LARGE SCALE ENRICHMENT PLANTING WITH DIPTEROCARPS AS AN ALTERNATIVE FOR CARBON OFFSET[1]

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INTRODUCTION

Increasing world-wide awareness of the effects of climate change is creating pressure to find ways to reduce the levels of greenhouse gases in the atmosphere (World Bank 1992). One strategy with great potential is to use trees to sequester CO_2, and it is bringing large investments to the forestry sector, particularly in the tropics (Marsh 1992 and 1993). This paper describes one such project.

The Innoprise-Face Foundation Rainforest Rehabilitation Project (Infapro) is a cooperative venture between Innoprise Corporation Sdn. Bhd. (Malaysia), and the Face (Forests Absorbing Carbon-dioxide Emissions) Foundation (The Netherlands), an organisation set up by the Dutch Electricity Generating Board to promote the planting of forests to absorb CO_2 from the atmosphere to partially offset the emissions of their power stations. The objective is to carry out the rehabilitation of 25,000 ha of degraded logged forests in Malaysia by enrichment planting and reclamation of degraded areas using indigenous tree species such as dipterocarps, fast growing pioneers and forest fruit trees.

Enrichment planting is a technique for promoting artificial regeneration of forests in which seedlings of preferred timber trees are planted in the under-storey of existing logged-over forests and then given preferential treatment to encourage their growth (Lamprecht 1986). Because of the problems and difficulties involved with large scale planting of logged over forests, the project has been established in the form of large field trials employing different systems with the objective of developing successful strategies for rehabilitation of logged forests (Pinso and Moura-Costa 1993)

The concept of sequestering atmospheric carbon by forestry is based on the principle that trees extract CO_2 from the atmosphere in the process of photosynthesis, and use it to produce structural compounds for their growth. The amount of carbon stored in trees in a forest can be calculated by determining the amount of biomass in the forest and applying a conversion factor. As longer-lived, high density trees store more carbon than short-lived, low density, fast-growing trees or other vegetation, enrichment planting logged forests with hardwood trees make it possible to obtain dense stands which accumulate higher amounts of carbon per area than logged forests which are left untreated.

This paper describes the methods used in this project, from plant production to planting. Preliminary results of planting trials are discussed. Finally, a preliminary estimate of carbon offset by enrichment planting of logged areas with dipterocarps based on the results achieved so far is shown.

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MATERIALS AND METHODS

Project area

The project area comprises 25,000 ha of logged-over dipterocarp forests in the Ulu Segama Forest Reserve, eastern Sabah (Malaysia), 5° N, 117° E. Mean annual rainfall is 2,800 mm, and mean annual temperature is 26.7°C. The geology, soils and topography of the region are very variable and are described by Marsh and Greer (1992). Since 1978 this area has been logged on an annual coupe basis; thus, at present, it includes plots of secondary forests at different stages of regeneration. Plots were logged with various timber extraction techniques (tractor or high-lead yarding) and differ in terms of remaining vegetation, canopy density, soil characteristics (bulk density, nutrient levels, infiltration rates) and topography. Plots were located in areas with low seedling density following logging.

Species used and propagation techniques

The project aims to plant a variety of dipterocarp species, although the species used so far were limited to those which produced seeds in the two years preceding the beginning of the project. The main species planted to date are *Shorea leprosula* (seraya tembaga), *Parashorea malaanonan* (urat mata daun licin) and *Dryobalanops lanceolata* (kapur paji). Other species planted in smaller quantities were *Shorea ovalis, Shorea johorensis, Shorea parvifolia, Shorea argentifolia, Shorea macrophylla, Dipterocarpus* spp., *Hopea nervosa* and the non-dipterocarp *Agathis dammara* (Araucariaceae).

Planting material was produced mainly from seeds and wildings. Seeds were collected in the forest and brought to the nursery for germination. Seeds not collected from the forest quickly germinated, and the resulting wildings were collected and cultivated. Wildings were simply pulled from the forest floor (one person can collect up to 180 wildings per hour) but this often damages their root system. Thus, special care was given during an acclimatization period after transfer to the nursery. Wildings were watered and kept in plastic covered chambers with high humidity for four weeks until a new root system was formed. Vegetative propagation by cuttings was also used, but on a smaller scale. Cuttings were set to root directly in 7 x 21 cm poly-bags containing a mixture of forest top-soil and sand (1:1) inside the chambers used for acclimatization of wildings. A detailed description of the propagation techniques used are available elsewhere (Moura-Costa 1993, Moura Costa et al. 1993, Moura-Costa and Lundoh 1993 a, b).

