EVALUATION OF ALTERNATIVE APPROACHES TO RAINFOREST RESTORATION ON ABANDONED PASTURELANDS IN TROPICAL NORTH QUEENSLAND, AUSTRALIA

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Received 25 April 2003; Revised 3 September 2003; Accepted 25 September 2003

INTRODUCTION

Approximately 50 per cent of the 36 000 km² of the pristine tropical rainforest in far north Queensland, Australia, has been logged for grazing and other agricultural activities. During the last three to four decades some grazed pasturelands have been abandoned due to low productivity and have been left for natural reforestation. Natural recruitment of native tropical rainforest species in abandoned pasturelands is a very slow process (Aide *et al.*, 1995;

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Chapman and Chapman, 1996). Natural recruitment in deforested and abandoned land is dependant on previous land-use pattern (Uhl *et al.*, 1988; Aide and Cavelier, 1994), soil seed bank depletion due to repeated burning (Uhl *et al.*, 1982, 1988; Nepstad *et al.*, 1991) and the non-attraction of frugivores that can bring native tropical rainforest species seeds to these areas (Chapman and Chapman, 1996). Though natural recruitment of seedlings has occurred in some instances, their subsequent survival and growth may be poor due to an inappropriate microenvironment and competition from weeds (Brown and Lugo, 1994). Therefore, planting native seedlings in abandoned lands has been proposed to accelerate reforestation process (Lugo, 1992; Aide *et al.*, 1995).

In general, two approaches have been followed in restoration programs. The first, direct seeding, is less expensive, but has the major disadvantages of poor germination, high mortality of seedlings, and severe weed competition (Evans, 1982). The second approach, transplanting seedlings raised in nurseries (Evans, 1982), is more widely followed in restoration programs. Planting seedlings raised in nurseries may help to accelerate the recovery process. Further, transplanting seedlings into abandoned or degraded lands can foster the establishment of species that exhibit different ecological characteristics features and that are capable of creating a favourable microclimate (by producing quick canopy closure). The seedling also can act as a 'bait' crop in attracting a frugivorous fauna, which can enhance the natural dispersal of seed on the site (Goosem and Tucker, 1995). Although the second approach has been widely followed, researchers and restoration groups are struggling to understand what species should be included in the restoration programs, and whether to use a single species or a group of native species from primary promoters, middle-phase species or mature-phase species.

Goosem and Tucker (1995) proposed two major types of tropical rainforest restoration for use in Australian systems: (1) the framework species method; and (2) the maximum species diversity method. In the framework species method, one or a group of fast growing species is planted to provide a dense canopy that will suppress weed species in a short period of time (approximately 1.5 to 2 years). The major advantages of this technique are: (1) it needs only a single planting; and (2) it is self-sustaining. However, this technique is only suitable to areas where native vegetation is located close by. In the maximum species diversity method, a larger percentage of species is from the mature phase and primary promoters are generally avoided. The major disadvantage is the slower growth rate of many mature-phase forest species, which requires intensive post-planting management. In this paper we examine the framework species method and maximum species diversity method. The objectives of this study were to investigate: (1) the success or failure of 502 forest seedlings belonging to 15 different species from 11 families planted approximately ten years ago; and (2) the influence of the different restoration techniques on enhancing natural recruitment during this period.

MATERIALS AND METHODS

Study Site

The study site (Figure 1) was located at the Centre for Rainforest Studies (CRS) which encompasses ~62 ha, on the Atherton Tableland, north Queensland, Australia (17° 15' 19" S, 145° 30' 59" E). The elevation is ~780 m a.s.l. and the mean annual rainfall is 1700 mm, mostly falling between December and May. The experimental plots were placed in a paddock that was clear felled ~60 years ago to provide pasture for beef cattle. The paddock was bounded on its north, south and west sides by ~40-year-old *Acacia* regrowth forest (~15 m from the experimental plots), which in turn is surrounded by ~40-year-old naturally regenerated rainforest on its northern, western and eastern sides (~400 m). This site was chosen mainly because it sloped at 10–12 per cent towards a creek, which was ~300–400 m away from the east and west borders. From north to south the experimental site was sloping at ~10–12 per cent and the southern border was ~300 m away from another creek. Before the clearing, this site was dominated by complex mesophyll type forest (Tracy, 1982). The paddock was abandoned in the 1970s. No natural recruitment has been successful and a number of grass species have invaded, including *Imperata cylindrica*, *Melinis minutiflora*, and *Panicum maximum*. The soil is mainly granitic and the pH range from 6.5 to 7.0.

