27 The effects of forest restoration activities on the species diversity of naturally establishing trees and ground flora

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ABSTRACT

The framework species method of forest restoration aims to rapidly re-establish forest ecosystem structure and function. At the same time, it aims to encourage wildlife, attracted to the planted trees, and accelerate recovery of biodiversity through facilitating seed dispersal into planted sites. The objectives of this study were to determine whether forest restoration encourages recruitment of non-planted tree species into planted areas and increases the species diversity or changes the species composition of the ground flora. The study was carried out on degraded, evergreen forest land in Suthep-Pui National Park, northern Thailand. The land had been planted with 30 framework tree species in 1997 and 1988 to compare the relative performance of different framework tree species and develop suitable silvicultural treatments to maximize tree performance. Treatments included fire protection, application of fertilizer, and weeding. Two non-planted control plots were also demarcated, in which only fire protection was implemented. Vegetation surveys were carried out in replicated 10-m diameter plots, recording the presence of ground flora species and naturally established trees (> 1 m tall). They were carried out three times in 1999: in the dry season, in the middle of the rainy season and at the end of rainy season. In the first year after planting, the species richness and evenness of the ground flora in the plot planted in 1998 increased, compared with the plot planted in 1997. This was probably due to the effects of weeding, which removed dominant perennial herbs, allowing invasion, in the 1998 planted plots, by annual herbs, especially those of the Compositae family. However, two years after tree planting, the diversity of the ground flora decreased in the 1997 planted plot. This was probably due to shade caused by closing of the forest canopy, which reduced opportunities for establishment

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of new ground flora species. Evenness was also lesser here as compared to the 1997 control plot, since fire removed most of the dominant weed species. Weeding and fertilizer accelerated establishment of natural seedlings and further increased the tree density of naturally established trees (wildings) in the planted plots. Most of planted tree species were in good health and fast growing. All of the planted tree species, except Nyssa javanica and Garcinia meckeaniana, were found suitable for forest restoration.

INTRODUCTION

Many countries have recognized the value of rehabilitating degraded tropical area, to utilize natural resource for sustainable development and maintain biodiversity. Techniques have been established to achieve objectives such as assisted natural regeneration (ANR) (Dalmacio 1986, RECOFTC 1994) and the Miyawaki method (Fujiwara 1993, Miyawaki 1993).

Assisted or accelerated natural regeneration (ANR) was suggested by Dalmacio and is already practised for accelerated reforestation of degraded uplands and *Imperata* grassland in the Philippines (Dalmacio 1986, Durst 1990). The basic concept of ANR emphasizes protection and nurturing of tree seedlings and saplings already existing on degraded sites, rather than establishment of entirely new forest plantations. ANR requires tree seedlings and saplings on degraded sites to be marked and assisted in their survival and growth by one or more of the following activities: 1) pressing or cutting of competing grasses; 2) weeding around existing seedlings and saplings; 3) fire protection; and 4) enrichment planting. The advantages of ANR are not only accelerated secondary succession of forest, but also maintenance of species diversity, provision of useful products and many ecological values. In ANR implementation can often be accomplished for as little as one-third the cost of conventional reforestation.

In Thailand, ANR has not been successful because knowledge of how to assist the natural regeneration of each species is lacking. Literature on fruit production, seed germination, seed banks, and tree seed dispersal is much needed. Different species require different ANR methods. Suitable methods may include planting *Beilschmiedia* sp. (Lauraceae) under the shade of existing herbaceous vegetation, direct sowing of *Prunus cerasoides* (Rosaceae), and for *Eugelhardia spicata* (Juglandaceae), cutting weeds (particularly grasses and ferns) or shading them out with nurse trees (Hardwick *et al*. 1997).

The Miyawaki method has been used successfully to restore forest in many places in Japan and in other places in Southeast Asia (Miyawaki 1993). The technique includes:

1) species selection using as many native canopy species as possible, based on the potential natural vegetation at each site by the phytosociological method;
2) mixed plantations;
3) use of potted seedlings with well-developed root systems (with heights of up to 80 cm);
4) soil preparation, including provision of good drainage and use of organic fertilizers such as compost, weeds, dropped, broken blocks, etc.;
5) dense planting (3–9 individuals per square meter);
6) mulching with rice straw, leaves, etc., for protection against soil dryness, soil erosion and loss of nutrients;
7) no management after two or three years from planting (Fukiwara 1984, 1993, Miyawaki 1984).

Miyawaki (1993) and Said (1993) reported the first assessment of planting native seedlings (such as *Shorea* spp., *Dipterocarpus* spp., *Hopea* spp., etc.) and using some techniques of the Miyawaki method at Bintulu, Sarawak State, Malaysia. The percentage survival of such seedlings on areas of soil erosion and compaction after planting for a year was very high (approximately 71%). Moreover, percentage survival was 89.2% where 1-m-wide strips of vegetation had been removed with half-meter-wide strips of existing vegetation retained to provide shade to the planted seedling. In addition, the planted seedlings grew well, and had well-developed crowns after weeding and using rice straw as a mulch (Miyawaki 1993). Native seedlings, 50 cm tall, planted using oil palm leaves as a mulch at a shopping center, Jaya Jusco in Malacca, Malaysia, grew to 150–270 cm six months later (Fujiwara 1993, Miyawaki 1993).

Such techniques for rehabilitating selected degraded areas will ultimately depend on the priorities of the stakeholders, the costs and benefits associated with available rehabilitation techniques, and the economic, social, and environmental values of these land resources in their current and desired future states (Lamb 1994, Parrotta *et al*. 1997).

