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Plant Species Diversity in Tropical Planted Forests and Implication for Restoration of Forest Ecosystems in Sakaerat, Northeastern Thailand

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Abstract

Plantations of single tree species which are usually set up to reafforest cleared lands in the tropics, have often been criticized for being associated with a low level of diversity in the ecosystems. However, our study of understorey plant species in various plantations of single exotic or indigenous species has shown that more plant species grew within stands near a natural forest than within grasslands in Sakaerat, northeastern Thailand. These forests contribute to the acceleration of the secondary succession from grassland, which before reafforestation was achieved by recurrent fires. In the natural regeneration of understorey tree species in planted forests, large tree species in the natural forest seem to be the major common seed source among the stands studied. The small leaf biomass in these planted forests generated enough shade to prevent the invasion of 2 fire-adapted competitive grasses and to provide a suitable light environment for seedling establishment at an early stage of forest development. These factors facilitated the establishment of other species within the plantations of single tree species. Faster-growing exotic species accumulated larger amounts of understorey biomass than indigenous species. The most suitable species was *Acacia mangium*. The association of forests planted with single tree species with a high species richness in the ecosystems may enable to achieve a high biological diversity at the landscape level, which could bring various benefits to the forests of Sakaerat.

Discipline: Forestry and forest products
Additional key words: catalytic effect, forest restoration, plantation, plant species richness

Introduction

Grasslands dominated by *Imperata cylindrica* widely occur on degraded lands in Southeast Asia after deforestation. Once the grasslands are established, secondary succession towards natural forest is markedly inhibited by recurrent fires[17]. The grasslands remain over a long period of time as fire disclimax vegetation, reducing the value of the forest ecosystem in terms of timber production, soil and water conservation, carbon storage and biological diversity. The recovery of forest from unproductive grasslands is, therefore, a very important forestry matter.

In Sakaerat, northeastern Thailand, degraded grasslands were reafforested to restore the forest ecosystem during the Research and Training for the Re-afforestation Project (Japan International Cooperation Agency) from 1982 to 1990. Various kinds of forests were established among remaining natural forest and grassland tracts. Many are composed mainly of single exotic species. Plantations of single tree species are often considered to be associated with the lowest biological diversity among forests. However, high species diversity of understorey plants within planted forests in the neighborhood of natural forests has been reported in the tropics[1,3,7,13,17,22–24]. This ability of a plantation to facilitate secondary succession or natural regeneration of indigenous species in its understorey could allow the restoration of biodiversity in degraded lands[19,23]. Although

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these phenomena have been observed widely, understanding of the process and the factors involved in species colonization is limited. The investigation of species colonization within a planted forest would allow the expansion of silvicultural techniques, not only to supply timber and other forest products, but also to enhance the biological diversity of degraded lands.

We evaluated the present status of plant species establishment in various stands composed of single tree species and compared it with that of neighboring grasslands and a natural forest. We also analyzed the factors influencing plant species establishment within the planted forests. We examined the significance of plant species richness within the planted forests for recovering forest ecosystems with high biological diversity in Sakaerat.

Materials and methods

Research sites and stands

The research site was the Sakaerat Field Station (lat. 14°12'N, long. 101°50'E, 610 m above sea level) of the Royal Forest Department, at the southeastern edge of the Khorat Plateau, about 300 km northeast of Bangkok, Thailand. The annual mean temperature and annual rainfall are 26.3°C and 1,101 mm. The region is characterized by a tropical monsoon climate with a rainy season from April to October and a dry season from November to April. The soils are Ferric Acrisols[31]. Natural forests covered this area about 50 years ago. However, population pressure and the demand for field crops led to the conversion of the forestst to agricultural land and grasslands on a large scale. Reafforestation of the grassland areas was initiated in 1982 with the planting of various exotic and indigenous tree species, totalling 2,500 ha by 1994. Small tracts of grassland and natural forest remain in the area. For the study, we selected 6 planted forests, 1 natural forest and 2 types of grasslands under similar site conditions. The planted forests were represented by 3 exotic tree species—*Acacia mangium*, *A. auriculiformis* and *Eucalyptus camaldulensis*—native mainly to Australia, and 3 indigenous species—*Xylia kerrii*, *Dalbergia cochinchinensis* and *Pterocarpus macrocarpus*—all components of mixed deciduous forests in Thailand. The study stands were planted in 1986. The canopies of all the stands except for *P. macrocarpus* were closed at the time of the study. All the 6 species are evergreen, although *P. macrocarpus* loses many leaves during several weeks in the dry season. All the stands were located within 500 m of a natural forest. The stands had not been weeded, thinned or otherwise tended. The natural forest was a dry evergreen forest representing the main forest type in mesic areas of the Khorat Plateau[25]. The 2 dominant grassland species studied were *Imperata cylindrica* and *Saccharum spontaneum*. Both are rhizomatous perennials.

