

LARGE SCALE ENRICHMENT PLANTING WITH DIPTEROCARPS AS AN ALTERNATIVE FOR CARBON OFFSET - METHODS AND PRELIMINARY RESULTS¹

Pedro Moura-Costa², Yap Sau Wai, Ong Chye Lye, Albert Ganing,
Ruth Nussbaum & Thomas Mojiun

Innoprise-Face Foundation Rainforest Rehabilitation Project (Infapro)
Innoprise Corporation Sdn. Bhd., Danum Valley Field Centre
PS 282, 91108 Lahad Datu, Sabah, Malaysia.

ABSTRACT

A large scale project for rehabilitation of logged forests to sequester atmospheric CO₂ was initiated in Sabah, Malaysia. The objective of the project is to rehabilitate 25,000 ha of logged forest by enrichment planting and reclamation of degraded areas using indigenous tree species such as dipterocarps, fast growing pioneers and forest fruit trees. The methods used and preliminary results from the first 700 ha are described here. Large numbers of plants of different species of dipterocarps were successfully propagated by seeds, wildings and cuttings. Initial survival of seedlings after planting in the field was 88.6 %. The main cause of mortality was low rainfall following planting. *Dryobalanops lanceolata* seedlings showed a height increment of 1.2 m year⁻¹ and diameter increment of 0.95 cm year⁻¹. Height growth of this species was positively correlated with the degree of canopy openness above planted seedlings. The labour efficiency of different activities is discussed. It is estimated that 195 t C ha⁻¹ can be offset by dipterocarp enrichment planted forests during a rotation of 60 years.

Keywords: carbon offset, enrichment planting, light, rainfall, dipterocarps.

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 CO₂, and it is bringing large investments to the forestry sector, particularly in the tropics (Marsh 1992, 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 CO₂ 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

¹ In: Proceedings of the 5th Round Table Conference on Dipterocarps, Chiang Mai, Thailand, November 1994. *Journal of Tropical Forest Science, FRIM, Kuala Lumpur.*

² Current Address: EcoSecurities Ltd. www.ecosecurities.com

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 CO₂ 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, and discusses working efficiency. 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.

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. A short description of the plots planted during the initial two years of the project is given in Table 1.

Table 1. Description of the plots planted during the initial two years of the project.

Year site was logged and plot code	Area (ha)	General description	Type of log extraction	Slope range (%)
1978.A	55	Close canopy consisting predominantly of pioneer tree species, medium slopes	tractor/ high lead	22 - 23
1978.B	53	Close canopy consisting predominantly of pioneer tree species, flat relief, lowland area in the margin of two rivers	tractor	0 - 2.5
1978.C	92	Close canopy consisting predominantly of pioneer tree species, medium slopes	high lead	22 - 24
1981.A	55	Extremely open site, few remaining trees, presence of bamboos and bushy vegetation and grasses, gentle slopes	high lead	14 - 31
1981.B	217	Dense canopy from remaining trees and pioneers, terrain ranging from flat, riverine, to steep slopes.	tractor/ high lead	9 - 31
1988.A	56	Bushy vegetation, presence of grasses and lianas, open canopy and patches of dense vegetation, steep slopes	tractor/ high lead	17 - 28
1988.B	52	A combination of patches of undisturbed forest with dense canopy cover, and areas with scant vegetation, pioneer trees and lianas	tractor	3 - 12
1988.E	47	" " " "	high lead	17 - 22
1988.F	94	" " " "	tractor	9 - 15
1991.A	28	Extremely disturbed site, large patches of bare land without any canopy cover, not yet colonised by vines, steep topography	tractor	12 - 33
1991.B	29	Extremely disturbed site, presence of vines (mostly <i>Merremia</i>), need for intensive weeding, absence of canopy cover	tractor	15 - 18
TOTAL	778		-	-

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 wildlings 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 2). 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 (Fig.1). 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.*, in this volume).

Table 2. 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	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.

