE, USA; quantum sensor; μmol m^{-2} s^{-1}). The instantaneous measurements were repeated three times at one hour intervals from 7.00 a.m. to 6.00 p.m., each cycle taking 15 minutes. Median value of the three repetitions was used in further transformations. An approximation of total PPFD for each sampled hour (mol m^{-2} h^{-1}) was calculated from the median value by assuming it to be constant during the sampled hour. These approximations were summed up to obtain the daily PPFD (mol m^{-2} d^{-1}) above each seedling.

Survival and growth of planted seedlings
Survival was recorded, and height and diameter 5 cm above ground level ($d_{0.05}$) were measured immediately at planting in December 1994 and at the age of 19 months in July 1996. Height and diameter growth was based on the increments between these two measurements. In addition, damage was recorded. Several seedlings of *A. marginata* (n = 17) and *S. parvifolia* (n = 11) were excluded from the analyses of height and diameter increment since the former ones were severely eaten by wild boars and the latter ones suffered from dieback of the leading shoot.

Natural understorey vegetation
The quantity of grass and shrub vegetation was sampled in December 1995, 13 months after opening the gaps. The above ground parts of all occurring plants were cut and their fresh biomass weighed separately for each species in 40 systematically located plots of 1.0 m^2 in every gap. Sample plots were located in the unplanted transects across gaps, and thus no weeding had been carried out. The collected samples were dried (105 °C) in the laboratory to obtain the dry biomass.

The inventories of native tree seedlings and saplings were carried out before, 17 and 23 months after opening the gaps. In the first inventory, all seedlings (height at least 0.3 m, but less than 1.3 m) and saplings (height at least 1.3 m) were recorded and identified separately for the actual gap (260 m^2) and for the closed stand (within an area between gap border and the outermost planted seedlings; 997 m^2). In the second inventory, only saplings were enumerated, marked with an aluminum tag and measured for height. In the third inventory, the tagged saplings were remeasured and new ones marked, identified and measured for height. In addition, seedlings were recorded and identified along two three-meter-wide and 40 meter long sampling transects in every gap.

Data analysis

All analyses concerning the planted seedlings were done separately for each species. Hypothesis (1) was studied by comparing survival and damage of seedlings in gap and closed stand with Mann-Whitney *U*-test. Hypothesis (2) was tested with two separate regression analyses. The first one assessed the dependence of seedling height and diameter ($d_{0.05}$) increments on the distance from gap centre. Combined means of increments (n = 10) pooled over the two equally located sample plots in the transect (opposite side from the gap centre) and the five replications were used. The second one assessed the dependence of seedling growth on the daily PPFD received above each seedling. This was measured in one gap only. Individual data values were used for the analysis. Since the relationships observed in diameter ($d_{0.05}$) growth were similar to those in height growth, only the regression analyses of the latter one are presented in the results.

Hypothesis (3) was tested separately for grass and shrub vegetation, and for naturally regenerated native tree seedlings and saplings. The relationship between distance from gap centre and dry biomass of grass and shrub vegetation was tested by regression analysis. Combined mean of the dry biomass (n = 10) was used as above (see hypothesis 1). Frequency and height of native tree seedlings and saplings in gap and closed forest were compared with *t*-test.

Results

Light availability

Mean daily photosynthetic photon flux density (PPFD) varied between 7.3 and 1.6 mol m^{-2} d^{-1} along the transect from gap centre into surrounding closed stand (Figure 1a). The rate of decrease varied along the transect. Due to small gap size, daily PPFD decreased immediately after the first measuring points in gap centre. Direct light was able to penetrate through the open canopy gap into the closed stand during morning and evening hours, causing the fairly high values of PPFD near the gap border in closed stand. Mean and maximum instantaneous PPFD values at noon were 348.0 and 480.4 μmol m^{-2} s^{-1} in gap, and 107.0 and 296.3 μmol m^{-2} s^{-1} in closed stand (Figure 1b). Both daily and instantaneous PPFD recordings were carried out on a partly cloudy day, which narrowed the differences between measuring points compared to those which could be obtained in cloudless conditions. It

