Journal of Tropical Forest Science 13(1):62–75 (2001)

ESTIMATION OF THE HARVESTABLE POTENTIAL AFTER LOGGING IN A LOWLAND MIXED DIPTEROCARP FOREST OF EAST KALIMANTAN

Vincent Favrichon*, **Nicolas Nguyen-The**

CIRAD-Forêt, Centre de Coopération International en Recherche Agronomique pour le Développement, Baillarguet, BP 5035. 34032 Montpellier Cedex 1, France

&

Anna Enggelina

PT. Inhutani I., Jalan Gatot Subroto, Gedung Manggala Wanabakti, Block VII Lt. 12, Jakarta Pusat 12 120, Indonesia

Received August 1998

FAVRICHON, V., NGUYEN-THE, N. & ENGGELINA, A. 2001. Estimation of the harvestable potential after logging in a lowland mixed dipterocarp forest of East Kalimantan. A model is used to assess in a simple way the number of dipterocarp stems above the cutting limit of 60 cm dbh through time after logging and silvicultural treatment. Different scenarios of simulation are set up depending on whether reduced impact logging techniques (RIL) and/or silvicultural treatment is applied. The data used are those of the STREK project implemented in East Kalimantan, Indonesia, complete with data from the literature. A scenario of reference is built with the assumptions of the TPTI (Indonesian selective cutting and planting system). In the strict observance of the TPTI, with RIL methods and regular subsequent thinnings, the time required to recover the initial number of dipterocarp stems above 60 cm dbh is around 50 y. With more realistic scenarios, this time is around 100 y or more. The use of RIL methods with silvicultural treatment leads to a reduction of 15 y compared with the recovery time of the conventional logging. After 35 y, the official TPTI cutting cycle, the simulation foresees a potential harvest of about 5 stems ha^{-1} with RIL methods and one thinning compared with 8 trees logged at the first harvest. The method does not take into account the volume and does not distinguish the injured or misshapened trees but provides a basic, adaptable tool to be used by field managers.

Key words: Logging - modelling - harvesting - reduced-impact-logging - felling cycle - dipterocarps - East Kalimantan

FAVRICHON, V., NGUYEN-THE, N. & ENGGELINA, A. 2001. Anggaran potensi boleh tebang selepas pembalakan di hutan tanah pamah dipterokarpa campur di Kalimantan Timur. Satu model digunakan untuk menilai dengan cara yang mudah

*Author for correspondence. Fax: (33) 467593733, e-mail: favrichon@cirad.fr

bilangan batang dipterokarpa di atas had keratan sebanyak 60 cm garis pusat aras dada menerusi masa selepas pembalakan dan rawatan silvikultur. Senario simulasi yang berbeza dibuat bergantung sama ada teknik larasan impak pembalakan (RIL) dan/ atau rawatan silvikultur digunakan. Data yang digunakan ialah data yang diambil dari projek STREK yang dilaksanakan di Kalimantan Timur, Indonesia, lengkap dengan data dari maklumat tersebut. Senario rujukan dibina dengan andaian TPTI (Sistem penanaman dan tebangan memilih Indonesia). Dalam cerapan yang tegas oleh TPTI, menggunakan kaedah RIL dan penjarangan secara tetap dan berturutan, masa yang diperlukan untuk memulihkan bilangan asal batang dipterokarpa di atas garis pusat ialah kira-kira 50 tahun. Dengan senario yang lebih realistik, pada kali ini ia memakan masa kira-kira 100 tahun atau lebih. Penggunaan kaedah RIL dengan rawatan silvikultur menyebabkan pengurangan sebanyak 15 tahun berbanding dengan masa pemulihan bagi pembalakan secara konvensional. Selepas 35 tahun, kitaran keratan TPTI secara rasmi, simulasi ini menjangkakan potensi penebangan bagi 5 batang ha^{-1} dengan kaedah RIL dan satu penjarangan berbanding dengan 8 batang pokok yang dibalak pada penebangan yang pertama. Kaedah ini tidak mengambil kira banyaknya dan tidak membezakan antara pokok-pokok yang cedera atau rosak tetapi menyediakan alat asas yang boleh diubahsuai untuk digunakan oleh pengurus-pengurus ladang.