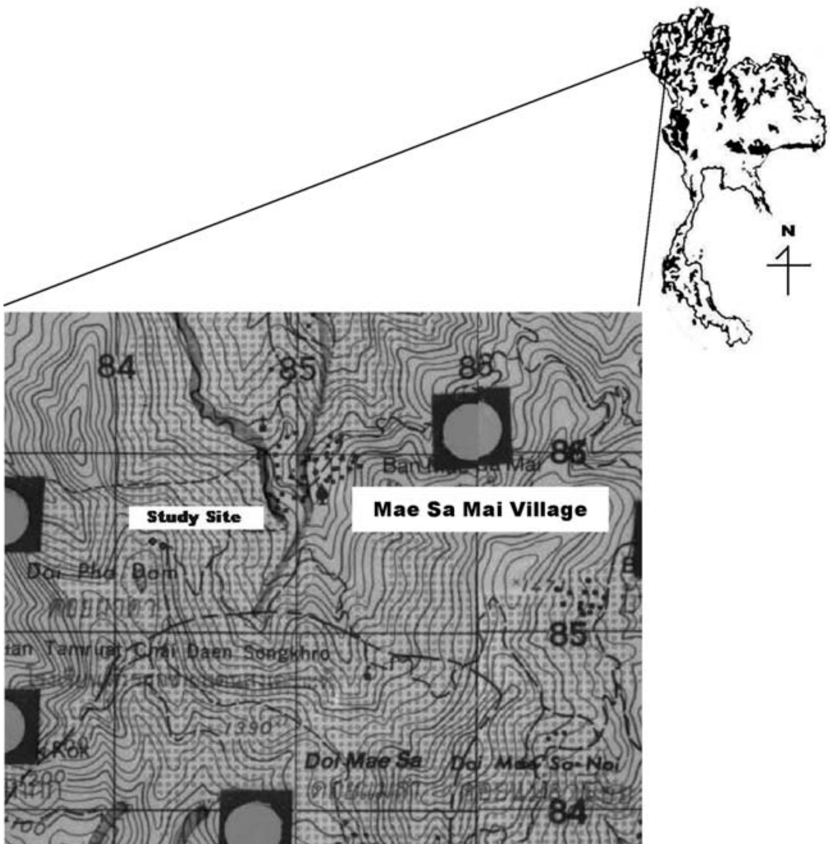


Figure 1. Map of Mae Sa Mai village, and location of the experimental plots

STUDY SITE DESCRIPTION

There are many suggested techniques to achieve forest restoration, but only the *framework species method* combined with various silvicultural treatments was applied in this field research project on degraded evergreen forest in the Doi Suthep-Pui National Park, Chiang Mai, Thailand (Figure 1). The framework species method uses native trees for planting in degraded areas, and matches these criteria: fast growing with dense spreading crowns, attractive to seed-dispersing wildlife (especially birds and bats), and easily propagated in the nursery. This method has been used successfully in ecological rehabilitation of forest and biodiversity conservation in north Queensland (Tucker & Murphy 1997). The aims of the framework species method are to rapidly re-establish forest ecosystem structure and function and accelerate recovery of biodiversity through facilitating seed dispersal into planted sites. The framework species in the planted sites were divided into three important groups: 20% of figs (*Ficus* spp., Moraceae), 10–15% of species of families Fagaceae and Leguminosae, and the rest of other species matching the framework criteria (FORRU 1998). The framework species are listed in Table 1.

Table 1. The framework species

No.	Botanical name	Family
1	*Bischofia javanica* Bl.	Euphorbiaceae
2	*Melia toosendan* Sieb. & Zucc.	Meliaceae
3	*Manglietia garrettii* Craib	Magnoliaceae
4	*Diospyros glandulosa* Lace	Ebenaceae
5	*Sapindus rarak* DC.	Sapindaceae
6	*Hovenia dulcis* Thunb.	Phamnaceae
7	*Aphanamixis polystachya* (Wall.) R. Parker	Meliaceae
8	*Quercus semiserrata* Roxb.	Fagaceae
9	*Spondias axillaris* Roxb.	Anacardiaceae
10	*Prunus cerasoides* D. Don	Rosaceae
11	*Ficus altissima* Bl.	Moraceae
12	*Gmelina arborea* Roxb.	Verbenaceae
13	*Eurya acumminata* DC. var. *wallichiana* Dyer	Theaceae
14	*Phoebe lanceolata* (Nees) Nees	Lauraceae
15	*Helicia nilagirica* Bedd.	Proteaceae
16	*Sarcosperma arboreum* Bth.	Sapotaceae
17	*Horsfieldia amygdalina* Warb. var. *amygdalina*	Myristicaceae
18	*Aglaia lawii* (Wight) Sald. & Rama.	Meliaceae
19	*Garcinia mckeaniana* Craib	Guttiferae
20	*Nyssa javanica* (Bl.) Wang.	Nyssaceae
21	*Heynea trijuga* Roxb. *ex* Sims	Meliaceae
22	*Markhamia stipulata* (Wall.) Seem. *ex* K. Sch. var. *kerrii* Sprague	Bignoniaceae
23	*Cinnamomum iners* Reinw. *ex* Bl.	Lauraceae
24	*Horsfieldia thorelii* Lec.	Myristicaceae
25	*Phoebe lanceolata* (Nees) Nees	Lauraceae
26	*Quercus kerrii* Craib var. *kerrii*	Fagaceae
27	*Erythrina subumbrans* (Hassk.) Merr.	Leguminosae, Papilionoideae
28	*Eugenia albiflora* Duth.*ex* Kurz	Myrtaceae
29	*Castanopsis calathiformis* (Skan) Rehd. & Wils.	Fagaceae

Such framework species were planted in deforested area in 1997 and 1998 (plots F97 and F98) combined with silvicultural treatments, i.e. fire protection, application of fertilizer, and weeding. Plots C97 and C98 were established as the control plots of each year, with no tree planting and activities except fire protection. The treatments in each plot are summarized in Table 2.