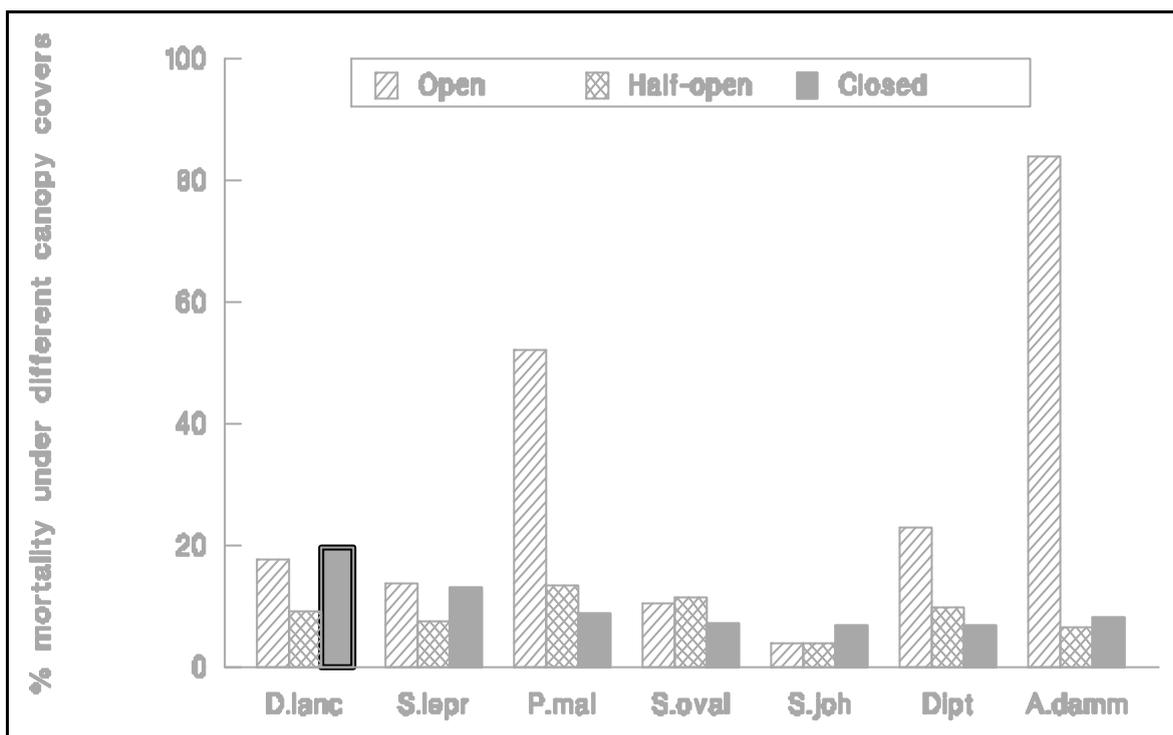


Figure 1. Percentage mortality of different species planted under different canopy covers (open, half-open and closed canopy). Figures were calculated as the percentage of plants which died from the total number of plants in that canopy category. Species and number of observations for open, half-open and closed canopy were, respectively: *D.lanceolata* (n = 13,002, 11,484, 12,474), *Shorea leprosula* (n = 13,530, 11,154, 13,024), *P.malaanonan* (n = 4,158, 3,102, 4,092), *S.ovalis* (n = 140, 131, 127), *S.johorensis* (n = 264, 198, 204), *Dipterocarpus* spp. (n = 66, 74, 62), *Agathis dammara* (n = 858, 792, 873).

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.*, in this volume).

Planting efficiency

Among the different activities of the project, site preparation was found to be the most time consuming, followed by the planting and the maintenance (Table 3). The efficiency of these three activities improved from the beginning of the project until the present (calculated from the performance in the first half as compared to the second half of the project's first year). Further improvements in efficiency are expected after field staff is given more practical training.

Table 3. Labour efficiency in different plots at different times after the beginning of the project (person days ha⁻¹). Mean (sd).

Year plot was logged	Site preparation	Planting	Maintenance/month
1978 (n = 3)	6.2 (1.35)	1.8 (0.46)	0.35 (0.04)
1981 (n = 2)	5.1 (1.51)	1.7 (0.14)	0.40 (0.15)
1988 (n = 4)	4.8 (3.54)	2.3 (1.67)	0.37 (0.21)
1992 (n = 2)	7.9 (1.15)	1.7 (0.01)	0.27 (0.07)
Average 1st year (n = 6)	6.4 (1.35)	2.0 (1.32)	0.37 (0.14)
Average 2nd year (n = 5)	5.0 (2.33)	1.8 (0.35)	0.30 (0.16)
MEAN	5.8	1.9	0.36

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 unplatable points (i.e. 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 4. 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 m³ 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 4. 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 (in this volume, 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, in this volume); 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.*, in this volume); dipterocarp mycorrhizae (Alexander *et al.*, in this volume); 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.