Introduction

Ecologically sound forest management has become a major topic of interest in the past few years. Such a goal requires a good understanding of the forest features and dynamics so as to know the response of the stand to various disturbances such as logging or silvicultural treatments. The next step is to foresee the evolution of the stand through time and to estimate how many years after logging it takes for the forest to return to its original state. This paper addresses two main issues: 1) what harvest can be expected after the first cutting cycle, and 2) what is the interest of reduced impact logging methods (RIL) and silvicultural treatments after logging for forest regeneration?

Growth and yield simulation studies have been recently developed based on many types of models such as matrix model (Favrichon 1995) or individual tree distant dependent models (Alder 1995, Vanclay 1995, Gourlet-Fleury 1997). However, these models are generally complex and difficult to be used or implemented by foresters. The main purpose of this paper is to present a more simple model to be used as a managerial tool by forest managers and forest concessionaires.

The growth model presented in this paper is related to a cohort model estimating through time the number of commercial stems reaching the cutting limit of 60 cm dbh after logging. The method enables one to estimate the importance of the harvest after a first felling cycle with various assumptions of simulation. We illustrated the method with the field data of the STREK project set up in East-Kalimantan, Indonesia (Bertault & Kadir 1998). The data set contains the information from approximately 40 000 trees recorded on 72 ha, over a period of 3.5 y.

Materials and methods

Study area

The study area is located in the Berau district, near Tanjung Redeb (2°N, 117° 15' E), within a 500 000 ha forest concession held by the state-owned company PT. INHUTANI I (Figure 1). The concession has been harvested during the last 15 years. The climate is equatorial with a mean annual rainfall of about 2000 mm. The geology consists mainly of alluvial deposits dating from the Miocene and Pliocene. Soils are mainly Ultisols (87%) with some Entisols (11%) and Inceptisols (2%) (Sumaryono 1996). The topography is gently undulating to hilly in the north, changing to steep slopes with elevations reaching 1000 m above sea-level in the south.

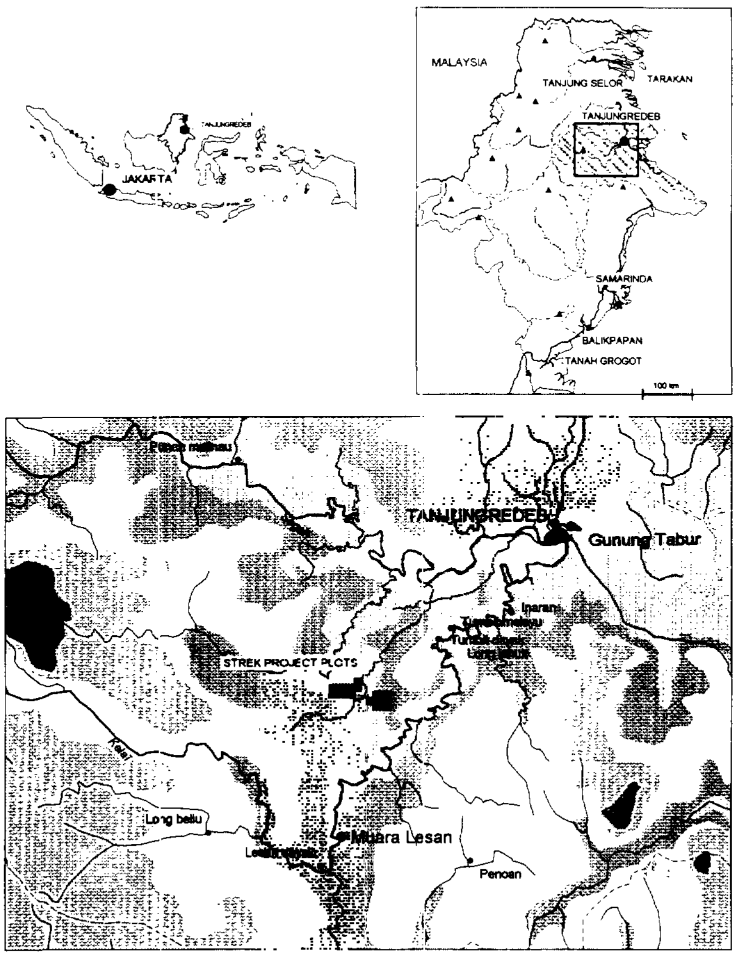

Figure 1. Location of the STREK project in East Kalimantan, Indonesia

STREK layout

Two sites representative of the vegetation in the area were selected. Those sites were RKL 1, logged 15 y ago at low intensity (3 stems ha^{-1}) and RKL 4, originally covered by primary lowland mixed dipterocarp forest. In RKL 1, 6 permanent sample plots, 4 ha each, were set up to carry out silvicultural trials with the aim of improving the growth of commercial trees (Sist & Abdurachman 1998). In RKL 4, 12 similar plots were set up to experiment different logging techniques, and particularly reduced impact logging (Sist & Bertault 1998).