Figure 1. Location of the study site.

Experimental Design and Species Used

The study area was divided into 10 plots each $17 \times 11 \text{ m}^2$ with a 5 m buffer zone between plots. A complete randomized block design was used, with two replications of the following five treatments (Figure 2):

- (1) Control (T1R1 & T1R2).
- (2) Framework species method, using only one pioneer species *Omalthus novo-guineensis* (T2R1 & T2R2).
- (3) Framework species method, using a group of pioneer species: *O. novo-guineensis* + eight primary-promoter species (T3R1 & T3R2).
- (4) Framework species method, using a group of pioneer species: *Alphitonia petriei* + eight primary-promoter species (T4R1 & T4R2).
- (5) Maximum species diversity method, using a group of primary promoters, middle-phase species and mature-phase species (T5R1 & T5R2).

In each plot, 63 tropical rainforest seedlings from a single species or combinations of species were planted in randomly allocated positions. The species compositions for each plot are provided in Table I.

Figure 2. Plot layout.

Site Preparation

A week prior to the transplanting of seedlings, most above-ground foliage of the ground cover (mainly *Imperata cylindrica*, *Melinis minutiflora* and *Panicum maximum*) was removed from the plots with a slasher. To facilitate better root establishment, soil aeration and rainwater percolation, plots were ploughed to approximately 30 cm. In December 1993, seedlings holes were dug at 2 m intervals, 30 g of Crop King[®] 77(S) fertilizer was added before seedlings were planted. Immediately after transplanting seedlings received ~7 L of creek water and the ground around them was covered to ~5 cm thickness with hay mulch. The same quantity of water was added 6, 14, and 27 weeks after transplanting. Seedlings were fertilized as described above at 18 and 72 weeks after being transplanted.

Data Collection

Tree height and diameter

Tree height and diameter data were recorded in July 2001. Live tree height was taken with a tree pole and diameter was taken with digital calliper for trees >2 m in height and diameter was taken at 1.3 m d.b.h. Whether the plants were dead or alive were also recorded.

Seedlings

Each $11 \times 17 \text{ m}^2$ plot was further divided into 187, $1 \times 1 \text{ m}^2$ subplots. Corners of the plots were marked with coloured flagging tape on wire stakes. Within each subplot all seedlings recruited naturally were located, marked with a numbered metal tag and identified.

Canopy cover and grass cover

Canopy cover was estimated in east–west directions at 1 m intervals in belt transects conducted in an east–west direction across plots. Each transect constituted one side of a continuous series of $1 \times 1 \text{ m}$ plots. Within each of these plots, grass and crown cover were estimated using the Braun-Blanquet cover abundance scale.

Statistical analysis

Data were analyzed by one-way ANOVA using SuperANOVA[®] software (Abacus Concepts, Berkley, CA). Residual plots of each ANOVA were obtained to examine the homogeneity of variance. Based on residual plots,

Table 1. Numbers of species planted (survived) during the restoration technique followed for this study