Project implementation and planting system

The main planting system used is enrichment line planting which involves opening 2 m-wide lines every 10 m through the secondary forest matrix and planting seedlings every 3 m along the lines. Lines are opened in an East-West direction. Planting holes are approximately 10 cm diam and 20 cm deep. Rock phosphate fertiliser is applied in each planting hole (100 g per plant). Planting is carried out throughout the year, only interrupted if there is more than 3 consecutive days without rain. Weeding is carried out when necessary, up to 4 rounds a year during the initial 3 years after planting. Figures of labour requirement for each activity of the project have been recorded to enable studies of planting efficiency in different sites.

Two months after each plot was planted, 100% of the planted area was surveyed to assess initial survival of seedlings. During this survey, a visual assessment of the degree of canopy cover above each seedling was carried out, classifying it as open, half-open or closed canopy. Rainfall patterns (total monthly rainfall and number of dry days during the first month following planting) were correlated to initial mortality.

The initial phase of the project aims to test different strategies and systems, thus planting is organised in the form of large trial plots testing a range of variables. One such trial tested the effect of the width of planting lines on growth of seedlings of *Dryobalanops lanceolata.* Lines of 1.5, 2.0 and 3.0 m width were opened (3 replicates for each width), and approximately 73 seedlings were planted in each line. The width of planting lines was measured at the ground level, and any vegetation apart from trees or seedlings of commercial species found within the lines was removed. The percentage canopy cover above each planted seedling was measured using a hemispherical canopy densiometer (Forestry Suppliers Inc., USA). Height of seedlings was measured one year after planting.

RESULTS AND DISCUSSION

Plant production and propagation techniques

During the initial year of the project, 500,000 dipterocarp seedlings were produced using different propagation systems. A total of 250,000 seedlings were grown from seeds. If fresh seeds were used, germination rates of up to 97 % were achieved after 2 weeks (results of batches of *Dryobalanops lanceolata*, *Shorea leprosula* and *Parashorea malaanonan* seeds). Sharp decreases in germination rates were observed when seeds were kept for more than two weeks, with less than 50 % germination (Moura-Costa et al. 1993). Satisfactory rates of survival of wildings were obtained using the high-humidity chamber system. Survival rates were 94.4 % for *Shorea parvifolia* and 88.2 % for *Dryobalanops lanceolata*, after a 4 week acclimatization period (Moura-Costa et al. 1993). Percentage rooting of *D. lanceolata* cuttings after 12 weeks in the high-humidity chambers was 78 % (n = 2,000, SE = 2.8). This method is being adapted to enable the propagation of other dipterocarp species.

Using these three systems it may be possible to maintain a steady supply of large numbers of planting material of different dipterocarp species to the project. Tissue culture techniques is yet another possibility which we are investigating, and preliminary results are promising (Linington 1991, Moura-Costa 1993).

Initial survival and causes of mortality

The mean survival rate of seedlings two months after planting was 88.6 % (Table 1). Although higher rates of initial mortality were expected in plots with less canopy cover, this did not appear to be true. The highest mortality rates were observed in plots 1988-A and 1991-B (18.7 % and 25.7 %, respectively), although plot 1988-A had a low percentage of plants under open canopy. It appeared that the most important factor determining initial survival of seedlings was rainfall following planting. The amount of rainfall and number of rain days during the 30 days following planting was lowest for plots 1991-B and 1988-A, possibly explaining the high mortality in these sites. It was found that survival was negatively correlated with number of dry days after planting ($r = -0.788$; $P = 0.050$), and positively correlated with rainfall following planting ($r = 0.813$, $P = 0.038$). There was no significant correlation between percentage of planting points under open canopy and mortality rates.

Most of the species showed similar mortality rates under the three categories of canopy cover, with the exception of *Parashorea malaanonan* and *Agathis dammara*, which showed significantly ($P < 0.01$) higher rates of mortality under open canopy (results not shown). For each canopy category, there were no differences in mortality rates of different species in different plots. However, as some of the plots have higher proportions of planting points under open canopy, species such as *P.malaanonan* and *A.dammara* should not be planted in these sites. The distribution throughout the planting sites and its relation to site features is being investigated with the aid of a geographic information system (van Oorschot et al. 1994).

Table 1. Rainfall patterns, canopy openness and initial survival of seedlings planted in six plots of the Infapro Project. Assessments were carried out 2 months after planting.

Year site logged	N[1]	% plants under open canopy	Planting month[2]	Total monthly rainfall following planting date (mm)	No of dry days during the month following planting date	% Survival
1978.A	16,057	3.7	April	169	10	95.4
1978.B	13,372	7.4	April	169	10	92.4
1981.A	15,770	15.9	February	270	12	93.5
1988.A	17,546	7.5	May	89	7	81.3
1988.B	16,046	13,9	January	288	9	94.5
1991.B	7,175	12.6	May	89	7	74.3
Total/Means	89,966	10.2	-	-	9.1	88.6

1: Number of plants assessed to date. 2: all plots were planted in 1993.