In all the plots, all the trees with a diameter at breast height (dbh) ≥ 10 cm were recorded and measured. Three measurements covering a period of 3.5 y have been carried out on the whole layout.

Methods

Simulation of a first felling cycle

The goal is to estimate the number of commercial trees above 60 cm dbh through time following the first harvest. The principle is to simulate the evolution of the remaining stand after logging by applying different growth and mortality rates according to the logging techniques and silvicultural treatments. In a primary forest before logging, the stand is characterised by the mortality m_0 and the overall growth Δd_0. Mortality caused by logging operation on trees which have not been harvested is m_d. During the post-harvesting period, the growth Δd_1 of remaining trees is increasing until the time t_1 of canopy closure. High mortality rates (m_1) are generally recorded several years following logging. This period of time is called t_{m1}. If silvicultural treatments are applied, growth Δd_2 can be increased again for a certain time t_2. In this case, mortality m_2 might also change for a period t_{m2} (Table 1).

Table 1. Periods taken into account with corresponding growth and mortality rates

Mortality		Growth	
Time after logging	Mortality rate	Time after logging	Growth rate
$t = 0$	m_d		
$t = 1$ to t_{m1}	m_1	$t = 1$ to t_1	Δd_1
$t = t_{m1}$ to $t_{m1} + t_{m2}$	m_2^*	$t = t_1$ to $t_1 + t_2$	Δd_2^*
$t = t_{m1} + t_{m2}$ to T	m_0	$t = t_1 + t_2$ to T	Δd_0

*: if silvicultural treatment applied.

Let us consider that logging operations are carried out in a virgin forest at time t=0. The number of stems with dbh above 60 cm T years afterwards come basically from two pools of stems:

- trees with dbh > 60 cm at the time of logging but not harvested (N_1),
- trees with dbh < 60 cm at the time of the first harvesting which have reached the harvestable diameter size afterwards (N_2).

Let N_{1i} be the initial number of trees above 60 which were not harvested. Through time, some of these trees may die because of logging damages (m_d) or because of the subsequent mortality (m_1). If silvicultural treatments are applied they will be affected by the mortality m_2. The rate m_0 will be applied afterwards. The rate m_d is applied once, m_1 during t_{m1} years and m_2 during t_{m2} years. The rate m_0 is applied during the remaining time, T- $(t_{m2} + t_{m1})$ years. Finally, N_1 through time is given by the following equation:

$$N_1 = N_{1i} (1 - m_d) (1 - m_1)^{t_{m1}} (1 - m_2)^{t_{m2}} (1 - m_0)^{T - (t_{m1} + t_{m2})}$$

Let N_{2i} be the initial number of stems below 60 cm that can reach this limit within T years. In the same way as above, N_2 through time is given by the following equation:

$$N_2 = N_{2i} (1 - m_d) (1 - m_1)^{t_{m1}} (1 - m_2)^{t_{m2}} (1 - m_0)^{T - (t_{m1} + t_{m2})}$$

While N_{1i} is a constant, N_{2i} is a function of T. The longer T is, the greater is N_{2i}. After logging, the remaining stand has a stimulated growth (Δd_1) during t_1 years. If silvicultural treatments are applied, the growth is enhanced (Δd_2) during t_2 years. Then, once the treatment is finished, the stand has finally the growth of a virgin forest (Δd_0) during the remaining time T- $(t_2 + t_1)$.

The diameter of the smallest tree (D_{inf}) that can reach 60 cm within the time T is therefore

$$D_{inf} = 60 - [(T - (t_2 + t_1))\, \Delta d_0 + t_2 \Delta d_2 + t_1 \Delta d_1]$$

Next, to calculate N_{2i}, we use the diameter distribution $f(d)$ of the stand that we integrate between the two limits D_{inf} and 60,

$$N_{2i} = \int_{D_{inf}}^{60} f(d)$$

The total number of commercial trees >60 cm dbh at time T, N_{tot} is finally $N_1 + N_2$.