ACKNOWLEDGEMENTS

This work was made possible through the support of the Face Foundation of the Netherlands, the Danum Valley Research and Training Programme, the Forestry Department of Sabah for use of their tissue culture facilities, the Danum Valley-ODA-Manchester University Hydrological Project for rainfall data, and to Chan Hing Hon and other colleagues in Innoprise Corporation for their participation in various aspects of the work. The authors would also like to thank R. Nussbaum, B. Howlett, M. Pinard, J. Putz, C. Marsh and M. Sherlock for comments on an early version of the manuscript.

REFERENCES

- Appanah, S. and Weinland, G., 1993. Planting quality timber trees in Peninsular Malaysia - a review. Malaysian Forest Record No. 38. Forest Research Institute Malaysia, Kepong. 221 pp.
- Brown, S.; Cannell, M.; Heuvelink, J.; Kauppi, P.; Sathaye, J.; Singh, N.; Weyers, S.; Dixon, R.; Grainger, A.; Leemans, R.; Moura-Costa, P.H.; Nilsson, S.; Pinard, M.; Schopfhauser, W.; Sedjo, R. and Trexler, M., 1994. Chapter III.F. Establishment and management of forests for mitigation of greenhouse gas emissions. In: Working group II, Intergovernmental Panel on Climate Change, 1995 Assessment for the Framework Convention On Climate Change.

- Chan, Y.H., 1982. Storage and release of organic carbon in Peninsular Malaysia. *International Journal of Environmental Studies* **18**:211-222.
- Hassan, A., Wan Razali, W.M., Idris, S. and Kassim, A.R., 1990. Growth performance of indigenous species under enrichment planting in logged over forests. In: Malaysian forestry and forest products research. Appanah, S., Ng, F.S.P. and Ismail, R. (Eds.). Pp. 30-40.
- Howlett, B. and Davidson, D. (this volume). Dipterocarp seed and seedling performance in secondary logged forests dominated by *Macaranga* spp.
- Kira, T., 1978. Community architecture and organic matter dynamics in tropical lowland rain forests of Southeast Asia with special reference to Pasoh Forest, West Malaysia. In: Tropical trees as living systems. Tomlinson, P.B. and Zimmermann, M.H. (Eds.). Cambridge University Press, New York. Pp. 561-590.
- Lamprecht, H., 1989. Silviculture in the tropics. TZ-Verlagsgesellschaft mbH, Rossdorf, 296 pp.
- Linington, I.M., 1991. *In vitro* propagation of *Dipterocarpus alatus* and *Dipterocarpus intricatus*. *Plant Cell, Tissue and Organ Culture* **27**: 81-88.
- Marsh, C., 1992. CO₂ offsets as a potential funding source for improved tropical forest management. *Tropical Forest Management Update* **2**(5):15 and **2**(7):2.
- Marsh, C., 1993. Carbon dioxide offsets as potential funding for improved tropical forest management. *Oryx* **27**: 2-3.
- Marsh, C. and Greer, A.G., 1992. Forest land-use in Sabah, Malaysia: an introduction to the Danum Valley. *Philosophical Transactions of the Royal Society of London* **B 335**:331-340.
- Moura-Costa, P.H., 1993. Nursery and vegetative propagation techniques for genetic improvement and large scale enrichment planting of dipterocarps. In: Primack, R.B. & Lovejoy, T. (Eds.). Ecology, Conservation and Management of Southeast Asian Rainforests. Yale University Press, Connecticut. (in press).
- Moura-Costa, P.H., Ganing, A., Lundoh L. and Ong, C.L., 1993. Experiments on nursery techniques for raising seedlings and wildings of dipterocarps on a large scale. ASEAN-Canada Forest Tree Seed Centre Project, Thailand, (in press).
- Moura-Costa, P.H. and Lundoh, L., 1993a. A method for vegetative propagation of *Dryobalanops lanceolata* (Dipterocarpaceae) by cuttings. *Journal of Tropical Forest Science* **6**: 533-541.
- Moura-Costa, P.H. and Lundoh, L., 1993b. The effects of auxins (IBA, NAA and 2,4-D) on rooting of *Dryobalanops lanceolata* (kapur, Dipterocarpaceae) cuttings. *Journal of Tropical Forest Science* (in press)
- Nabuurs, G.J. and Mohren, G.M.J. 1993. Carbon fixation through forestation activities. A study of the carbon sequestration potential of selected forest types commissioned by the Face Foundation. Institute for Forestry and Nature Research (IBN), Wageningen. 205 pp.
- Nussbaum, R., Anderson, J. and Spencer, T., 1993. The effects of selective logging of tropical rainforest on soil characteristics and growth of planted dipterocarp seedlings in Sabah, Malaysia. In Primack, R.B. & Lovejoy, T. (Eds.). Ecology, Conservation and Management of Southeast Asian Rainforests. Yale University Press, Connecticut. (in press).
- Nussbaum, R., Anderson, J. and Spencer, T., 1994. Factors limiting the growth of dipterocarp and pioneer tree seedlings planted on disturbed soils following rainforest logging in Sabah, Malaysia. *Forest Ecology and Management* (in press).
- Pinso, C. and Moura-Costa, P.H., 1993. Greenhouse gas offset funding for enrichment planting - a case study from Sabah, Malaysia. Case study paper, Fourteenth Commonwealth Forestry Conference, Kuala Lumpur, Malaysia, September 1993. *Commonwealth Forest Review* **72**:343-349.