Table 2. Summary of treatments in each experimental plot

Plot	Activity
F98 (40 × 40 m)	*Before and when planting* 1. No cutting of naturally established tree seedlings, saplings, and trees. 2. A non-residual herbicide was used to clear the plot before planting. 3. Planting with native trees (29 species, 500 trees/rai or 3 125 trees/ha) in June 1998 with 100 g of fertilizer applied, when planted. 4. Fire-break. *After planting* 1. Weeding with hand tools once per month, in the rainy season and application of fertilizer (about 100 $tree^{-1}$) immediately after weeding, and weeds used as mulch. 2. Fire-break before dry season.
C98 (40 × 40 m)	No planting, weeding, and fertilizing except fire-break
F97 (20 × 20 m)	The same with plot F98, but native trees were planted in June 1997 and there was a partial burn in the dry season of 1998.
C97 (20 × 20 m)	The same as plot C98, but partial burn in the dry season of 1998.

To maintain the planted areas, new seedlings are planted to replace dead ones one year and, if necessary, two years after planting.

METHODOLOGY

Data collection

To determine whether forest restoration increases the species diversity or changes the species composition of the ground flora and encourages recruitment of non-framework tree species into planted areas, vegetation surveys were carried out in replicated 5-m diameter subplots, and covered about 24% of each plot, recording the presence of ground flora species (< 1 m tall) and naturally established trees (> 1 m tall). The Braun Blanquet scale was used to quantify abundance of the herbaceous ground flora (Shimwell 1971, Goldsmith *et al*. 1986). The naturally established trees were surveyed and labeled by both circular subplots and walking survey. Their height and health were measured with a measuring tape and scored respectively.

For the framework trees, their health, survival and growth were monitored only in the subplots, to know how they were effective in reforestoration for this area.

The surveys were done three times in 1999: in the dry season, in the middle of the rainy season and at the end of the rainy season. Some specimens of vegetation were collected and identified at the Herbarium, Department of Biology, Chiang Mai University.

Table 3. The Braun Blanquet scale for ground flora abundance and health scale for naturally established and framework trees

The Braun Blanquet scale	
	+ = less than 1%, sparsely or very sparsely present, cover very small
	1 = 1–5%, plentiful, but of small cover value
	2 = 6–25%, very numerous or covering at least 5% of the area
	3 = 26–50%, any number of individuals covering $^1/_4$ to $^1/_2$ of the area
	4 = 51–75%, any number of individuals covering $^1/_2$ to $^1/_4$ of the area
	5 = 76–100%, covering more than $^1/_4$ of the area
The health scale was divided into 4 levels:	
	0 = dead
	1 = not healthy, no leaves but still alive
	2 = normal, but may have some yellow leaves, brown spots, insect damage, etc.
	3 = very good

Data analysis

Ground flora

Different aspects of ground flora communities, i.e. species richness, evenness, diversity, and distance coefficient between sampling sites, were analysed from the formulas (Table 3 and 4) using the basic computer programs SPDIVERS.BAS and SUDIST.BAS (Ludwig & Reynolds 1988).

To compare the similarities and differences of ground flora in each experimental plot, the two indices were used (Table 4).

Table 4. The calculation formulas of species richness, species diversity, evenness and distance coefficient using the basic computer programs SPDIVERS.BAS and SUDIST.BAS

Species richness

Species richness was determined by direct count or

N0 = total number of ground flora species.

Species diversity (Hill's number)

1. $N1 = e^{H'}$
2. $N2 = 1/\lambda$

where: N1 = number of abundant species in the sample
N2 = number of very abundant species in the sample
H' = Shannon's Index
λ = Simpson's Index

Shannon's Index (H') is computed as:

$$H' = \sum_{i=1}^{s} (p_i \ln pi)$$

Simpson's Index (λ) is computed as:

$$\lambda = \sum p_i^2$$

where: p_i = proportion of individuals belonging to i^{th} species and is computed as:

$$p_i = n_i / N$$

where: n_i = number of individuals of the i^{th} species
N = total number of individuals
S = number of species

Evenness (Modified Hill's Index)

$$E5 = \frac{(1/\lambda) - 1}{e^{H'} - 1}$$

Table 5. The distance coefficient formula

Sorensen's Index (SI) for similarity coefficient

$$SI = 2C / (A + B)$$

where: C = number of species common to both community
A = total number of species in community A
B = total number of species in community B

Chord distance (CRD) for difference coefficient

(Calculation using the basic computer programs SPDIVERS.BAS and SUDIST.BAS)

$$CRDjk = 2\ (1\text{-}ccosjk)$$

where: CRDjk = chord distance between sample unit j(SUj) and sample unit k (Suk) which range from 0 to 2
ccos = chord cosine is computed from

$$ccos = \frac{\sum_{i=1}\{(Xij) \times (Xjk)}{\left[\sum_{i=1} Xij^2\right] \times \left[\sum_{i=1} Xjk^2\right]}$$

where: X_{ij} = number of individuals of the ith species in sample unit j
Y_{ik} = number of individuals of the ith species in sample unit k
S = number of species

Naturally established and framework trees

Species richness of naturally established trees was determined by direct count. The health, survival and the growth of naturally established trees and framework trees were calculated as health average, % survival and relative growth rate (RGR) (Table 6).

Table 6. The calculation of relative growth rate, health average and % survival

Relative growth rate (RGR)

Height relative growth rate

$$\text{RGR (\% increase in height per year)} = \frac{(1nh1 - 1nh2)}{(T2-T1)} \times 100 \times 365$$

where: RGG = relative growth rate
H1 = height of species A in the first survey
H2 = height of species A in the last survey
T2 –T1 = number of days between T1 and T2
ln = natural log

Health average

Ha = (H1 + H2 + H3)/3
where: Ha = health average
H1 = health score of plant species A in first survey
H2 = health score of plant species A in second survey
H3 = health score of plant species A in third survey

% Survival rate

Percent survival rate = (SN / TN) x 100
where: SN = number survived
TN = total number of species

RESULTS AND DISCUSSION

One hundred and thirty-six plant species (except framework trees), including 103 ground flora and 48 naturally established trees, were recorded in this study (Table 7).