Mortality and growth assessment

The mortality rate between two measurements M_i and M_{i+1} is defined as the ratio of the number of dead trees at the measurement M_{i+1} to the number of individuals at the previous measurement, expressed in percentage. All the rates given in this study are annual mortality rates (AMR) calculated by taking into account the time span between two measurements. After logging, we did not try to separate the natural mortality from that induced by the logging operations. We calculated the rates of an overall "mortality after logging". The growth rates are mean annual increments in diameter (DMAI), calculated as the mean difference in diameter between two measurements scaled to one year.

The bulk of the commercial timber being mainly composed of dipterocarps, the growth and mortality rates used in our simulation are those calculated from the dipterocarp stand only, all species included. Moreover, to take into account the possible influence of diameter on rates, we assumed that for a cutting cycle of 35 y as recommended by TPTI, most of the trees reaching 60 cm dbh come from the class (40–60). Therefore, mortality and growth rates were calculated from the dipterocarp stand of the class (40–60), all species included.

Growth and mortality data in primary forest were computed from the records of 12 ha of the RKL 4 over a period of 3.5 y, those from the logged-over forest 2 y after logging, from the records of 36 ha of the RKL 4 over a period of 2 y. The results obtained for the forest logged 15 years ago with subsequent silvicultural treatment were calculated from the records of 16 ha of the RKL 1 over a period of 2 y (Nguyen-The *et al.* 1998).

To determine the diameter distribution ($f(d)$) of the stand, different types of functions can be used as pointed out by Sumaryono (1996). We chose here to estimate this distribution by an exponential function that is biologically suitable and provides a satisfying adjustment to the data (Sumaryono 1996). Since we used it only with the stems below 60 cm, we made our adjustment only on this part of the stand.

Scenarios of simulation

Five basic scenarios of forest management were set up in order to upraise different combinations of silvicultural treatments:

Scenario 1: Conventional logging: One harvest with usual logging techniques and without any particular silvicultural treatments until the next harvest.

Scenario 2: Conventional logging + thinning operations: One harvest with usual logging techniques plus one thinning operation when the forest has recovered from the logging operations.

Scenario 3: Reduced impact logging: One harvest with RIL techniques to lessen damages and no particular silvicultural treatments until the next harvest.

Scenario 4: Reduced impact logging + thinning operations: One harvest with RIL techniques plus one thinning operation when the forest has recovered from the logging operations.

Scenario 5: TPTI (Indonesian selective cutting and planting system): The forest management following a strict observation of the TPTI recommendation. After logging, the high growth of the remaining stand is maintained throughout the 35 y of the cutting cycle by regular thinning operation.

Results

Stand characteristics and dynamics in primary and logged-over forest

Number of stems

The primary forest was composed on average of 530 stems ha^{-1}, all species included and 130 dipterocarps ha^{-1}, with the usual decreasing frequencies with increasing diameter (Figure 2). Description of forest richness and forest structure can be found in Sist and Saridan (1998). There was on average 16 dipterocarps ha^{-1} above 60 cm dbh. The adjustment of the dipterocarp diameter distribution ($f_{(d)}$) with an exponential is

$$N = 11.306 \exp^{-0.0547d} \quad (\text{with } r^2 = 0.93, \ p = 0.0001)$$

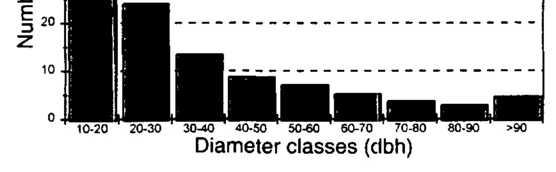

Figure 2. Diameter distribution of the dipterocarps in virgin forest (RKL 4, 12 ha)

Mortality

In primary forest, the overall annual mortality rate was 1.5% y^{-1}. There was no evidence that mortality rates differed between diameter classes ($\chi^2 = 9.1$ p = 0.33). Moreover, all diameter classes included, there was no significant difference between dipterocarps and non-dipterocarps ($\chi^2 = 0.04$, $p = 0.84$). The value of m_0 was therefore fixed to 1.5 % (Table 2).

Table 2. Recapitulatory table on the growth and mortality rates calculated from STREK project data. (Dipterocarps, diameter class 40–60).

Mortality rates (% y^{1})		Growth rates (cm y^{1})	
$m_{d\ (conventional\ logging)}$	8.5		
$m_{d\ (RIL\ techniques)}$	6.5		
$m_{l\ (conventional\ logging)}$	2.5	Δd_1	0.53
$m_{l\ (RIL\ techniques)}$	1.7	Δd_2*	0.59
m_0	1.5	Δd_0	0.41

*: if silvicultural treatments are applied.