Table 1. Description of the study plots

Plot	Plot size (m^2)	Planting space (m)	No. of trees (No. ha^{-1})	Mean DBH[a)] (cm)	Mean canopy height[a)] (m)
Planted forest					
Exotic species					
Acacia auriculiformis	575	2 × 3	1,493	13.8	22.4
Acacia mangium	573	2 × 3	955	18.6	25.7
Eucalyptus camaldulensis	575	2 × 3	1,389	11.7	22.4
Indigenous species					
Dalbergia cochinchinensis	573	2 × 3	1,510	10.0	15.4
Xylia kerrii	574	2 × 2	2,257	8.7	12.9
Pterocarpus macrocarpus	766	2 × 4	1,107	10.1	10.3
Natural forest					
Dry evergreen forest	1,582		1,612	10.5	28.5
Grassland					
Imperata cylindrica	100				2.1
Saccharum spontaneum	200				4.2

a): The measurements were performed in November 1998.

Methods of study

A sample plot was set up in each of the 6 forest stands in May 1998 (12 years after the plantation of the stands) and in the natural forest (Table 1). All the trees in the planted forests and trees with a DBH (diameter at breast height) of 4.5 cm or more in the natural forest were measured for DBH and height in May 1998 and November 1998. Sample trees were cut down in the planted forests, and tree dimensions and weight of the leaves, branches and stems were measured in November 1998 to determine the biomass of the stands. To assess the understorey floral composition, we recorded the names of all the vascular plants established in all the 7 plots. We also identified vascular plant species outside the sample plots within each stand to determine the suitability of the size of each sample plot to estimate the species richness in each stand. To measure the biomass of understorey plants in the planted forests, we set up 12 quadrats, 1 m^2 in size, outside of the sample plot in each stand. All the plants growing in the quadrat were identified and cut, and the aboveground dry weight was determined separately for the trees, shrubs, herbs and vines.

In the *I. cylindrica* and *S. spontaneum* grasslands, sample plots, 100 and 200 m^2 in size, respectively, were set up in November 1998. All the vascular plants were identified inside and outside of the sample plots. To estimate the biomass of the grasslands, we set up 6 and 8 quadrats, respectively, 1 m^2 in size, in the sample plots. All the vascular plants in each quadrat were identified and cut, and the dry weight of the trees, shrubs, herbs and vines was measured.

Relative light intensity was measured with Minolta digital photometers in the forest sample plots in November 1998.