Table 7. Total numbers of ground flora species, natural established trees and planted trees found in all surveys

Plot	Number of ground flora species found	Number of natural tree species found*	Total number of species found**	Framework tree species found
F98	75	29	95	22
C98	51	27	71	–
F97	28	5	33	14
C97	37	4	41	–
All plots	103	48	136	29

Remarks

* = including naturally established seedlings, saplings and trees in both circle and walking surveys.

** = not including planted trees. Some of the ground flora and natural tree species were the same.

GROUND FLORA

Diversity indices

Ground flora species were abundant in all plots. The most abundant ground flora species recorded in all surveys were *Pteridium aquilinum, Ageratum conyzoides, Eupatorium adenophorum, Mucuna bracteata* and *Pennisetum polystachyon* (Table 8).

Table 8. Percent cover of ground flora species recorded in all plots

Species	F98	C98	F97	C97	Total	No. of plots recorded
Ground flora*						
Pteridium aquilinum	5	260	7	167	439	4
Ageratum conyzoides	208	5	67	13	293	4
Eupatorium adenophorum	110	25	33	103	271	4
Mucuna bracteata	2	25	23	220	270	4
Pennisetum polystachyon	10	0	193	33	236	3
Mitracapus villosus	150	22	47	0	219	3
Conyza sumatrensis	122	13	60	17	212	4
Bidens pilosa	55	15	87	43	200	4
Phragmitus vallatoria	107	90	0	0	197	2
Imperata cylindrica	33	150	0	7	190	3
Cyperus cyperoides	42	15	47	57	161	4
Thysanolaena latifoia	27	100	0	0	127	2
Crassocephalum crepidiodes	38	22	40	20	120	4
Eupatorium odoratum	52	47	3	17	119	4
Setaria parviflora	63	10	3	17	93	4
Rhynchelytrum repens	27	12	47	3	89	4
Microstegium vagans	8	73	0	0	81	2
Digitaria setigera	25	5	23	20	73	4
Artemisia indica	35	27	10	0	72	3
Polygonum chinense	7	0	13	40	60	3
Spilanthes paniculata	47	0	7	3	57	3
Clerodendrum glandulosum	5	28	3	20	56	4
Centella asiatica	43	10	0	0	53	2
Drymaria diandra	7	0	33	10	50	3
Mimosa diplotricha	0	0	0	50	50	1
Alectra avensis	48	0	0	0	48	1
Dioscorea glabra	7	32	0	0	39	2
Solanum nigrum	12	0	20	7	39	3
Blumea balsamifera	37	0	0	0	37	1
Galinsoga parviflora	17	0	10	10	37	3
Triumfetta pilosa	7	30	0	0	37	2
Triumfetta rhomboidea	0	0	3	33	36	2
Trichosanthes tricuspidata	0	0	0	33	33	1
Panicum notatum	7	17	0	7	31	3
Setaria palmifolia	17	10	0	0	27	2

Species	F98	C98	F97	C97	Total	No. of plots recorded
Buddleja asiatica	25	0	0	0	25	1
Oroxylum indicum	7	0	0	17	24	2
Paspalum conjugatum	8	3	13	0	24	3
Millettia pachycarpa	0	0	0	23	23	1
Oxalis corniculata	3	0	20	0	23	2
Anaphalis margaritacea	12	8	0	0	20	2
Desmodium heterocarpon	5	15	0	0	20	2
Dioscorea alata	0	10	0	10	20	2
Solanum torvum	3	7	0	10	20	3
Seteria verticillata	0	17	0	0	17	1
Alpinia malaccensis	13	3	0	0	16	2
Sporobolus diander	13	0	3	0	16	2
Boehmeria chiangmaiensis	0	3	0	10	13	2
Neyraudia reynaudiana	13	0	0	0	13	1
Sida rhombifolia	0	0	3	10	13	2
Sonchus oleraceus	13	0	0	0	13	1
Acacia megaladena	2	10	0	0	12	2
Carex baccans	2	0	0	10	12	2
Eugenia albiflora	7	5	0	0	12	2
Asparagus filicinus	10	0	0	0	10	1
Cissampelos hispida	0	0	0	10	10	1
Commelina benghalensis	0	0	0	10	10	1
Dioscorea prazeri	0	10	0	0	10	1
Merremia vitifolia	0	0	0	10	10	1
Urena lobata	2	5	3	0	10	3
Desmodium velutinum	0	5	0	3	8	2
Pterocarpus macrocarpus	8	0	0	0	8	1
Aneilema sinicum	7	0	0	0	7	1
Arthraxon castratus	7	0	0	0	7	1
Boehmeria diffusa	0	0	0	7	7	1
Borreria laevis	7	0	0	0	7	1
Murdannia scapiflora	7	0	0	0	7	1
Rauvolfia verticillata	0	0	0	7	7	1
Capillipedium parviflorum	3	0	3	0	6	2
Argyreia aggregata	0	5	0	0	5	1
Embelia sessiliflora	0	5	0	0	5	1
Entada rheedii	0	5	0	0	5	1
Gmelina arborea	0	5	0	0	5	1
Helicteres elongata	0	5	0	0	5	1
Ixora cibdela	5	0	0	0	5	1
Kuniwatsukia cuspidata	5	0	0	0	5	1
Maesa montana	0	5	0	0	5	1
Melastoma normale	2	3	0	0	5	2
Paris polyphylla	0	5	0	0	5	1
Saccolepis indica	5	0	0	0	5	1