The mean extraction rate on the whole layout was 8 stems ha^{-1}, representing 50% of the initial stock. The mean number of stems damaged by logging was 214 stems ha^{-1}. Damages (m_d) on dipterocarps of the class 40–60 cm dbh were on average of 8.5%. The RIL techniques made it possible to reduce this to 6.5 % (Sist & Bertault 1998).

Two years after logging, the mortality (m_l) calculated was 2.5% y^{1}, which was significantly different from the mortality of the primary forest during the same period ($\chi^2 = 46.7$, $p = 0.001$). Just as in virgin forest, nothing allowed making a difference of mortality, neither between diameter classes, given the overlay of the confidence intervals, nor between dipterocarps and non-dipterocarps ($\chi^2 = 0.67$, $p = 0.41$). With the RIL techniques this rate was reduced to 1.7% y^{1} (Table 2).

The STREK layout allowed one to assess whether the thinning operations resulted in a higher mortality and we made the assumption that the mortality during the silvicultural treatments (m_2) was not different from the mortality in primary forest (m_0) and therefore, t_{m2} is nil.

Growth

In the primary forest, all diameter classes and species included, the overall growth rate was 0.22 cm y^{1}. Dipterocarps had a mean growth rate of 0.3 cm y^{1}. There was an influence of the diameter class (Figure 3) and the DMAI increased with size class. The growth rate of the dipterocarps in the class 40–60 cm dbh (Δd_0) was 0.41 cm y^{1} (Table 2).

Two years after logging, the growth rate for all the stand was 0.39 cm y^{1} with dipterocarps reaching on average 0.51 cm y^{1}. The growth rate of the class 40–60 cm dbh (Δd_l) was 0.53 cm y^{1}. The silvicultural treatments carried out in the RKL 1 led to a growth increase of +44 % in the class 40–60 after 2 y (Δd_2), that is 0.59 cm y^{1} if applied to the growth of the primary forest.

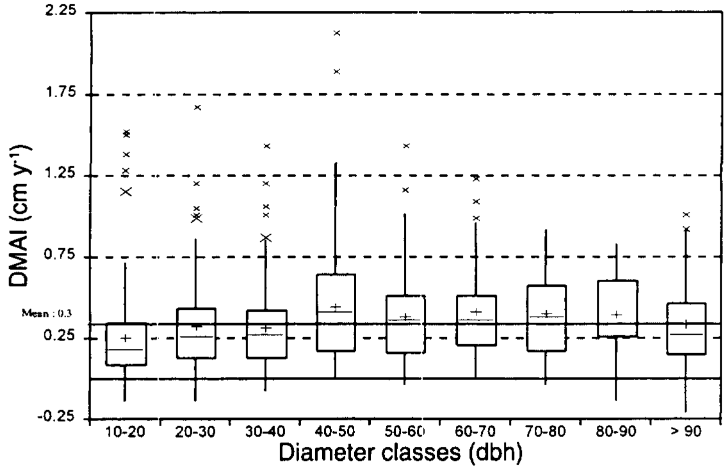

Figure 3. Diameter mean annual increment (DMAI) by diameter class. Dipterocarps in virgin forest (RKL 4-12 ha).

For the simulation, the variables t_e, t_l and t_2, that is how long the high growth and mortality rates will be maintained after logging or thinning operations, are still unknown. The STREK layout did not make it possible to answer this question. For this, we referred to the literature.

Data from the literature

Mortality

Several studies in tropical forests showed that maximum mortality occurred 2 y after logging (Tang & Wan Razali 1981, Durrieu 1993, Petrucci & Tandeau de Marsac 1994). In most cases, after approximately 5 y, the mortality rates become similar to those of virgin forest (Yong 1990, Durrieu 1994, Petrucci & Tandeau de Marsac 1994). However, Silva *et al.* (1995) in the Amazon did not find any decrease over a period of 11 y after a logging intensity of 16 trees ha^{-1}. We chose to estimate t_{ml} to 5 y (Table 3).