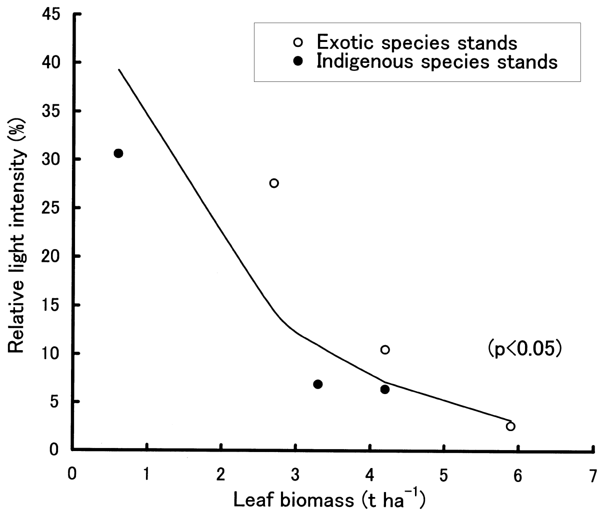

Fig. 1. Relationship between leaf biomass and relative light intensity

Results

Stand description

The growth of the stands varied considerably among the planted forests. The aboveground biomass ranged from 28 to 196 t ha^{-1}, being larger in the exotic species stands than in the indigenous species stands. The largest biomass was recorded in the *A. mangium* stand, which is characterized by a high biomass production in tropical plantations[10–12, 26]. The smallest biomass was recorded in the *P. macrocarpus* stand. This small biomass was associated with the widest tree spacing and a smaller biomass increment than that of the other species. The leaf biomass showed a narrower range among the stands than the aboveground biomass, being 2.7 to 5.9 t ha^{-1}, except for the *P. macrocarpus* stand, whose canopy was not completely closed. The leaf biomass in these stands was almost the same as that in various fast-growing plantations in the tropics[10–12,26,30], which have a generally low leaf biomass among the various forests[29].

The relative light intensity varied among the study stands from 2.6 to 27.6% under closed canopy and amounted to 30.6% in the *P. macrocarpus* stand. Leaf biomass showed a significant relation to the relative light intensity (Fig. 1). The relative light intensity in tropical forests with a larger leaf biomass (7.4 to 9.1 t ha^{-1}) than that in our study stands ranged from 0.5 to 1.9%[16,20]. Thus, leaf biomass was considered to be an appropriate indicator of light intensity under the canopy among different forests.

Understorey species richness

Fig. 2 shows the understorey species richness in each sample plot. The number of understorey plant species in the sample plots reflected well the composition in the planted forests, natural forest and grasslands with a close positive correlation ($R = 0.93$, $p < 0.01$). The number of understorey plant species in the planted forests was larger than that in the grasslands and smaller than that in the natural forest, accounting for 31 to 52% of the understorey species in the natural forest.

The number of understorey plant species in the sample plots in the planted forests ranged from 35 to 59; there was no difference between the exotic and indigenous stands. The *S. spontaneum* grassland exhibited a slightly greater species richness than the *I. cylindrica* grassland.

Trees and vines comprised a large proportion (29 to 40% and 34 to 40%, respectively) of the total plant species. The number of understorey tree species found in the planted forests was 1.5 to 2.8 times as large as that in the *S. spontaneum* grassland and 4.0 to 7.3 times as large as