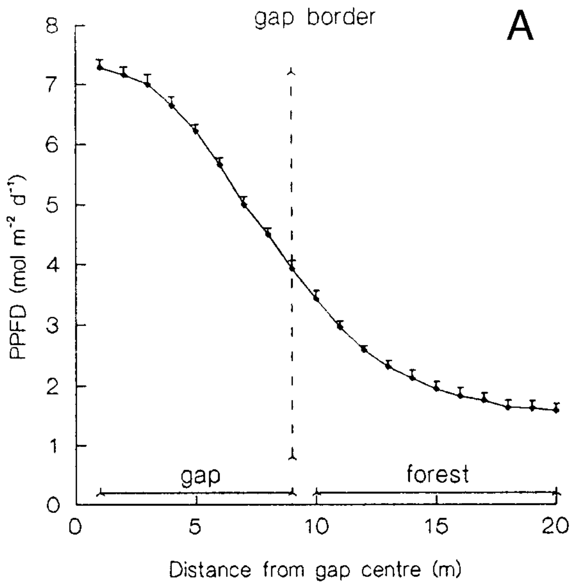

Figure 1a. Daily PPFD (mol m^{-2} d^{-1}) values along transects from gap centre into surrounding closed *Acacia mangium* stand in a cloudy day in Riam Kiwa, South Kalimantan, Indonesia. $n = 2$ in each data point. Standard error of mean is presented by thin vertical bars.

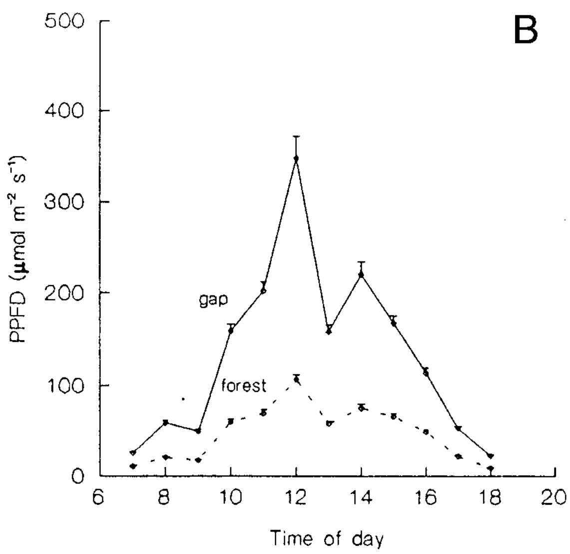

Figure 1b. Development of PPFD (mol m^{-2} s^{-1}) values on a cloudy day in gap (n = 20) and closed stand (n = 20) in an *Acacia mangium* stand in Riam Kiwa, South Kalimantan, Indonesia. Standard error of mean is presented by thin vertical bars.

is also evident that the gaps experienced very big changes in light conditions between the periods of direct light into the gaps and those affected either by canopy shade or cloud. According to separate observations during clearer days, the gap centres were able to receive two hours of direct radiation around noon.

Survival and damage of planted seedlings

At the age of 19 months, average survival rates were 96.5 (S.E. = 0.5) for *A. marginata*, 94.0 (2.0) for *P. canescens* and 71.3% (2.3) for *S. parvifolia* with no statistical differences between gap and closed stand. In the case of *A. marginata* and *P. canescens*, all mortality occurred within the first six months after establishment. During the same period, the survival rate of *S. parvifolia* dropped to 75%.

Wild boars attacked 0, 11 and 12% of planted *P. canescens*, *A. marginata* and *S. parvifolia* seedlings, respectively, by pulling up whole seedlings or by cutting stems above ground level. The damage was more common inside the gaps than in closed stand, but the differences were not statistically significant. 77% of the damaged seedlings of *A. marginata* were able to recover by sprouting from the cut stems, whereas seedlings of *S. parvifolia* died after attacks. In addition, 5% of the seedlings of *S. parvifolia* suffered from shoot dieback, which was more common in the gaps than in closed stand ($p = 0.049$). 2% of the seedlings of *A. marginata* suffered from insect pests (grasshoppers), which prevented the normal seedling growth by repeated removal of the apical bud, resulting in multiple stems or development of a new leading shoot. Grasshopper damage was more common in the gaps than in closed stand ($p = 0.043$).