Primary-promoter species	Family	Height (m)	Fruit type	Dispersal agent	T2R1	T2R2	T3R1	T3R2	T4R1	T4R2	T5R1	T5R2
<i>Acronychia acidula</i>	Rutaceae	20–25	Fleshy	Mammal			5 (5)	5 (5)	5 (5)	5 (4)	2 (2)	2 (2)
<i>Alphitonia petriei</i>	Rhamnaceae	10–15	Capsule	Bird/mammal			—	—	23 (22)	23 (20)	2 (2)	2 (2)
<i>Castanospermum albandii</i>	Fabaceae	40–45	Capsule	Mammal			5 (1)	5 (4)	5 (0)	5 (1)	2 (1)	2 (1)
<i>Cryptocarya triplinervis</i>	Lauraceae	30–35	Fleshy	Mammal			5 (2)	5 (5)	5 (3)	5 (5)	2 (0)	2 (2)
<i>Elaeocarpus angustifolius</i>	Elaeocarpaceae	35–40	Fleshy	Bird			5 (5)	5 (5)	5 (4)	5 (5)	2 (2)	2 (2)
<i>Euroschinus falcata</i>	Anacardiaceae	25–30	Capsule	Bird			5 (5)	5 (0)	5 (5)	5 (3)	2 (0)	2 (0)
<i>Guioa acutifolia</i>	Sapindaceae	18–20	Capsule	Bird			5 (4)	5 (3)	5 (3)	5 (2)	2 (2)	2 (2)
<i>Oncalanthus novo-guineensis</i>	Euphorbiaceae	3–5	Capsule	Bird	63 (45)	63 (43)	23 (17)	23 (16)	—	—	2 (0)	2 (2)
<i>Ptilidostigma tropicum</i>	Myrtaceae	20–25	Fleshy	Bird			5 (0)	5 (0)	5 (0)	5 (0)	2 (0)	2 (0)
<i>Terminalia sericocarpa</i>	Combretaceae	15–20	Fleshy	Bird/bat			5 (5)	5 (3)	5 (5)	5 (5)	2 (2)	2 (2)
Per cent survival											75	75
Middle-phase species												
<i>Agathis robusta</i>	Araucariaceae	50–55	Cone	Wind							3 (3)	3 (3)
<i>Brachychiton acerifolius</i>	Sterculiaceae	10–12	Capsule	Bird							3 (3)	3 (3)
<i>Cardwellia sublimis</i>	Proteaceae	15–20	Follicle	Wind							3 (3)	3 (2)
<i>Flindersia bourjoiana</i>	Rutaceae	30–35	Woody capsule	Wind							3 (3)	3 (3)
<i>Flindersia pimentelliana</i>	Rutaceae	30–35	Woody capsule	Wind							3 (3)	3 (3)
<i>Melicope elleryana</i>	Rutaceae	12–15	Capsule	Bird							3 (3)	3 (3)
<i>Symplocos cochinchinensis</i>	Symplocaceae	10–15	Fleshy	Bird							3 (3)	3 (1)
Per cent survival											100	85
Mature-phase species												
<i>Argyrodendron peralatum</i>	Sterculiaceae	20–30	Winged	Wind							3 (1)	3 (3)
<i>Cinnamomum laubatii</i>	Lauraceae	30–35	Fleshy	Bird							3 (2)	3 (2)
<i>Cryptocarya hypospodia</i>	Lauraceae	25–30	Fleshy	Bird							3 (3)	3 (3)
<i>Prunus turnerana</i>	Rosaceae	30–35	Fleshy	Mammal							3 (0)	3 (0)
<i>Syzygium papyraceum</i>	Myrtaceae	25–30	Fleshy	Bird							3 (0)	3 (1)
<i>Syzygium wesa</i>	Myrtaceae	20–25	Fleshy	Bird							3 (0)	3 (0)
<i>Toona ciliata</i>	Meliaceae	20–25	Capsule	Wind							3 (3)	3 (3)
Per cent survival											42	57
Total survived					63 (45)	63 (43)	63 (44)	63 (41)	63 (48)	63 (45)	62 (41)	62 (45)
Per cent of total survived					71	68	69	65	76	71	66	72

data were transformed to log or square root as appropriate and reanalyzed. Means were compared using Tukey's HSD comparison (Day and Quinn, 1989).

RESULTS

Survival Rates

The survival rate of planted seedlings varied across the treatment plots. Approximately ten years after the restoration in the abandoned pasture, the survival rate ranged from 65 to 75 per cent of primary-promoter species, 85 to 100 per cent of middle-phase species and 42 to 57 per cent of mature-phase species.

Primary Promoter Species

Of 126 *Omalanthus novo-guineensis* Planted in Treatment 2 only 71 and 68 per cent survived in Replicates 1 & 2 respectively. The survival rate of the individual primary-promoter species varied within Treatment 3. A similar trend was observed in Treatment 4. Although an equal percentage of seedlings had survived in Treatment 5, Replicates 1 and 2, but no *Eurochinus falcata* survived in Replicate 1, and no *Pilidiostigma tropicum* seedlings survived in either replicate.

Middle-phase Species

Seven middle-phase species were included in Treatment 5. In Replicate 1 there was 100 per cent survival rate. By contrast, only 85 per cent of plants survived in Replicate 2. In Treatment 5, Replicate 2, *Cardwellia sublimis* and *Symplocos cochinchinensis* had lost 4 per cent and 9 per cent of their seedlings respectively.

Mature-phase Species

Along with ten primary and seven middle-phase species, a total of seven mature-phase species was also included in Treatment 5. In both replicates a poor survival rate of mature-phase species was observed. In Replicate 1, no seedlings of the *Prunus turnerana* and *Syzygium wesa* survived. All *C. hypospodi* and *Toona ciliata* had survived in Replicates 1 and 2.