Species	F98	C98	F97	C97	Total	No. of plots recorded
Smilax perfoliata	5	0	0	0	5	1
Sterculia villosa	0	5	0	0	5	1
Abrus pulchellus	0	3	0	0	3	1
Castanopsis argyrophylla	0	3	0	0	3	1
Codonopsis javanica	0	3	0	0	3	1
Dalbergia stipulacea	3	0	0	0	3	1
Firmiana colorata	0	3	0	0	3	1
Laggera pterodonta	3	0	0	0	3	1
Pteris biauria	3	0	0	0	3	1
Schima wallichii	0	3	0	0	3	1
Vernonia divergens	3	0	0	0	3	1
Aporusa villosa	2	0	0	0	2	1
Argyreia obtecta	2	0	0	0	2	1
Chamaecrista leschenaultiana	2	0	0	0	2	1
Crotalaria dubia	2	0	0	0	2	1
Cyrtococcum accrescens	2	0	0	0	2	1
Eleusine indica	2	0	0	0	2	1
Embelia subcoriacea	2	0	0	0	2	1
Erythrina suberosa	2	0	0	0	2	1
Mussaenda parva	2	0	0	0	2	1
Paederia wallichii	2	0	0	0	2	1
Phyllanthus urinaria	2	0	0	0	2	1
Wendlandia scabra	2	0	0	0	2	1
Total	1 615	1 202	824	1 087	4 728	
Total number of species	75	51	28	37	103	

* Percent cover average X 100

Considering diversity indices of the ground flora (Table 8) shows that plot F98 had higher species richness (75), more abundant (N1 = 32.16) and very abundant (N2 = 19.12) species, and a more even distribution of ground flora species (E5 = 0.61) than plot C98. It can be explained that coming up of ground flora species in F98 plot would be affected from weeding which produced gaps in the herbaceous ground flora, allowing the establishment of a wider range of species. Five species, *Ageratum conyzoides, Conyza sumatrensis, Bidens pilosa, Crassocephalum crepidiodes* and *Rhynchelytrum repens,* became especially abundant in the framework plots but less abundant in the control plots (Table 8). Most of them (except *Rhynchelytrum repens*, Gramineae) are fast-growing annual herbs in the family Compositae, with small seeds that readily germinate on exposed soil after weeding. Therefore, they can survive and flourish even in frequently weeded plots. Planting trees and associated activities, especially weeding, probably caused an increase in abundance of these ground flora species. Weeding removed dominant herbs and created patches of bare earth which favoured seed germination of these species.

The abundant ground flora species in the control plots were *Pteridium aquilinum* (Dennstaedtiaceae), *Mucuna bracteata* (Leguminosae, Papilionoideae) and *Clerodendrum glandulosum* (Verbenaceae). These ground flora species are perenial herbs which were not weeded in the control plots, so their percent cover was higher than in the planted plots.

Table 9. Species richness, diversity (Hill's number) and evenness (modified Hill's ratio) in the four plots

Plot	Species richness	Species diversity		Evenness (E5)
		N1	N2	
F98	75	32.16	19.12	0.61
C98	51	21.20	10.92	0.49
F97	28	15.70	10.62	0.66
C97	37	19.22	11.51	0.58

For 1997 plots, the richness and diversity of ground flora species in plot C97 were higher than in plot F97, and also had a greater number of abundant (N1 = 19.22) and very abundant species (N2 = 11.51). However, C97 had fewer very common species because the evenness index of ground flora (E5 = 0.58) was less than in plot F97 (E5 = 0.66). Moreover, three ground flora species, *Eupatorium adenophorum* (Compositae), *E. odoratum* (Compositae) and *Setaria parviflora* (Gramineae), were very abundant in plot C97 and less abundant in plot F97 (Table 8). This result was inverted in the 1998 plots since these species were less abundant in plot C98 and most abundant in plot F98. These results might indicate that these species are affected by fire, because there was partial fire in plots F97 and C97. It means that these three ground flora species were very abundant after tree planting and weeding, but their abundances decreased after fire occurred.

Considering the five most abundant ground flora species in the 1997 and 1998 plots (Table 10), the most dominant ground flora species in the 1998 plots (except *Phragmites vallatoria*, Gramineae) were quite different. So by eye, the plots appeared very different. Also there were completely different abundances in ground flora species in the 1997 plots. It means that the main ground flora compositions of plant communities changed after tree planting and weeding. Comparing the five most abundant ground flora species between the planted and control plots, there were three species, viz. *Ageratum conyzoides* (Compositae), *Conyza sumatraensis* (Compositae) and *Mitracarpus villosus* (Rubiaceae), found in the planted plots, but only one ground flora species (*Pteridium aquilinum*, Dennstaedtiaceae) was found in the control plots (Table 10). It means that even though there were no tree planting and any activities in the control plots, the main ground flora composition of plant communities changed after fire occurred.

Table 10. The five most abundant ground flora species found in each plot

Plot	Abundant species	Per cent cover average
F98	*Ageratum conzoides*	208
	Mitracapus villosus	150
	Conyza sumatraensis	122
	Eupatorium adenophorum	110
	Phragmites vallatoria	107
C98	*Pteridium aquilinum*	260
	Imperata cylindrica	150
	Thysanolaena latifolia	100
	Phragmites vallatoria	90
	Microstegium vagans	73
F97	*Pennisetum polystachyon*	193
	Bidens pilosa	87
	Ageratum conyzoides	67
	Conyza sumatraensis	60
	Mitracarpus villosus	47
C97	*Mucuna bracteata*	220
	Pteridium aquilinum	167
	Eupatorium adenophorum	103
	Cyperus cyperoides	57
	Mimosa diplotricha	50

Similarity and difference indices

Different methods of measuring similarity and difference coefficients yield different results. Between plots C98 and C97, the similarity coefficient was lowest (0.43, indicating less similarity, Table 11), but CRD was also lowest (1.00, indicating less difference, Table 12). The highest similarity coefficient was in plot pair F97 and C97, but they had CRD (1.16) higher than the plot pairs F98 and F97 (1.01), and C98 and C97 (1.00). Only the plot pair F98 and F97 had a high similarity coefficient (indicating high similarity) and also low CRD (indicating less difference). These contradictory differences in results are common when using Sorensen's index and CRD. Sorensen's index is a great advantage in terms of rapid assessment, but it does not take into account the abundance of each species. CRD does take into account relative abundance of different species. In this survey, the biggest differences occurred between the dominant or abundant species and these are given more weight when using CRD. However, Sorensen's index and CRD should be used together in vegetation analysis to find the similarities between communities and to get more accurate results.