Height and diameter ($d_{0.05}$) increment of planted seedlings

At the age of 19 months, overall range in height and diameter ($d_{0.05}$) were 50.0–260.0 cm and 4.4–23.8 mm for *A. marginata*, 40.0–312.0 cm and 3.7–34.5 mm for *S. parvifolia*, and 31.3–485.0 cm and 4.8–60.4 mm for *P. canescens*, respectively. All tree species showed non-linear (quadratic) relationship between mean height increment and distance from gap centre into the surrounding closed stand (Figure 2), i.e. the further the seedlings were situated from gap centre the lower the height increment was. The non-linear relationship was clearest for *P. canescens*, which can be explained by its strongest light-dependence and fastest early growth inside the gaps. This is also seen in Figure 3, which shows the relationship between height increment and daily PPFD measured above each of the seedlings in one gap. Compared to *P. canescens*, *A. marginata* and *S. parvifolia* seedlings exhibited greater

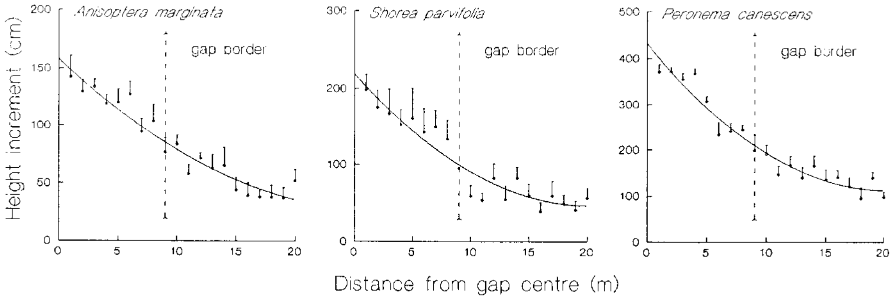

Figure 2. Relationship between height increment of *Anisoptera marginata* (y = 157.995 − 9.676x + 0.178x^2, r^2 = 0.934), *Shorea parvifolia* (y = 219.22 − 17.043x + 0.42x^2, r^2 = 0.907) and *Peronema canescens* (y = 431.656 − 31.826x + 0.794x^2, r^2 = 0.949), and distance from gap centre into surrounding closed *Acacia mangium* stand in Riam Kiwa, South Kalimantan, Indonesia. n = 10 in each data point. Standard error of mean is presented by thin vertical bars.

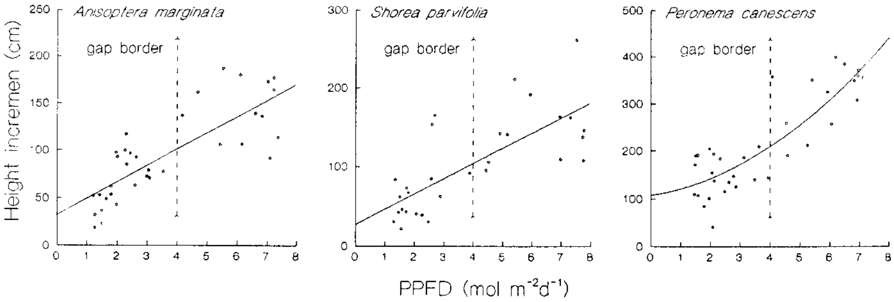

Figure 3. Relationship between height increment of *Anisoptera marginata* (y = 32.192 + 17.215x, r^2 = 0.646), *Shorea parvifolia* (y = 27.271 + 19.217x, r^2 = 0.549) and *Peronema canescens* (y = 107.313 + 9.611x + 4.027x^2, r^2 = 0.737), and daily PPFD (mol m^{-2} d^{-1}) along the transect from gap centre into surrounding closed *Acacia mangium* stand in Riam Kiwa, South Kalimantan, Indonesia. Each data point presents an individual value.

variation between the individuals in their growth response to increasing daily PPFD, even though the most severely damaged seedlings had been excluded from the analyses.