Height and Diameter Distribution

The mean height (m) and diameter (mm) of survived seedlings are given in the Tables II and III. The height distribution of primary-promoter species ranged from 0.8 (*C. alphandii*, T3R2) to 9.82 m (*A. petriei*, T5R2). Diameters ranged from 5.8 mm (*C. triplinervis*, T5R2) to 145 mm (*A. petriei*, T5R1). The mean height and diameter range of primary-promoter species for each plot showed an interesting trend. The mean height and diameter ranged from 3.50 (s.d. ± 1.54 ; T3R2) to 6.11 (s.d. ± 4.04 , T5R2). The lowest mean diameter was recorded for the plot T4R2, with 31.52 (s.d. ± 15.78) and the highest mean diameter was recorded in the T2R1 plot (57.20 s.d. ± 20.89).

Although the mean height of middle-phase species was less than that of primary-promoter species, the overall mean heights of middle-phase species in T5R1 and R2 were higher. The smallest tree was *B. acerifolius* (3.22 ± 0.94 , $n = 3$) and the tallest tree was *C. sublimis* (8.68 ± 0.30 , $n = 2$). Overall mean height was 6.51 ± 23.18 , $n = 7$ and 6.58 ± 1.82 , $n = 7$, for T5R1 and T5R2 respectively. Similarly, the overall mean diameter of the middle-phase species is higher than that of primary-promoter species. The mean diameter was 66.38 ± 23.18 , $n = 7$ and 52.90 ± 20.37 , $n = 7$, for T5R1 and T5R2 respectively.

Natural Seedling Recruitment

Natural seedling recruitment varied noticeably within and between treatments (Table IV). Fourteen species recruited naturally across the treatment plots. A total of 410 seedlings from 11 different families recruited naturally in the 10-year-old reforested site. The seedling density ha^{-1} ranged from 66 to 1697 ha^{-1} . The total number of species ranged from 2 to 10. The highest number of seedling recruitments (1697 ha^{-1}) was recorded in Treatment 3 where *O. novo-guineensis* and eight primary promoters were planted together. Species richness was greater in Treatment 3 (17 species) than in Treatment 2 (seven species).

Table II. Mean height (m) ($\pm$ s.d.) in 2001 of seedlings planted in 1982

Species	T2R1	T2R2	T3R1	T3R2	T4R1	T4R2	T5R1	T5R2
Primary-promoter species								
<i>A. acidula</i>			4.10 (0.69)	3.8 (0.53)	2.96 (1.58)	3.1 (1.13)	3.20 (0.72)	2.74 (0.79)
<i>A. petrei</i>					8.09 (1.88)	7.55 (2.41)	6.33 (3.89)	9.82 (0.24)
<i>C. albandii</i>			5.60 (0.86)	0.8 (0.68)	AD	1.58	AD	7.69
<i>C. triplinervis</i>			3.59 (1.09)	2.21 (0.64)	2.60 (0.85)	2.09 (0.79)	AD	2.20 (0.28)
<i>E. angustifolius</i>			9.51 (1.21)	5.31 (1.00)	8.24 (1.73)	7.79 (2.66)	7.55 (5.26)	13.49 (3.54)
<i>E. falcatus</i>			4.68 (0.83)	AD	2.77 (0.41)	3.66 (1.28)	6.22	AD
<i>G. acutifolia</i>			3.60 (1.16)	3.53 (1.28)	2.8 (0.60)	3.2 (0.70)	4.41 (1.23)	2.10 (0.68)
<i>O. novo-guineensis</i>	4.55 (1.35)	3.86 (1.35)	6.64 (0.90)	4.69 (1.17)	AD	AD	AD	5.63 (2.33)
<i>P. tropicum</i>			AD	AD	AD	AD	AD	AD
<i>T. sericocarpa</i>			5.13 (1.75)	4.21 (1.18)	6.26 (0.63)	4.36 (0.88)	7.18 (0.02)	5.26 (3.94)
Mean ($\pm$ s.d.)	4.55 (1.35)	3.86 (1.35)	5.35 (1.97)	3.50 (1.54)	4.81 (2.61)	4.53 (2.24)	5.85 (1.53)	6.11 (4.04)
Middle-phase species								
<i>A. robusta</i>							6.30 (1.57)	7.92 (1.70)
<i>B. acerifolius</i>							4.53 (0.90)	3.22 (0.94)
<i>C. sublimis</i>							8.56 (0.35)	8.68 (0.30)
<i>F. bourjoiana</i>							6.93 (1.28)	5.46 (1.43)
<i>F. pimentellana</i>							6.85 (3.95)	6.87 (4.62)
<i>M. elleryana</i>							8.0 (1.25)	6.31 (2.93)
<i>S. cochinchinensis</i>							4.30 (1.25)	7.65
Mean ($\pm$ s.d.)							6.51 (1.61)	6.58 (1.82)
Mature-phase species								
<i>A. perlatum</i>							4.10	2.56 (0.82)
<i>C. laubatii</i>							4.0 (0.09)	2.16 (1.64)
<i>C. hypospodia</i>							1.40 (1.33)	1.52 (0.92)
<i>P. turnerana</i>							AD	AD
<i>S. papyraceum</i>							AD	4.75
<i>S. wesa</i>							AD	AD
<i>T. ciliata</i>							AD	AD
Mean ($\pm$ s.d.)							5.12 (0.90)	3.57 (0.10)
Overall mean ($\pm$ s.d.)	4.55 (1.35)	3.86 (1.35)	5.35 (1.97)	3.50 (1.54)	4.81 (2.61)	4.53 (2.24)	5.59 (1.91)	3.26 (1.15)
								5.47 (3.12)