Width of planting lines, canopy cover and seedling growth

Considering the effect of light on seedlings, it is necessary to develop a cost effective way to manipulate light conditions in the planted plots. We attempted to change the degree of canopy density by manipulating the width of planting lines. However, there were no significant differences in the average canopy density above seedlings planted in lines of different widths (1.5, 2.0 and 3.0 m). Since line width was measured on the ground, opening wider lines did not necessarily affect the canopy. In many cases seedlings were shaded by branches of trees located outside the lines, which were not removed. Our site preparation guidelines are being modified to take into consideration these practical problems.

Although there were no significant differences in the average canopy density of different planting lines, there was great variability in the canopy density above individual seedlings. This factor was used to analyze the effect of light on seedling growth. There was a positive correlation between height of *Dryobalanops lanceolata* seedlings and the degree of canopy openness ($r = 0.28$, $P < 0.01$, $N = 650$). Average height increment of these seedlings after one year was 1.2 m (sd = 0.19) and the mean height of the 50 best trees per hectare was 1.8 m (sd = 0.22). Average diameter increment was 0.9 cm $year^{-1}$ (sd = 0.31), and the average of the 50 fastest growing trees per ha was 1.6 cm $year^{-1}$ (sd = 0.22). The effect of light on growth of other species is being investigated and preliminary results are shown elsewhere (van Oorschot et al. 1994).

CARBON SEQUESTRATION ESTIMATE

The projected amount of carbon sequestered by the project was estimated. Figures used were either based on data from literature or from the project data. As the planting system used for the project includes clearing 2 m-wide lines 10 m apart, an initial 20 % reduction in the site's above ground biomass will be assumed for this paper, although trees with dbh larger than 10 cm and existing seedlings of commercial timber species and fruit trees are not removed during site preparation. After discounting unplantable points (ie. rivers, rocks, points already occupied by natural regeneration or trees) and the initial mortality (ca. 5% during first month), an average of 280 seedlings are established per ha.

Additional assumptions used for the calculations in this paper were:

- pre-planting carbon of logged forest (5 years after logging) of 200 t ha^{-1}, divided as above-ground biomass (80 t C ha^{-1}), roots (25 t C ha^{-1}), soil (70 t C ha^{-1}) and necromass (25 t C ha^{-1}), based on Putz and Pinard (1993).

- carbon stored in biomass of the forest in the absence of enrichment planting increases at a rate of 1 t ha^{-1} $year^{-1}$. In the case of enrichment planted sites, it was assumed that the biomass of the surrounding forest matrix increases until planted trees reach 20 cm dbh. After that, the main increases in biomass will be due to the growth of planted trees, and we assumed a decrease in carbon of the surrounding forest of a rate of 0.3 t C ha^{-1} $year^{-1}$;

- dipterocarp trees growing at a rate of 1.1 cm dbh $year^{-1}$. Although the average diameter increment of our plots is 0.9 cm $year^{-1}$, this was measured for all the 280 trees ha^{-1} initially planted. A higher mean increment is expected by discarding the slow growing trees, either due to natural mortality or during the thinning operations. This figure of diameter increment is consistent with other studies (Appanah and Weinland 1993, Hassan et al. 1990, Tang and Chew 1980). The growth rate of the 100 faster trees per hectare in our plots was 1.4 cm dbh $year^{-1}$.

- tree mortality of 5 trees ha^{-1} $year^{-1}$, until they reach 10 cm dbh, and then 2 trees ha^{-1} $year^{-1}$ (Hassan et al. 1990);

- a 50 % thinning will be carried out 30 years after planting. The carbon accumulated in the trees removed is considered stored until the end of the rotation;

- the formulas:

$1/H = 1/2D + 1/61$; where H is height in m, D is dbh in cm (Kira 1978);
$Ws = 0.313\ ((D^2H)^{0.9733})$; where Ws is stem biomass in kg (Kira 1978);
$Wb = 0.136\ (Ws^{1.07})$; where Wb is branch biomass in kg (Kira 1978);
$C = 0.56\ W$; where C is carbon and W is biomass (Chan 1982).