Natural understorey vegetation

The abundance of grasses and shrubs was extremely low (<0.01 t ha^{-1}) before opening the gaps. Thirteen months after gap creation, a perennial shrub *Chromolaena odorata* (L.) R.M. King and H. Robinson was the dominant species with 94.9% of total dry biomass. *Imperata* grass accounted for 1.4%. The rest consisted of shrubs (*Clibadium* spp. 1.8%), and several climbing vines (1.0%) and grass species (0.9%). Dry above ground biomass varied

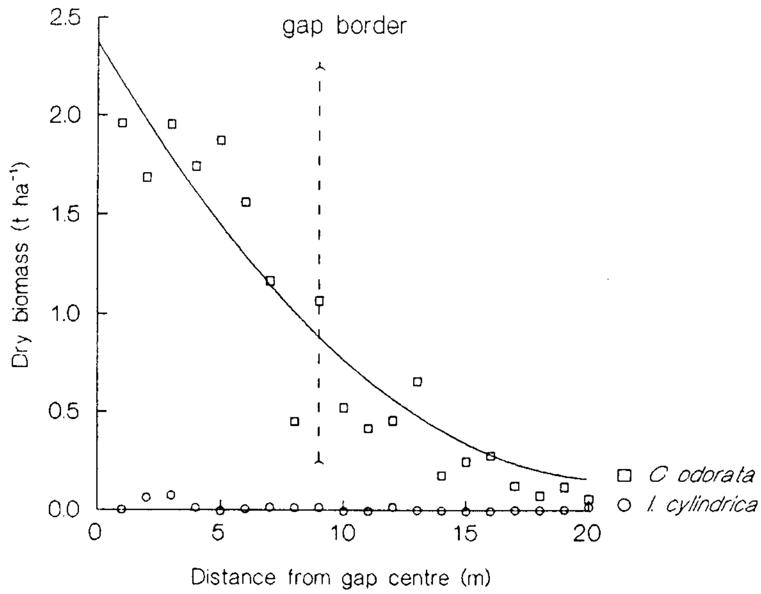

Figure 4. Relationship between dry above ground biomass of *Imperata cylindrica* and *Chromolaena odorata* (t ha^{-1}) along transect, and distance from gap centre into surrounding closed *Acacia mangium* stand in Riam Kiwa, South Kalimantan, Indonesia. n = 10 in each data point. Line is fitted for *Chromolaena odorata* ($y = 2.377 - 0.211x + 0.005x^2$, $r^2 = 0.901$) only.

from 0 to 0.1 t ha^{-1} for *Imperata* grass and from <0.1 to 2.1 t ha^{-1} for *C. odorata* along the transect from gap centre into the surrounding closed stand. There was a significant quadratic relationship between the mean dry biomass of *C. odorata* and distance from gap centre (r^2 = 0.901) (Figure 4).

Before opening the gaps, 14 species of naturally regenerated seedlings and two species of saplings were recorded in *A. mangium* understorey. The density of seedlings was 398 (S.E. = 48) ha^{-1} and of saplings 32 (13) ha^{-1}. 23 months after opening the gaps, seedlings of 21 and saplings of 24 species were observed. Seedling density was higher in *A. mangium* understorey compared to that in the gaps, even though no statistical differences occurred (Table 1). There were statistically significant differences between gap and closed stand in the density of saplings and height increment during a period of six months, which were higher in the gaps. Pioneer and secondary species dominated the recruitment: *Alstonia angustiloba* (Apocynaceae) was the most common sapling species (23%) followed by *Acalypha caturus* (Euphorbiaceae) (14%) and *Psychotria viridiflora* (Rubiaceae) (9%). *Leea indica* (Leeaceae) (24%) and *Ficus grossularioides* (Moraceae) (11%) were the most frequent seedling species.

Table 1. Density of naturally regenerated native tree seedlings and sapling, height and height increment of saplings in gaps (n = 5) and *Acacia mangium* understorey (n = 5) in South Kalimantan, Indonesia. Density and height were measured 23 months after opening the gaps and height increment during a period of six months. Standard error of mean is indicated in parentheses.

Location	Density ha^{-1}		Height, m	Height increment, m
	Seedlings	Saplings	Saplings	Saplings
Gap	1367 (335)	377 (14)	2.3 (<0.1)	1.0 (<0.1)
Closed forest	2100 (567)	116 (15)	2.1 (0.1)	0.5 (0.1)
df	8	8	8	7
t-value	−1.1	12.5	1.302	2.8
p-value	0.3	<0.001	0.23	<0.001

Discussion

Results of the study indicate that the early survival of *Anisoptera marginata*, *Shorea parvifolia* and *Peronema canescens* was not influenced by planting location and light availability. However, there was a clear positive relationship between their growth and light availability. Fairly constant survival rates across different light conditions are consistent with the earlier experiences from planting *Anisoptera marginata* on *Imperata* grasslands (Otsamo et al. 1997; Otsamo 1998a) and from planting *Shorea parvifolia* in logged-over secondary forests (Ådjers et al. 1995). *Shorea parvifolia* had the highest mortality, but a substantial part of it was caused by wild boars.