AD = All of the seedlings planted died.

Table III. Mean diameter (mm) ($\pm$ s.d.) in 2001 of seedlings planted 1982

Species	T2R1	T2R2	T3R1	T3R2	T4R1	T4R2	T5R1	T5R2
Primary-promoters								
<i>A. acidula</i>			40.44 (20.76)	37.02 (5.59)	26.79 (12.28) 94.26 (29.71)	24.88 (13.64) 49.36 (31.85)	25.64 (11.13) 145.08 (88.94)	24.91 (1.44) 144.78 (68.25)
<i>A. petrei</i>			16.42 (7.55)	8.13 (2.93)	AD	8.11	AD	52.67 (43.80)
<i>C. albandii</i>			32.14 (6.32)	15.09 (6.01)	16.18 (8.20)	12.50 (5.82)	AD	5.84 (1.02)
<i>C. triplinervis</i>			50.60 (44.85)	34.57 (7.34)	87.46 (21.08)	41.49 (28.72)	66.97 (51.79)	58.94 (61.00)
<i>E. angustifolius</i>			60.09 (15.56)		26.07 (8.73)	41.63 (21.38)	67.73	AD
<i>E. falcatus</i>			45.08 (31.56)	34.36 (14.27)	19.22 (3.29)	26.91 (9.14)	36.54 (7.90)	28.99 (8.67)
<i>G. acutifolia</i>			88.51 (15.22)	66.72 (14.68)	AD	AD	AD	31.56 (27.38)
<i>O. novo-guineensis</i>	57.20 (20.89)	49.62 (18.11)	AD	AD	AD	AD	AD	AD
<i>P. tropicum</i>			49.19 (19.38)	50.28 (12.30)	75.27 (10.25)	47.28 (10.22)	82.85 (19.09)	46.18 (29.01)
<i>T. sericocarpa</i>	57.20 (20.89)	49.62 (18.11)	47.84 (21.15)	35.16 (19.84)	49.32 (34.64)	31.52 (15.78)	54.34 (46.96)	43.61 (44.56)
Middle-phase species								
<i>A. robusta</i>							64.39 (14.25)	26.04 (2.75)
<i>B. acerifolius</i>							43.00 (12.24)	34.31 (26.26)
<i>C. sublimis</i>							90.96 (47.68)	83.4 (4.52)
<i>F. bourjoitiana</i>							60.95 (13.76)	59.77 (8.19)
<i>F. pimenteliana</i>							69.08 (47.62)	59.62 (1.26)
<i>M. elleryana</i>							100.00 (6.13)	67.74 (37.62)
<i>S. cochinchinensis</i>							36.32 (28.12)	39.43 (7.63)
Mean ($\pm$ s.d.)							66.38 (23.18)	52.90 (20.37)
Mature-phase species								
<i>A. perlatum</i>							26.54	15.94 (6.15)
<i>C. laubatii</i>							31.15 (6.10)	12.08 (8.87)
<i>C. hypospodia</i>							11.24 (4.81)	47.67 (6.46)
<i>P. turnerana</i>							AD	AD
<i>S. papyraceum</i>							AD	35.33 (0.0)
<i>S. wesa</i>							AD	AD
<i>T. ciliata</i>							AD	AD
Mean ($\pm$ s.d.)							67.71 (16.12)	36.03 (12.03)
Overall mean ($\pm$ s.d.)	57.20 (20.89)	49.62 (18.11)	47.84 (21.15)	35.16 (19.84)	49.32 (34.64)	31.52 (15.78)	34.16 (23.93)	29.41 (14.95)
							60.36 (33.06)	41.51 (31.53)

AD = All of the seedlings planted died.