Table 11. Similarity coefficients (Sorensen's Index) of ground flora in all four plots.

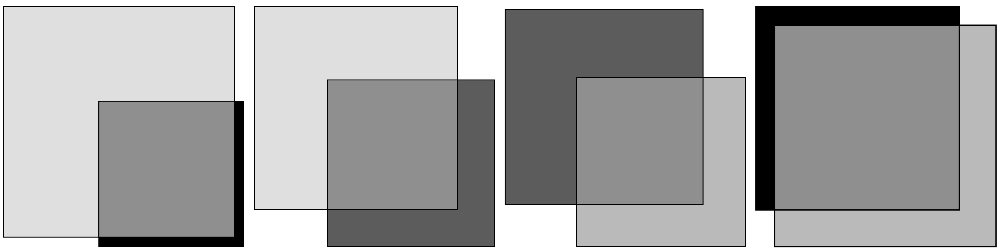
Experimental plot pairs	A	B	C	2C/(A+B)
F98-C98	75	51	31	0.49
F98-F97	75	28	26	0.50
C98-C97	51	37	19	0.43
F97-C97	28	37	21	0.65

Table 12. Chord distances (CRD) between four experimental plots in plot x plot matrix form (ground flora)

Plot	C98	F97	C97
F98	1.20	1.01	1.24*
C98		1.34*	1.00
F97			1.16
C97			

Remark: * this value is not discussed because there is no point to compare the control plot from one year with the planted plot from another.

In addition, ground flora species overlap diagrams were made to visualize changes during the succession process in each experimental plot pair (Figure 2). In plot pair F98 and C98, CRD was highest (1.20, indicating less similar, Table 12). Plot F98 accumulated more ground flora species than plot C98 which was also observed from the residual yellow in plot F98 compared with the remaining blue area in plot C98. This means that tree planting and weeding caused a gradually shifting of the ground flora to a different composition. Also the ground flora composition was fairly different in plot pair C98 and C97, with no tree planting and weeding. However, the difference was reduced after planting which could be noticed from plot pair F98 and F97. Plot F98 accumulated more ground flora species than plot F97. The number of ground flora species in plot F97 was a smaller subset of essentially the same ground flora species as in plot F98. It means that the number of ground flora species increased after tree planting and weeding. Although fire occurred in plot F97, the number of ground flora species did not change. Most of the ground flora species in plot F97 were also found in plot F98. In plot pair F97 and C97, the similarity coefficient of ground flora species was highest (0.65, Table 11). This result was probably caused by fire, because the succession process was the same in both plots, although the dominant ground flora species were different. Before fire occurred, the dominant herbaceous weeds in the 1997 plots were *Conyza sumatrensis* and *Cyperus cyperoides*, and also with very common species, e.g. *Bidens pilosa*, *Crassocephalum crepidioides*, *Solanum nigrum* and *Triumfetta pilosa*. After fire occurred, *B. pilosa* and *C. sumatrensis* were still found as the dominant herbaceous weeds in plot F97, but the dominant ground flora species changed in plot C97 (only *C. cyperoides* was found, Table 10). *Bidens pilosa* was still found in plot F97, because it is an annual herb and common in abandoned areas and silvicultural plots (Saelee 2000).



Plots F98-F97 Plots F98-C98 Plots C98-C97 Plots F97-C97

Figure 2. Ground flora species overlap diagrams from Sorensen's Index in the four plots

Naturally established trees

A total of 49 species of naturally established seedlings, saplings, and mature trees were found in both circle plots and walking surveys (Table 13). One hundred and forty-two individuals of naturally established trees were recorded. The most common naturally established tree species recorded was *Litsea cubeba*. The species richness of naturally established seedlings, saplings and mature trees was highest in plot F98, which also had the second highest total number of individuals.

Table 13. Numbers of naturally established tree species recorded at each plot

Species	F98	C98	P7	C97	Total	No. of sites recorded
Naturally established trees (h > 1 m)						
Litsea cubeba	7	20	0	0	27	2
Acacia megaladena	9	7	0	0	16	2
Albizia chinensis	9	5	0	0	14	2
Glochidion sphaerogynum	2	5	0	0	7	2
Gmelina arborea	0	5	0	1	6	2
Markhamia stipulata	0	5	0	0	5	1
Antidesma acidum	3	1	0	0	4	2
Prunus persica	0	0	2	2	4	2
Albizia odoratissima	0	1	1	1	3	3
Dillenia parviflora	0	3	0	0	3	1
Melia toosendan	2	1	0	0	3	2
Eugenia albiflora	1	2	0	0	3	2
Artocarpus gomezianus	2	0	0	0	2	1
Berrya mollis	2	0	0	0	2	1
Buddleja asiatica	1	0	1	0	2	2
Castanopsis armata	0	2	0	0	2	1
Erythrina suberosa	1	1	0	0	2	2
Phoebe lanceolata	2	0	0	0	2	1
Phylanthus emblica	1	1	0	0	2	2
Pterocarpus macrocarpus	2	0	0	0	2	1
Schima wallichii	1	1	0	0	2	2
Wendlandia tinctoria	1	1	0	0	2	2
Lagerstroemia speciosa	0	0	1	0	1	1
Aporusa dioica	1	0	0	0	1	1
Aporusa villosa	1	0	0	0	1	1
Boehmeria chiangmaiensis	0	1	0	0	1	1
Bridelia glauca	0	0	1	0	1	1
Callicarpa arborea	0	1	0	0	1	1
Clerodendrum glandulosum	1	0	0	0	1	1
Cratoxylum formosum	0	1	0	0	1	1
Dalbergia discolor	1	0	0	0	1	1
Dalbergia stipulacea	0	1	0	0	1	1
Dillenia pentagyna	1	0	0	0	1	1
Diospyros glandulosa	1	0	0	0	1	1
Fernandoa adenophylla	1	0	0	0	1	1