P. canescens had very fast early growth and, in spite of its ability to survive in shade, it showed the clearest difference in growth across the transect from closed forest to the gap centre. In addition, its seedlings were healthy. Its further use and testing in mixed plantations is recommended.

A. marginata seedlings experienced major damage and growth loss by wild boars, even though the cut seedlings recovered and started vigorous sprouting. The minor growth losses were caused by the grasshoppers, which attacked *A. marginata* seedlings more commonly inside the actual gaps than in *A. mangium* understorey. It may be possible that opening of gaps accelerated the growth of insect pest populations which are adapted to more open conditions than the ones prevailing in the understorey of closed forest. In spite of the above damage, the growth of *A. marginata* inside gaps was reasonably good, but slower than that of *S. parvifolia*. Compared to *S. parvifolia*, *A. marginata* is more adaptable to poor sites with water and nutrient deficit (Soerianegara and Lemmens 1994). The present and earlier results (Otsamo

1998a, 1998b) show that *A. marginata* is able to tolerate occasional high temperatures and moisture stress in fast-growing plantations. This makes it a promising species when indigenous slow-growing tree species are selected for enrichment planting on grasslands.

Several seedlings of *S. parvifolia* experienced dieback, especially inside the gaps. Smits (1994) has explained the dieback of some *Shorea* species by the excess light and light-induced high temperatures and low soil moisture contents, which can result in lack of mycorrhizal symbiosis that is important for dipterocarps. In spite of these implications of adverse conditions, several individuals of *S. parvifolia* had very fast early growth. In relation to its growth pattern and environmental requirements, *S. parvifolia* is known to resemble *S. leprosula*, one of the most promising generally planted dipterocarp species which, however, is more tolerant to high surface temperatures and moisture stress (Appanah and Weinland 1993; Otsamo et al. 1996).

The fairly high survival of the two dipterocarps and the clear relationship between their fast growth and light availability indicate that these species are able to establish under conditions of direct light for some hours per day and thus need not to be planted under overhead shade. This is in accordance with Ådjers et al. (1995) who concluded that light-hardwood *Shorea* species need plentiful light from above with protection from the sides when planted in secondary forest. The present study, however, covered only one gap size in one site during a short period with average rainfall. In fairly similar grassland conditions, prolonged drought caused high mortality of *S. parvifolia* three years after planting and high initial survival (Otsamo et al. 1996). Recent studies with dipterocarps emphasize the importance of water relations in determining survival and growth of different and fairly related species (e.g., Kai et al. 1996). Most probably moisture fluctuations in fast-growing plantations are greater compared to the regeneration sites in natural forests. In addition to the studies on physiological responses of seedlings to moisture stress, further research is needed on the relationship between microclimate and development of ectomycorrhiza in mixed communities in fast-growing plantations.

The used gap size (260 m^2) seemed to create suitable microclimatic conditions. In *A. mangium* plantations in Malaysia, the survival and growth rates of several dipterocarps were best when the width of opened strips was 60–100% of the stand height (JICA 1994; cited in Appanah and Weinland 1996), which is approximately the same ratio as used in the present trial. Light conditions in relation to growth requirements of several dipterocarps have been studied e.g., by Ashton (1992) and Brown (1993, 1996) in different sized gaps in natural rain forests, which substantially differ from the fairly homogenous fast-growing plantations. Comparison of seedling growth and survival is difficult even in the gaps and strips of the same size due to differences in structure and growth of the surrounding canopies as well as the topographical position and orientation of the gap. Therefore, the results cannot be directly applied to other gaps of the same size in different environments.

The question, whether the gaps could be larger, needs further research in plantation environments. It is possible, as postulated by Brown (1993), that a large gap creates only a small central area of extreme climate, and that a large area around its edge has microclimate similar to those found in the centre of small gaps. In fast-growing plantations, large gaps would be easier to create and manage, especially if wood harvested from the gaps is to be utilised. In the present study, none of the species performed well in the gap edge area.