Table IV. Natural recruitment of native species recorded in restored plots

Species	Family	Fruit type	Dispersal agent	COR1	COR2	T2R1	T2R2	T3R1	T3R2	T4R1	T4R2	T5R1	T5R2
<i>Acacia</i> sp.	Mimosaceae	Capsule	Bird/insect					23	98	9	6	74	
<i>Alphitonia petriei</i>	Rhamnaceae	Capsule	Bird/mammal	1	1				3	8	4		
<i>Alstonia muelleriana</i>	Apocynaceae	Capsule	Wind			2							
<i>Athertonia diversifolia</i>	Proteaceae	Fleshy	Mammal				2	3	1		1		
<i>Carrarvonnia aralifolia</i>	Proteaceae	Winged	Wind					1				1	
<i>Glochidion sessiliflorum</i> var. <i>pedicellatum</i>	Euphorbiaceae	Capsule	Bird	1	3	1	2	2	3			4	
<i>Guioa acutifolia</i>	Sapindaceae	Capsule	Bird										3
<i>Melastoma affine</i>	Melastomataceae	Fleshy	Bird		1				1			1	
<i>Mischocarpus lachnocarpus</i>	Sapindaceae	Capsule	Bird/bat/mammal	1	3			7					
<i>Neolitsea dealbata</i>	Lauraceae	Fleshy	Bird					1					
<i>Pittosporum venulosum</i>	Pittosporaceae	Capsule	Bird	3				1					
<i>Polyscias elegans</i>	Araliaceae	Capsule	Bird/insect	2				43	6	4	2	5	
<i>Rhodomyrtus pervagata</i>	Myrtaceae	Fleshy	Bird	1		1	1	21	15	1		3	7
<i>Stenocarpus sinuatus</i>	Proteaceae	Capsule	Wind							1			
Unidentified	—	—	—					7					
Total families				6	3	4	3	8	7	5	4	7	2
Total species				6	3	4	3	10	7	8	4	7	2
Total individuals				9	7	5	5	109	127	23	13	89	10
No. of individual per ha				120	93	66	66	1457	1697	307	173	1189	133
No. of species per ha				80	40	53	40	133	93	106	53	93	26
No. of individuals excluding <i>Acacia</i> sp. + <i>P. elegans</i>								574	307	133	66	133	

COR1 + COR2 = Control Replicates 1 & 2; T2R1 + T2R2 = Treatment 1, Replicates 1 & 2; T3R1 + T3R2 = Treatment 1, Replicates 1 & 2, and T5R1 + T5R2 = Treatment 1, Replicates 1 & 2.

Table V. Analysis of variance between treatments

Source	C	T2	T3	T4	T5	F-value	p
No. of families ($n = 2$)	4.5 $\pm$ 1.5	3.5 $\pm$ 0.5	7.5 $\pm$ 0.5	4.5 $\pm$ 0.5	4.5 $\pm$ 2.5	1.24	NS
No. of species ($n = 2$)	4.5 $\pm$ 1.5	3.5 $\pm$ 0.5	8.5 $\pm$ 1.5	6.0 $\pm$ 2.0	4.5 $\pm$ 2.5	1.26	NS
Natural recruitment ($n = 2$)	8.0 $\pm$ 1.0 ^b	5.0 $\pm$ 0.0 ^b	118.0 $\pm$ 9.0 ^a	18.0 $\pm$ 5.0 ^b	49.5 $\pm$ 39.5 ^{ab}	6.67	*
No. of natural recruitment without <i>Acacia</i> sp. & <i>P. elegans</i> ($n = 2$)	8.0 $\pm$ 1.0 ^b	5.0 $\pm$ 0.0 ^b	33.00 $\pm$ 10.0 ^a	7.5 $\pm$ 2.5 ^b	10.0 $\pm$ 0.00 ^b	6.15	*
Per cent of primary promoters survived ($n = 2$)	NA	69.5 $\pm$ 1.5	67.0 $\pm$ 2.0	73.5 $\pm$ 2.5	69.0 $\pm$ 3.0	1.38	NS
Per cent of grass cover	98.75 $\pm$ 0.85 ^a	95.93 $\pm$ 2.55 ^a	68.31 $\pm$ 8.7 ^b	64.37 $\pm$ 11.89 ^b	31.12 $\pm$ 9.95 ^c	11.67	***
Per cent of canopy cover	0 $\pm$ 0 ^c	7.5 $\pm$ 0.65 ^{bc}	35.06 $\pm$ 2.50 ^b	40.53 $\pm$ 2.53 ^b	80.00 $\pm$ 21.1 ^a	13.11	***

Values represent means $\pm$ standard error.