Species	F98	C98	P7	C97	Total	No. of sites recorded
Ficus hispida	0	1	0	0	1	1
Firmiana colorata	1	0	0	0	1	1
Garuga pinnata	1	0	0	0	1	1
Glochidion eriocarpum	1	0	0	0	1	1
Helicia nilagirica	1	0	0	0	1	1
Ixora cibdela	1	0	0	0	1	1
Maesa montana	0	1	0	0	1	1
Michelia baillonii	0	1	0	0	1	1
Mussaenda parva	0	1	0	0	1	1
Phoebe sp.	0	0	0	1	1	1
Securinega virosa	0	1	0	0	1	1
Sterculia villosa	0	1	0	0	1	1
Stereospermum colais	1	0	0	0	1	1
Turpinia pomifera	0	1	0	0	1	1
Total number of individuals	59	72	6	5	142	
Total number of species	29	27	5	4	49	

In order to find out if forest restoration activities increase naturally established seedlings, saplings, and mature trees, the rate of seedling establishment between the first and last surveys must be compared (Table 14). Only planted trees taller than one meter were considered in this analysis because they have high potential to develop into saplings and trees, and finally contribute to be the structure of the re-established forest. Naturally established trees were surveyed in both circle sample plots and walking surveys, but planted trees were recorded only in circle sample plots.

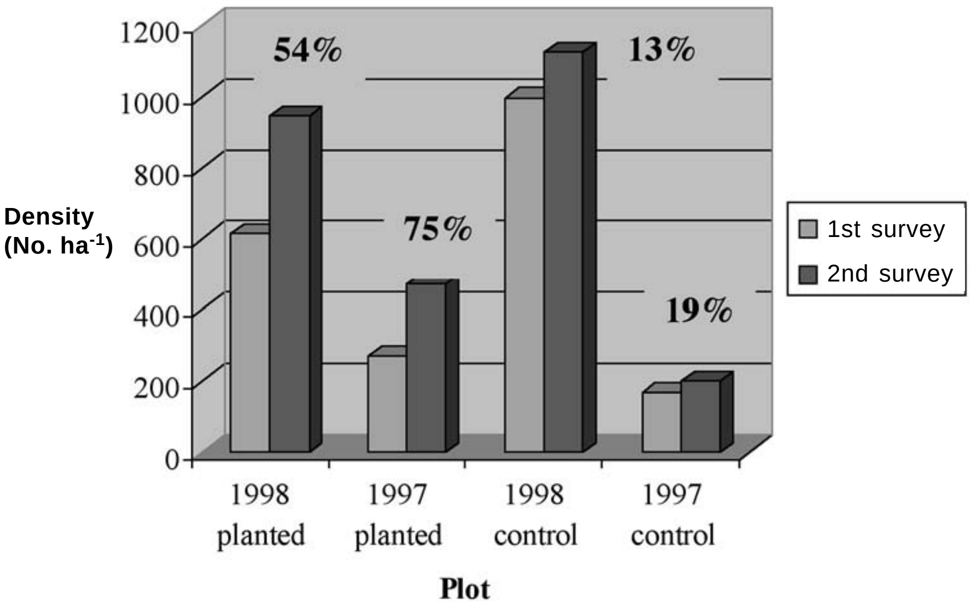


Figure 3. Density of naturally established trees in all surveys

The numbers of species of naturally established trees in the plots with planted framework trees (F) and control (C) in the first survey in summer were equal (Total C = 23, Total F = 23) but the F plots had accumulated more species than the C plots by the last survey in November (Total C = 29; increased 6 species, Total F = 33; increased 10 species). Considering density (Figure 3), the C plots had a higher density (728 No. ha^{-1}) than the F plots (528 No. ha^{-1}) in both the first and last surveys, but the F plots had a higher % rate of increase (830 No. ha^{-1}; increased 57.20%) than the C plots (867 No. ha^{-1}; increased 19.09%). Therefore, not only did tree planting and associated activities increase the species diversity of ground flora, but it also increased the % density of naturally established trees in the 1998 plots.

Similarly plots F98 and C98 showed that the numbers of species of naturally established trees in the first survey were equal (plot C98 = 22, plot F98 = 22), but by the last survey, plot F98 had more species than plot C98 (plot C98 = 27; increased 5 species, plot F98 = 29; increased 7 species). As for density, plot F98 had a higher % rate of increase (946 No. ha^{-1}; an increase of 54.32%) than plot C8 (1 126 No. ha^{-1}; an increase of 13.05%) although plot C98 retained a higher density throughout the study.

In plots F97 and C97, which were partially burnt, only 3 and 2 naturally established tree species respectively were recorded in the first survey, but by the last survey plot F97 had more species than plot C97, even though the increase in species was equal (plot C97 = 2; increased 2 species, plot F97 = 5; increased 2 species). Due to the disappearance of *Prunus persica* (2 individuals, an introduced fruit tree species planted by villagers) in the third walking survey in plot C97, density decreased (201 No. ha^{-1}) and to less than that in plot F97 (473 No. ha^{-1}). Furthermore, 2 other species were found in the last walking survey in plot C97, so the number of species found in this case was 3 (Table 13), but the total species found in all surveys was 4 (Table 7).

Framework tree species

Forty-nine individuals of 13 species of framework tree species taller than one meter were recorded in both plots F98 and F97 (Table 15). The most common planted tree species found was *Hovenia dulcis* (6 individuals). The total density of planted trees was 1 698 No. ha^{-1}. Plot F98 had less density (1 528 No. ha^{-1}) than plot F97 (1 935 No. ha^{-1}) (Table 14).