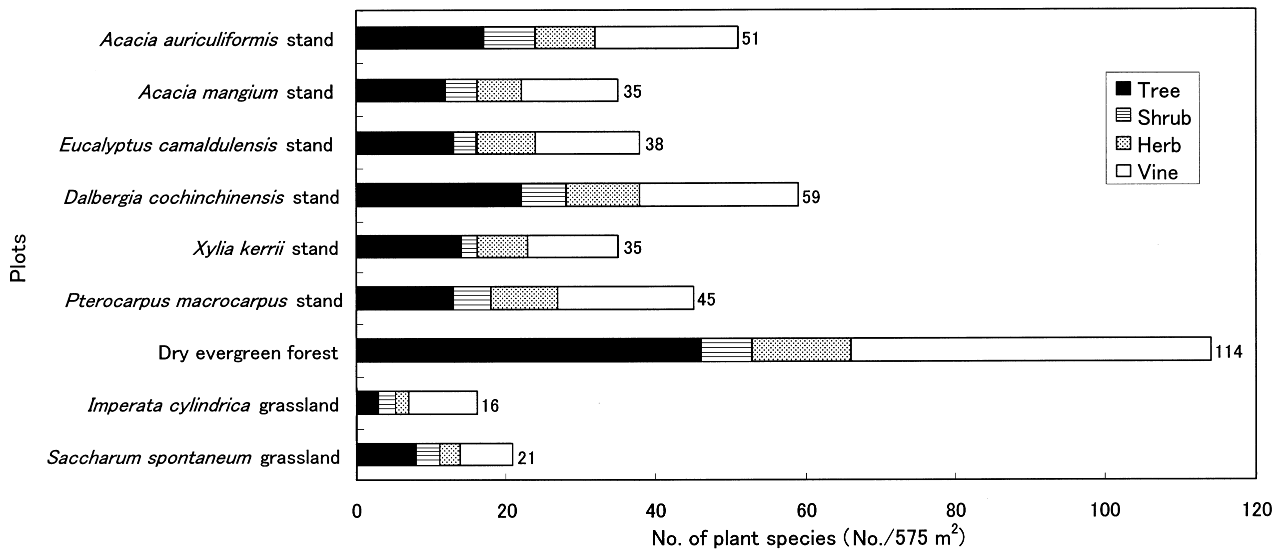

Fig. 2. Species richness of understorey plants in the study plots

Owing to differences in plot sizes, the numbers of plant species in the plots except for *A. auriculiformis* and *E. camaldulensis* were adjusted with a species-area curve for each plot to the plot size of planted forests (575 m^2) .

that in the *I. cylindrica* grassland, or 26 to 48% of that in the natural forest.

No seedlings of the plantation species had become established in the planted forests, except for *Leucaena leucocephala*.

Similarity indexes

Similarity indexes (Nomura-Simpson's coefficient[14]) for all the understorey vascular plant species between the natural forest, the planted forests and the 2 grasslands are shown in Table 2. The degree of similarity was not appreciably high between the plots. The degree of similarity was also not very high among the tree species (Fig. 3).

The mean similarity index of the understorey tree species was calculated for all the tree species found in the planted forests, and large tree species (DBH ≥ 10 cm) and small tree species (DBH < 10 cm) in the sample plot of the natural forest (Fig. 3). The similarity index for large tree species in the natural forest was significantly higher

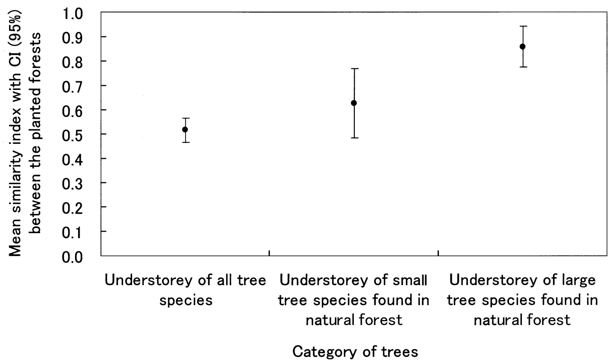

Fig. 3. Mean similarity index between the planted forests for understorey tree species

Table 2. Similarity index between the study plots for all the plant species

Site	Aa	Am	Ec	Dc	Xk	Pm	Ic	Ss
Am	0.54							
Ec	0.58	0.41						
Dc	0.44	0.58	0.48					
Xk	0.55	0.49	0.44	0.59				
Pm	0.46	0.51	0.45	0.57	0.52			
Ic	0.71	0.54	0.63	0.67	0.58	0.50		
Ss	0.53	0.56	0.35	0.65	0.53	0.47	0.38	
DEF	0.42	0.45	0.42	0.57	0.50	0.46	0.54	0.56

Aa: *A. auriculiformis* stand, Am: *A. mangium* stand, Ec: *E. camaldulensis* stand, Dc: *D. cochinchinensis* stand, Xk: *X. kerrii* stand, Pm: *P. macrocarpus* stand, Ic: *I. cylindrica* grassland, Ss: *S. spontaneum* grassland, DEF: dry evergreen forest.