* $p < 0.05$; *** $p < 0.000$; NS indicates that means are not significantly different.

Different superscript letters indicate the means are significantly different.

NA = analysis is not applicable.

Since both *Acacia* spp. and *Polyscias elegans* were dominant in Treatments 3, 4 and 5, a separate calculation was performed without these species to examine the natural seedling recruitment density and species richness. Results showed that, even without those two species, Treatment 3 had a higher density than Treatments 4 and 5. The order of highest to lowest as follows: T3R1 (574 ha⁻¹) > T3R2 (307 ha⁻¹) > T4R1 (133 ha⁻¹) & T5R1 (133 ha⁻¹) > T4R2 (66 ha⁻¹).

With the exception of *Alphitonia petriei*, the 14 species were different from the transplanted species. Hence, these species must have been transported by agents such as birds, mammals, insects, bats and wind.

Analysis of variance on the numbers of families, species, seedlings recruited naturally, with and without *Acacia* sp. and *P. elegans*, found a significant difference. No significance difference was found either in the number of families or the number of species recruited naturally (Table V).

Grass Cover

The grass cover, mainly of *Melinis minutiflora* and *Panicum maximum*, differed in the planting regimes 8.5 years after the planting ($F = 11.67$; $p < 0.0001$). The maximum species diversity treatment had a lower grass cover than the control and other treatments. Grass cover tended to decline with increasing species diversity of seedlings. (Table V).

Canopy Cover

A significant difference in canopy cover was found between treatments ($F = 13.11$; $p < 0.0001$). The highest canopy cover was found in Treatment 5 where primary promoters, middle-phase and mature-phase species were planted together. Treatment 2 (T2), using the single species *O. novo-guineensis*, showed a very low canopy cover compared with other treatments. There was no significance difference between the canopy covers in Treatments 3 and 4 (Table V).

DISCUSSION

Approximately 10 years after restoration in an abandoned pasture, the seedling survival rate ranged from 65 to 75 per cent for primary-promoter species, 85 to 100 per cent for middle-phase species and 42 to 57 per cent for mature-phase species. None of the *P. tropicum* seedlings survived across the treatment plots. Significantly more seedlings of early successional species were recruited with the framework species method, where *O. novo-guineensis* was planted with eight primary-promoter species. Increasing the canopy cover reduced the grass cover. Although the survival rate varied between and within the treatments, that of middle-phase species planted with eight primary promoters and mature-phase species was higher than other treatments. As expected, poor survival rates were observed in the mature-phase species. It could be argued that the survival rate of the mature-phase

species could vary temporally and spatially, however, both replicates showed a similar trend. Though spatial variability could be the factor, it cannot account for the poor survival rates shown here. A likely explanation would be an unsuitable microclimate and microhabitats for the mature-phase species.

In general, forest succession is slower in abandoned pastures than in other natural and disturbed sites in the tropics (Aide *et al.*, 1995). Because of the short viability of seeds of tropical rainforest trees and shrubs, soil-stored seed-bank species composition in the abandoned pasture land may have been substantially depleted as early as one year after clearing (Garwood, 1989; Vazquez-Yanes and Orozco-Segovia, 1996). As expected, our restoration plots had a higher number of native species than the control plots. Tucker and Murphy (1997) found that seedlings recruited naturally in restored plots were either dispersed by birds or mammals, reflecting that these sites started to attract a faunal community that had a catalytic effect on rainforest species colonization. However, in the absence of data on soil-stored seed-bank species composition at the time of planting, it is difficult to claim that the seedlings that appeared in the restoration plots germinated after establishment of seedlings planted ten years ago. If that is the case, then there should not be any difference in species composition and density of seedlings recruited in different treatments. The seedling-recruitment data therefore suggests that different restoration techniques have an influence on the pattern of natural seedling recruitment because they differ in their attractiveness to seed dispersing animals.

Some species, such as *Acacia* sp. and *P. elegans*, may have germinated from the soil-stored seed bank. This is suggested mainly because a *P. elegans* tree was removed prior to the restoration and the restoration plots are surrounded by *Acacia* regrowth forest. Therefore, other species that have recruited from restoration plots could have been brought in by different agents, and it could also be suggested that the restoration plots started to provide suitable conditions for tropical rainforest species to germinate.