The species composition of ground vegetation was dramatically changed compared to the original grassland situation; the increased light availability in gaps did not result in regrowth of *Imperata* grass. The gaps were dominated by the shrub species *Chromolaena odorata*, which is regarded as a later successional species, being able to suppress *Imperata* grass in the absence of fire. Its occurrence is also considered as an indication of improved soil conditions compared to those under *Imperata* grass (Eussen and Wirjahardja 1973). Fast occupation by shrub vegetation has probably had positive effects on microclimate and soil productivity by preventing leaching of minerals available after decomposition of dead materials following gap creation, and by diversifying the contents of litter.

The abundance of naturally regenerated native pioneer and secondary species dispersed from the adjacent forest patches clearly increased between the inventories. This can be explained by the positive effects the fast-growing trees have on their growing sites (see e.g., Parrotta et al. 1997) and the natural opening of the *A. mangium* canopy allowing more light into the shady understorey. The early development of seedlings was more vigorous in closed stand than inside the actual gaps, probably due to less extreme variation in soil moisture and temperature as well as lack of competition with shrub vegetation. The growing conditions inside gaps seemed to stimulate the growth of already established seedlings and saplings. Even though these fairly fast-growing species do not have high economic value, they may nurture regeneration of planted dipterocarps by modifying microclimate to resemble the conditions in natural forests. On the other hand, they can be seen as competitive species preventing the penetration of light beneath the canopy.

Management of multistoried stand is more complicated than that of fast-growing stands. The seedlings of slow-growing species need continuous tending for longer time than the seedlings of fast-growing species. Regular weeding around seedlings has to be carried out until the trees are taller than the shrub vegetation. Thereafter the controlling of surrounding spontaneously regenerated pioneer and secondary trees as well as cutting of climbing vines become more important than understorey weeding. Because of the light-demanding nature of the studied species, the mixed stand needs manipulation of the overstorey canopy of *A. mangium* trees. This can be done by harvesting the innermost fast-growing trees around the gaps. Otherwise the stands should be kept multistoried and diverse containing planted fast-growing and slow-growing trees as well as spontaneously regenerated native trees.

Planting in artificial gaps was an efficient way to test the effect of canopy openings. However, opening strips in fast-growing plantations and planting indigenous trees in these strips may be an equally effective method to provide suitable growing conditions for the partly shade-demanding species in practice. By this method harvesting and management of the stand may be implemented more effectively. These strip-planting methods and species mixtures of indigenous species with different growth rates need further studies.

Conclusions

Results clearly indicate that after the reforestation of *Imperata* grasslands with fast-growing tree species, slower growing indigenous species can be integrated by planting in artificial gaps. Distinct relationships between light availability and growth of all three species studied indicate the necessity of stand manipulation either by opening gaps or by other methods, if heavy-shading tree species like *Acacia mangium* are used for initial grassland reclamation. Successful early growth without an overhead shade may be obtained with other fairly light-demanding dipterocarp species as well. However, the optimum light, temperature and moisture conditions vary among species, and need to be considered when other species, larger gaps or other stand manipulation methods are used. In addition, insect and herbivore damage may cause high mortality and therefore they need special attention if large-scale plantations by using these silvicultural principles are planned.

Enrichment planting of indigenous species in commercial plantations can be seen as a step in restoration of these former grassland ecosystems to forest systems resembling the original rain forests. At the same time, these plantations provide wood and other forest products for multiple usage and give alternatives to grassland and plantation management. In the future, management practices, socio-economics and policy issues that influence the applicability and effectiveness of this silvicultural approach to native forest rehabilitation and restoration have to be evaluated.

Acknowledgements

The field work was done under the auspices of the Reforestation and Tropical Forest Managament Project (ATA-267) jointly financed by the Finnish International Development Agency (FINNIDA) and the Ministry of Forestry, Indonesia, and carried out by Enso Forest Development Ltd. in cooperation with Balai Teknologi Reboisasi Banjarbaru (BTR). The work is a part of a study financed by the Academy of Finland. The author wishes to thank the BTR staff for important field assistance and Mr. Antti Otsamo for his crucial advice and comments during the process of the study.

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