- Putz, F.E. and Pinard, M.A., 1993. Reducing the impacts of logging as a carbon-offset method. *Conservation Biology* **7**: 755-757.
- Sabah Forestry Department, 1989. Forestry in Sabah. 164 pp.
- Tang, H.T. and Chew, T.K., 1980. Preliminary results of two six-year old under-planting trials at Tapah Hills Forest Reserve, Perak. *Malaysian Forester* **43**:193-211.
- van Oorschot, G., van Winkel, I. and Moura-Costa, P.H., in this volume. The use of GIS to study the influence of site factors in enrichment planting with dipterocarps.
- World Bank, 1992. World development report 1992. Development and the environment. Oxford University Press, Oxford. 308 pp.
- Yap, S.W., 1994. Leaf water potential of *Dryobalanops lanceolata* Burck. and *Shorea leprosula* Miq. potted seedlings in Ulu Segama Forest Reserve, Sabah, Malaysia. In: *Handbook of field methods for plant physiological ecology*. Barker, M.G., Pinard, M.A. and Putz, F.E. (Eds.). Forest Research Centre, Sabah, Malaysia. (in press).
- Yap, S.W., Chia, F.R. and Rahimah Hj. Ahmad, 1994. A preliminary study of photosynthetic rates of *Parashorea malaanonan* (Blco.) Merr. and *Shorea leprosula* Miq. in Ulu Segama Forest Reserve, Sabah, Malaysia. In: *Handbook of field methods for plant physiological ecology*. Barker, M.G., Pinard, M.A. and Putz, F.E. (Eds.). Forest Research Centre, Sabah, Malaysia. (in press).
- Yap, S.W. and Moura-Costa, P.H. (in this volume). Effects of nitrogen fertilization and soil texture on growth and morphology of *Dryobalanops lanceolata* Burck seedlings.
- Yap, S.W. and Ong, R.C., 1994. Nutrient content in relation to herbivory in *Shorea leprosula* Miq. seedlings. In: *Handbook of field methods for plant physiological ecology*. Barker, M.G., Pinard, M.A. and Putz, F.E. (Eds.). Forest Research Centre, Sabah, Malaysia. (in press).
- Yap, S.W., 1994. *Dryobalanops lanceolata* Burck. and *Shorea leprosula* Miq. leaf herbivory in relation to leaf nutrient content. In: *Handbook of field methods for plant physiological ecology*. Barker, M.G., Pinard, M.A. and Putz, F.E. (Eds.). Forest Research Centre, Sabah, Malaysia. (in press).