Some restoration techniques had a negligible effect on natural seedling recruitment, except in Treatment 2 where significantly higher numbers of seedlings were recruited. Little difference was detected between the control plots and Treatment 1, which used a single-species (*O. novo-guineensis*) framework method. However, the framework method using *O. novo-guineensis* with eight primary promoters (Treatment 2) led to 239 seedlings being recruited. However, 50, 36 and 74 per cent of those recruited seedlings in Treatments 2, 3 and 4 respectively, were *Acacia* spp. Hopkins and Graham (1984) found that the common nomads or early secondary tree species: *Polyscias* sp., *Acacia* sp., and *A. petriei* dominated in abandoned 30-year-old regrowth forests. Our study also indicates that *Polyscias* sp., *Acacia* sp., and *A. petriei* germinated in restored sites. In our experiment significant numbers of *Acacia* species recruited, possibly because the experiment plots were surrounded by ~40-year-old *Acacia* stand, ~10 to 15 m distance from their north, south and west sides. It is surprising to note that no *Acacia* seedlings recruited in the control plot and Treatment 1. This was possibly a consequence of the high grass cover present in these sites. This finding further emphasizes that, even after 40 years of abandonment, fast-growing pioneer species like *Acacia* will not establish easily. Further, although a large number of *O. novo-guineensis* seedlings were planted ten years ago, no *O. novo-guineensis* seedlings were found recruited across the treatment plots. This can be attributed to two factors: first, lack of seed production by planted *O. novo-guineensis* seedlings; and second, young *O. novo-guineensis* seedlings may be poor competitors. The latter seems the most likely reason for the apparent lack of *O. novo-guineensis* seedling recruitment.

The grass cover shows that considerable numbers of grass species seeds (*Melinis minutiflora* and *Panicum maximum*) are in the soil seed bank and they may continue to supply a significant amount of seed every flowering season. This would further delay the process of natural recruitments in these restored sites. The reforested site is surrounded by ~40-year-old regrowth forest at ~400 m distance, there is a possibility, therefore, that native tree species seeds may have disseminated into the restored sites. However, the lack of seedling establishment can be attributed to the thick grass cover present across the treatment, which may have prevented the seed from reaching the soil (Aide *et al.*, 1995). In addition, Whelan *et al.* (1991) found that in degraded grasslands seed predation eliminates significant numbers within a few weeks of their arrival. Even if the seeds reached the soil substrate they face competition with the already established grass species (Parrotta, 1992).

Several studies have demonstrated that the continuous use of land for pasture and any subsequent land degradation may also delay natural recovery (Reiners *et al.*, 1994). Soil physical and chemical properties of this

experimental site showed that the concentrations of N or C were significantly lower under the abandoned pasture or in the reforested plots than in the undisturbed rainforest (Rasiah *et al.*, 2003). These findings show that, even with the restoration, the full recovery process back to a rainforest is slow.

In conclusion, without any restoration, abandoned pasture will not begin transition back into rain forest within a decade. To accelerate the recovery process, artificial tree planting using fast-growing, native, tropical-rainforest species has widely been practised in the tropics. Our study shows that some restoration procedures can enhance this process, particularly those involving the use of multiple species from the pioneer and middle phases of rainforest plant succession. Even with restoration, degraded, abandoned grass-dominated pasture will take a considerable time to recover. The success depend on several factors, mainly post-restoration management and, in particular, grass control. It would be wrong, however, to conclude that our reforestation in an abandoned paddock did not show any encouraging results. As previously reported, seedling recruitment under reforested sites will take some time. Considerable numbers of planted seedlings have reached up to ten meters in height. These trees provide suitable shelter and perches for seed-dispersing animals. Further work on soil seed bank species composition and an avifauna utilization study on reforested plots may provide further information about the effectiveness of the restoration in an abandoned paddock.

ACKNOWLEDGEMENTS

We would like to thank Alan H., Katherine K., and Katherine M. for their assistance during the data collection. Tony Cummings, Barry Thurling, and Nigel Tucker are thanked for initially setting up of this experiment. We are grateful to Dr Per Milberg (Linköping University, Sweden), Dr Graeme Ambrose (University of Ballarat), Professor C. J. Barrow (University of Wales Swansea, UK) and two anonymous reviewers for providing comments and suggestions on early versions of the manuscript. We would also like to thank Bruce Williams, Tracy Farrell, and Paul Houlihan for providing support and encouragement of this project and Mathew Gibson for preparation of the study site map. This research was funded by School for Field Studies, USA.

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