Figures for stand development and biomass production are given in Table 2. After approximately 12 years, planted trees are large enough to compensate for the reductions in biomass assumed to result from site preparation. The total carbon offset after 30 years would be 92 t ha^{-1}. At this time trees would have reached diameter *ca.* 30 cm, when a commercial thinning can be carried out. At the end of a 60 year rotation, it is expected that enrichment planted forests would have offset

213 t C ha^{-1}. Furthermore, *ca.* 329 m^3 of sustainably produced high value timber can be expected from planted stands. If the reduced impact logging techniques currently implemented in the Ulu Segama Forest Reserve (Putz and Pinard 1993) are used for extraction of this timber, this will cause minimal damage to the residual trees and natural regeneration. In this way, the forest can regenerate naturally without the need for further enrichment planting.

Table 2. Figures of growth, survival, biomass and carbon accumulation of enrichment planted and non-planted logged forests.

year	C unf (t ha^{-1})	C epf (t ha^{-1})	N (trees ha^{-1})	dbh (cm)	Height (m)	Tree volume (m^3)	C trees (t ha^{-1})	TC ep (t ha^{-1})	C offset (t ha^{-1})
0	220	176	280	0.3	0.3	0.0	0.0	176	- 43
5	227	182	255	5.3	9.0	1.2	1	183	- 43
10	235	188	245	10.3	15.4	7.5	9	197	- 37
20	250	185	225	20.3	24.4	42.6	49	234	- 15
30	265	182	102	30.3	30.4	53.9	61	243	40
40	280	179	97	40.3	34.7	103.6	117	296	77
50	295	176	92	50.3	37.9	167.5	188	364	130
60	310	173	87	60.3	40.5	242.8	271	444	195

C unf = carbon in untreated logged forest; C epf = carbon in forest matrix surrounding planted trees; dbh = diameter at breast height; C trees = carbon in enrichment planted trees; TC ep= total carbon in enrichment planted forests (C ep + C trees); C offset = TC ep - C unf.

CONCLUSIONS

The initial phase of the project has established large areas of dipterocarp enriched forests. It is necessary for these stands to be monitored and silviculturally treated so that growth and survival rates are maintained at high levels. The project now also includes the rehabilitation of severely degraded areas such as log landings and skid trails, since these can account for up to 30 % of logged areas (Nussbaum et al. 1993, Sabah Forestry Department 1989), and little regeneration is observed in these areas even many years after logging. This has been done by ploughing, application of fertilisers and planting of pioneer trees and cover crops, following procedures described by Nussbaum et al. (1994, and in this volume) and Howlett and Davidson (1994, also working in the Ulu Segama Forest Reserve). In order to increase biodiversity and attract wildlife, 10 % of the project area has been planted with indigenous fruit trees such as *Durio*, *Artocarpus*, *Mangifera Diospyros* and *Dacryodes*.

The project also incorporates a research programme which covers many aspects of dipterocarp research, such as the effects of fertilisers (Yap and Moura-Costa 1994); vegetative propagation (Moura-Costa and Lundoh 1994 a & b) and genetic improvement (Moura-Costa 1993); plant physiology (Yap 1994 a & b; Yap and Ong 1994; Yap et al. 1994); the use of GIS for forest management (van Oorschot et al. 1994); dipterocarp mycorrhizae; and carbon sequestration (Brown et al. in press; Nabuurs and Mohren 1993). The objective of the programme is to sustain a scientific input to the project, so that different methods for rehabilitation of logged rainforests can be developed and tested. Ten percent of the budget of the project is directed specifically towards research. Research priorities are identified and scientists approached to pursue particular investigations. Some of the projects are done in collaboration with other institutions working with forest rehabilitation, such as the Forestry Department of Sabah, the Forest Research Institute Malaysia (FRIM, Kepong), Tropenbos/Wanariset Research Station (Samarinda, Indonesia) and the ASEAN-Canada Forest Tree Seed Centre (Thailand). Another important source of expertise and scientific advice comes from researchers linked to other organisations currently working at Danum, such as the Royal Society (UK), the Unesco/MAB Rainforest Rehabilitation Project (Univ. of Exeter and Cambridge, UK) and the Universities of Florida and Utah (USA).

The carbon estimates given showed that substantial amounts of carbon can be stored in enrichment planted forests. Another factor to be considered is that the timber from enrichment planting could be classified as "sustainably produced" by wood certification schemes, not subjected to trade embargoes and possibly attain higher market prices. Other benefits of enrichment planting include conservation of biodiversity, wildlife, and large areas of natural tropical forest, which otherwise would attain higher opportunity costs by conversion to plantations of fast growing trees or oil palm. Furthermore, the research related to the project is enabling a better understanding of the practical aspects of large scale planting of dipterocarps.

This project is an example of joint implementation of forestry projects with the objective of carbon sequestration, and how such schemes can benefit tropical forestry and sustainable forestry management.

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