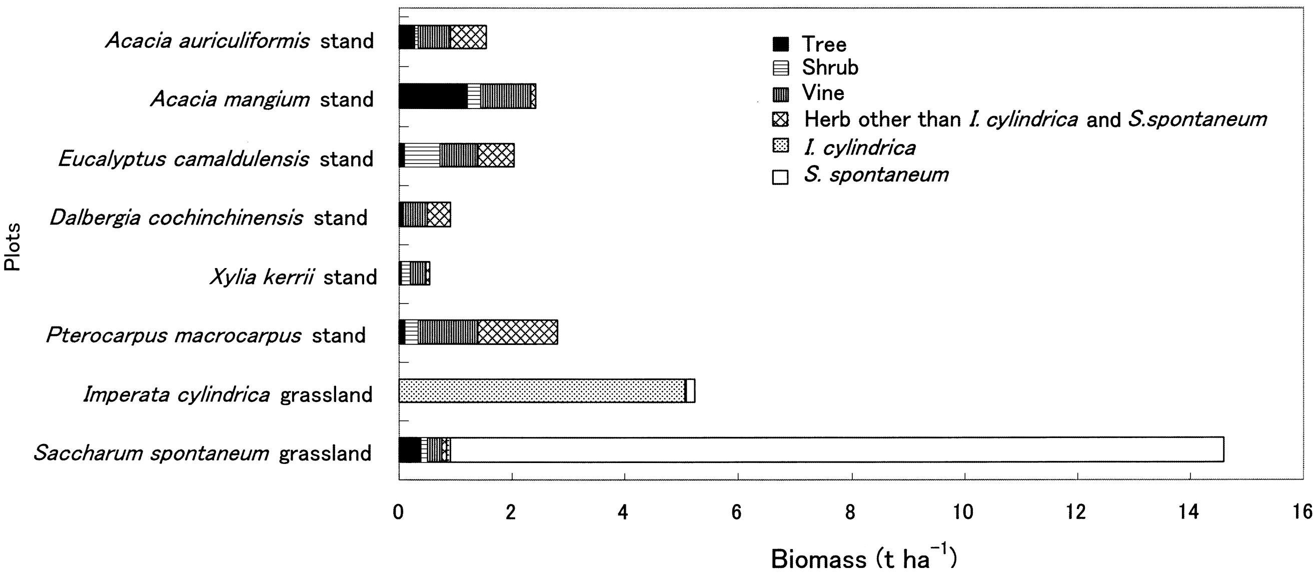

Fig. 4. Biomass of understorey plant species in the study plots

than that for the small tree species in the natural forest and for all the tree species within the planted forests.

Understorey biomass

The biomass of the understorey plant species in the planted forests was smaller than that of the grasslands (Fig. 4). No *I. cylindrica* or *S. spontaneum* grasses grew in the sample plots of the planted forests, although a few were found outside the sample plots. Among the planted forests, the total biomass of the understorey plant species was largest in the *P. macrocarpus* stand. However, a large proportion of biomass was occupied by shrubs and herbs, presumably because of the higher relative light intensity (30.6%) in this stand than in the other stands. Yet even in this light environment, *I. cylindrica* and *S. spontaneum* did not become established in the sample plots, indicating the strong shade intolerance of these 2 grasses.

Stand parameters and understorey plant species richness and biomass

The correlations between the stand parameters, and the species richness and the biomass of the understorey and tree species among the planted forests, are shown in Table 3. None of the stand parameters showed a significant correlation with the species richness of the understorey plant species. On the other hand, the tree density exhibited a significant negative correlation with the biomass of all the understorey plant species. A significant positive correlation was found between the biomass of the understorey tree species and the parameters related to the stand growth performance (mean height, basal area,

Table 3. Correlation analysis between various stand parameters of planted forests and species richness and biomass of understorey plant species and tree species

Dependent variables (Category of plant)	Stand parameters					
	Tree density (No. ha^{-1})	Mean height (m)	Basal area (m^2 ha^{-1})	Leaf biomass (t ha^{-1})	Above-ground biomass (t ha^{-1})	Relative light intensity (%)
Understorey species richness						
Tree species	ns	ns	ns	ns	ns	ns
All the plant species	ns	ns	ns	ns	ns	ns
Understorey biomass						
Tree species	ns	positive*	positive*	ns	positive*	ns
All the plant species	negative**	ns	ns	ns	ns	ns

ns: Not significant, * Significant at 5 % level, ** Significant at 1% level.

aboveground biomass), but there was no significant correlation between the biomass of all the understorey plant species or understorey tree species and leaf biomass or relative light intensity.