Table 14. Densities and numbers of species of planted (h >1 m) and naturally established trees found in circle sample plots and walking surveys

	First survey, April 1999						Last survey, November 1999					
	Total C	**Total F**	**C98**	**F98**	**C97**	**F97**	**Total C**	**Total F**	**C98**	**F98**	**C97**	**F97**
Circle plots survey												
Naturally established trees												
Density (No. ha^{-1})	441	340	661	407	102	204	509	543	713	611	102	407
No. species	8	7	7	5	1	2	9	13	8	9	1	4
Framework trees												
Density (No. ha^{-1})	0	0	0	0	0	0	0	1698	0	1528	0	1935
No. species	0	0	0	0	0	0	0	23**	0	13	0	13
Total												
Density (No. ha^{-1})	441	305	661	357	102	204	509	2241	713	2139	102	2342
No. species	8	7	7	5	1	2	9	35*	8	21	1	18
Walking surveys												
Naturally established trees												
Density (No. ha^{-1})	287	223	335	256	66	66	358	287	413	335	99	66
No. species	20	18	19	17	1	2	25	23	24	22	2 ***	2
Total of naturally established trees in circle plots and walking surveys												
Density (No. ha^{-1})	728	528	996	613	168	270	867 (+19.09 %)	830 (+57.20 %)	1126 (+13.05 %)	946 (+54.32 %)	201 (+19.64 %)	473 (+75.19 %)
No. species	23	23	22	22	2	3	29	33	27	29	3 ***	5

Remark * Planted tree and naturally established tree species were the same.
** Planted tree species in plots 1998 and 1997 were the same.

Table 15. Number of planted tree species recorded at each plot

Species	F98	C98	F97	C97	Total
Planted trees (h> 1m)					
Hovenia dulcis	4	0	2	0	6
Prunus cerasoides	3	0	2	0	5
Bischofia javanica	3	0	0	0	3
Gmelina arborea	2	0	1	0	3
Heynea trijuga	0	0	3	0	3
Manglietia garrettii	3	0	0	0	3
Melia toosendan	3	0	0	0	3
Sarcosperma arboreum	3	0	0	0	3
Erythrina suberosa	2	0	0	0	2
Phoebe lanceolata	0	0	2	0	2
Quercus semiserrata	2	0	0	0	2
Sapindus rarak	1	0	1	0	2
Spondias axillaris	2	0	0	0	2
Bridelia glauca	0	0	1	0	1
Castanopsis acumminatissima	0	0	1	0	1
Diospyros glandulosa	1	0	0	0	1
Ficus benjamina	0	0	1	0	1
Ficus subulata	0	0	1	0	1
Glochidion kerrii	0	0	1	0	1
Helicia nilagirica	1	0	0	0	1
Cinnamomum iners	0	0	1	0	1
Markhamia stipulata	0	0	2	0	2
Total number of individuals	30	0	19	0	49
Total number of species	13	0	13	0	0

Relative growth rate (RGR)

Most of the planted trees and naturally established seedlings species grew well. Weeding and fertilizing might have caused the differences in RGR between the planted and naturally established trees. The native tree species with the highest RGR was *Melia toosendan* (181.21 cm $cm^{-1}year^{-1}$) followed by *Manglietia garrettii* (175.24 cm $cm^{-1}year^{-1}$), *Diospyros glandulosa* (174.60 cm $cm^{-1}year^{-1}$) and *Sapindus rarak* (170.84 cm $cm^{-1}year^{-1}$). Surprisingly, *Erythrina subumbrans*, usually a fast-growing tree species, had low RGR in this survey, because most of individuals had their shoots broken by wind. Although most naturally established tree species grew well, their RGR were lower than those of planted tree species. Only two planted framework tree species, viz. *Gmelina arborea* and *Markhamia stipulata*, had higher RGR than those of naturally established trees of the same species. Therefore, weeding and applying fertilizer caused the increased RGR of these two tree species.

Health average and % survival rate

The health of natural and planted tree species was very good. The natural and planted tree species had high % survival rate except some planted tree species which were recorded as dead in the first survey, viz. *Garcinia mckeaniana*, *Nyssa javanica*, *Phoebe lanceolata* and *Aphanamixis polystachya*. However, *P. lanceolata* and *A. polystachya* were found in the other circle plots and in the other surveys, but *G. mckeaniana* and *N. javanica* were found just in the first survey. The % survival rate of *G. mckeaniana* and *N. javanica* could not be compared and should not be planted in this area. Furthermore, there was coppicing in many individuals of *Buddleja asiatica* (h < 1 m, treelet) only in plot P98 in all three walking surveys. Tree planting with weeding and fire protection probably caused this result.

CONCLUSION AND RECOMMENDATIONS

It could be concluded that:

1. In the first year after tree planting, the species richness and evenness of the ground flora in plot F98 increased when compared with plot C98, probably because weeding removed dominant perennial herbs, allowing invasion of plot F98 by annual herbs, especially of the family Compositae.
2. Two years after planting, the diversity of the ground flora species in plot F97 decreased because the planted tree canopy closed, which also shaded out and reduced opportunities for establishment of new species of ground flora. Ground flora diversity was higher in plot C97, but evenness was lower than in plot F97.
3. Weeding and fertilizing accelerated the establishment of natural seedlings and increased natural plant density in the planted plots, although the increase in species of naturally established seedlings was equal in the 97 plots and the numbers of natural tree species found did not differ significantly in both the 1998 and 1997 plots.
4. Most planted native tree species were in good health and growing fast. All of them, excluding *Nyssa javanica* and *Garcinia mckeaniana*, were suitable and proper species to plant for forest restoration in this area.

We should consider the value of biodiversity and ecology when we wish to restore the forest. The results showed that planting native trees with associated fire protection, weeding, and fertilizer application not only encouraged the establishment of natural seedlings, but also increased the diversity of ground flora species. Although this research was a preliminary study, the success of forest restoration will be recorded if the project is monitored continuously for at least three years. This research shows one way of accelerating forest succession. In other forest restoration projects, native tree species should be studied in other areas to find potential framework species in those areas before making decisions to restore the forest. Also after-care techniques, i.e. fire protection, weeding in the rainy season and applying fertilizer, should be considered and applied to support the growth and survival of planted and naturally established trees.

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