Discussion

Plantations of single tree species are usually set up for reafforestation in the tropics. However, single species plantations have often been criticized for being associated with a low level of diversity in the ecosystems. The results of this study indicate that many plant species, including tree seedlings, became established in the planted forests with single tree species in the neighborhood of a natural forest. It is noteworthy that relatively many plant species became established in the *E. camaldulensis* stand, although eucalypts are often considered to have very few plant species on their forest floor, which is a cause for concern in eucalypt plantations[4].

In Sakaerat, before the plantations were established, fire occurred frequently in the *I. cylindrica* and *S. spontaneum* grasslands, mainly in the dry season, hampering the initiation of secondary succession to natural forest. After the forest stands were established, the fire frequency decreased markedly (personal communication, Thaingam). We found that *I. cylindrica* and *S. spontaneum* had almost disappeared under the canopy of the planted forests, owing to their strong shade intolerance. Thus, the disappearance of the 2 grasses within the stands was a major cause of the reduction of fires after stand establishment.

In the reversion of *I. cylindrica* and *S. spontaneum* grasslands to natural forest, the planted forests at the research site appeared to play a significant role in accelerating secondary succession. Fire had not been recorded in the *S. spontaneum* grassland at the site for more than 10 years, while the *I. cylindrica* grassland had often been burned. The tree species richness was slightly higher in the *S. spontaneum* grassland than in the *I. cylindrica* grassland (Fig. 2). In some parts of the grassland where *S. spontaneum* had died, tree species began to invade. These observations imply that preventing fire should initiate secondary succession. The planted forests contained more plant species, including tree seedlings, than the *S. spontaneum* grassland, which in turn contained more species than the *I. cylindrica* grassland (Fig. 2). These facts imply that the plantations at the research site facilitated the establishment of various plant species, and consequently promoted secondary succession.

One of the major factors that affect the abundant colonization of tree species in a planted forest is the proximity to a natural forest, i.e. seed source[18, 24]. The planted forests we studied were located near a natural forest with a high species diversity (Kamo et al., unpublished data). This might be one of the factors that contributed to the abundance of tree species within the planted forests.

Analysis of similarity indexes (Table 2) showed that the species composition differed between the study stands to more or less extent and that there were relatively few common species. However, among the large tree species (canopy tree species) in the natural forest that became established in the planted forests, common species tended to prevail (Fig. 3). This shows that the seedlings of large tree species in a natural forest can become widely established in plantations. The larger and most commonly established tree species included *Xerospermum intermedium*, *Melia azedarach*, *Hopea ferrea*, *Vitex pinnata* and *Shorea henryana*, a major canopy dominant in the natural forest in Sakaerat. In the process of natural regeneration, animals play an important role in seed dispersal in the tropics[8,33]. In this connection, birds might perch on the overstorey trees [6,33] of the planted forests and disperse seeds.

Many plant species, including tree seedlings, became established within the planted forests (Fig. 2), while almost no *I. cylindrica* or *S. spontaneum* grew (Fig. 4). The relative light intensity in the planted forests ranged from around 3 to 30%. The small leaf biomass of the stands caused this low degree of shade (Fig. 1). However, such a light environment was sufficient to allow seedling establishment while shading out the 2 grasses.

Watt[32] has recognized 4 characteristic phases after disturbance in a plant community: regenerative phase, building phase, mature phase and degenerative phase. In the building phase, or the stem exclusion stage in Oliver and Larson's stand development model[21], the colonization of understorey species was markedly inhibited by the intense competition associated with vigorous growth of the stand. Thereafter, understorey species became gradually established[5]. In vigorously growing evergreen forests with a large leaf biomass, the forest floor often lacks undergrowth[5,27] for a relatively long period of time after canopy closure. The relative light intensity then is extremely low, often less than 1%. Stand leaf biomass increased as the stand aged and reached a maximum value at the time of vigorous growth after canopy closure, and thereafter decreased to reach a constant level[15]. The period of large leaf biomass would correspond to that of vigorous growth of the stand[15], i.e. the building or stem exclusion stage. The intervention of the building or stem exclusion stage during stand development would cause the initiation of the much-delayed natural regeneration within these stands. Many late successional tree species had become established at the late stage of forest development in *Cryptomeria japonica* stands, suggesting that a 60-year rotation would not be sufficient to develop a high species diversity in the stands[9]. In a sitka spruce—western hemlock forest in Alaska, during the first 70 to 80 years of 100-year rotations, the forest floor accumulated little understorey[2]. The leaf biomass of these evergreen forests[29] would be much larger than that of the stands we studied. In contrast, the seedlings of the tree species in our study stands would have begun to colonize the forest floor at an early stage of stand development, since the 12-year-old plantations already had many seedlings. This might be ascribed to the small leaf biomass in the stands. The leaf biomass remained low even during the period of largest biomass production at an early stage of forest development in a tropical stand of fast-growing tree species with a small leaf biomass[12]. The peak of leaf biomass tended to be less conspicuous, remaining low in stands with a small leaf biomass during forest development[28]. This temporal leaf dynamics may obscure the building or stem exclusion stage in the stand, with the small leaf biomass allowing seedling establishment early in the forest development and promoting an earlier build-up of tree seedlings in these stands than in the stands with a larger leaf biomass. Thus, fast-growing tree species with a small leaf biomass would act as a better catalyst than tree species with a large leaf biomass.

Stands of both exotic and indigenous species contained approximately the same number of plant species and tree species (Fig. 2). This suggests that both types of stands may allow similar plant species establishment in the understorey, although their stand biomass and growth performance differed. On the other hand, exotic species stands were superior to indigenous species stands for the accumulation of biomass of the understorey tree species (Fig. 4). The biomass of the understorey tree species showed a positive correlation with the stand parameters related to biomass and growth performance of the stands (Table 3). This indicates that the faster-growing tree species are likely to accumulate a larger biomass of understorey tree species. The growth of the understorey is influenced by various factors, including competition for light and nutrients, pattern of tree regeneration, soil and microclimatic effects and past stand conditions (disturbance)[2]. It remains to be determined which factors were most important in our study stands. However, one explanation associated with the better growth of the stands that favored the accumulation of understorey might be earlier canopy closure in the stands of the faster-growing tree species. Canopy closure would shade out the 2 grasses and vines and herbs (Fig. 4), allowing the establishment and growth of seedlings on the forest floor. Among the planted forests, the largest understorey biomass accumulator was found to be *A. mangium*. This species was also reported to be a promising tree species in degraded grasslands in Indonesia[17]. *A. mangium* displayed a very low sprouting capacity and a relatively narrow crown in Sakaerat (Kamo et al., unpublished data). These traits are likely to free regenerating seedlings from competition and allow them to escape with lighter damage after the stand is thinned or cut during the process of stand conversion. These species characteristics would also make *A. mangium* a superior catalyst.

Leaving stands untended after establishment may facilitate the establishment of indigenous tree species within planted forests[23]. This was the case in Sakaerat. However, vines should still be cut: we observed abundant vines (Figs. 2, 4) that were damaging the stands.

Traditionally, foresters tend to consider tree plantations as a renewable resource for producing timber and cellulose. Using a plantation to catalyze the natural regeneration of tree species is a very different concept from the traditional approach. However, the 2 practices should not be alternative but complementary for creating a forest ecosystem with high biological diversity. Various understorey tree species arising in stands with single tree species could be used to achieve high biological diversity at the landscape level by creating various types of forests—such as human-induced natural forest, mixed indigenous stands and mixed exotic and indigenous stands—through various silvicultural treatments, while stands with single tree species could be managed for traditional timber and cellulose production at the same time. High biological diversity at the landscape level could bring about many benefits from forests, including wood production, water and environmental conservation, carbon stocking, education and scenic recreation. To achieve this objective, it is essential to retain some natural forests in the reafforestation areas, avoiding large-scale clear-cutting.

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