Growth

Time length of high growth rate after logging is still not clearly assessed. According to Silva *et al.* (1995) and Primack *et al.* (1988), growth stimulation after logging lasts 3 y only. Favrichon and Higuchi (1996) in Brazil showed a return to the primary forest rates after 7 y, and on two sites of Africa and French Guiana, the high rates were maintained at least during 8 y (Favrichon *et al.* 1997). However, these values depend on the logging intensity and damages (Nguyen-The *et al.* 1998). Based on these general considerations, for this study, t_l was fixed to 5 y (Table 3). Finally, based on the results of studies by Maître (1985) and Bryan (1980), the time period of growth rate stimulation following silvicultural treatment (t_2) was also assessed to 5 y.

These results are used in each scenario (Table 3). Concerning the fifth scenario (TPTI), it is assumed that the overall growth rate after logging is 1 cm y^1. Sutisna (1994) indeed observed growth rates ranging from 0.5 to 1.5 cm y^1 in areas managed under the TPTI system. But according to Burgess *et al.* (1992), the average value of 1 cm y^1 in the TPTI seems probably too high. These authors suggest a more realistic rate of 0.6 cm y^1 lasting for 35 y according to the results of Uebelhor *et al.* (1990). We kept this latter rate for our simulation. The lack of information on the mortality rates led us to apply those of the STREK project with the RIL techniques (damages: 6.5%, mortality after logging 1.7 %) (Table 3).

Table 3. Scenarios: mortality and growth rates kept for the different simulations

Scenario	Mortality rates and periods				Growth rates and periods				
	m_d	m_l	t_{ml}	m_0	Δd_l	t_l	Δd_2	t_2	Δd_0
S1	8.5	2.5	5	1.5	0.53	5	-	-	0.41
S2	8.5	2.5	5	1.5	0.53	5	0.59	5	0.41
S3	6.5	1.7	5	1.5	0.53	5	-	-	0.41
S4	6.5	1.7	5	1.5	0.53	5	0.59	5	0.41
S5	6.5	1.7	5	1.5	0.53	5	0.60	+∞	0.41

Results of the simulation

The total number of dipterocarps (N_{tot}) above 60 cm dbh *T* years after logging is given in Table 4. The simulation has been carried out for different values of *T* ranging from 20 to 60 y, with a special simulation for *T* = 35 y which is the official cutting cyle of the TPTI. In addition, we calculated the necessary time required for the forest to reach the initial number of stems above 60 cm dbh ($N = N_i$).

Table 4. Number of dipterocarp stems above 60 cm dbh *T* years after logging

Scenario	N_i	0	*T*						*T*opt
			20	30	35	40	50	60	($N = N_i$)
S1	16	8	8.7	9.2	9.5	9.8	10.4	11.1	114
S2	16	8	9.1	9.7	10.0	10.3	10.9	11.7	106
S3	16	8	8.9	9.5	9.8	10.2	10.9	11.7	105
S4	16	8	9.3	10.0	10.3	10.7	11.4	12.3	98
S5	16	8	10.3	12.0	13.1	14.3	>16	>16	47

N_i is the initial number of stems before logging. At *T* = 0, the number of stems corresponds to the remaining stand after logging.

In the first four scenarios, the time required before the forest returns to the initial state is about 100 y or more. With the fifth scenario (S5), this time is only 47 y. However, with this last scenario, high growth rates are maintained throughout the cutting cycle by regular thinnings. This scenario must be considered as that of an ideal forest in the best conditions but is far from the reality.

The silvicultural treatment as applied in the STREK project (S2) leads to a reduction of 10 y on the necessary time to return to the initial state, compared to the logged forest without any treatment (S1). The reduced impact logging methods (S3) lead to the same result and both methods combined (RIL + thinnings, scenario S4) lead to a reduction of 15 y on the recovery time.

Regarding the estimation of the harvestable stock after 35 y, with the first four scenarios, the expected number of stems with a diameter above 60 cm to be harvested after 35 y is around 10 stems ha^{-1}. Considering the confidence interval of the growth rates, it ranges from 8.6 to10.5 trees ha^{-1} after 35 y.

At the first harvest, the extraction rate was of 50% on average. After 35 y with the prediction of 10 stems ha^{-1} above 60, we can therefore foresee a harvest of 5 stems ha^{-1} in the best case. The RIL methods in addition to silvicultural treatments lead approximately to the gain of 1 stem after 35 y (+10 %) compared to the natural reconstitution after conventional logging.

Discussion

The results of the simulation indicate the long time required for the forest to recover and return to the initial state. Even in the most favourable case, which is not the most realistic, the time required is at least around 50 y. In all the other cases, it is rather around 100 y. The reduced impact logging techniques enable this time to be reduced (10 to 15 y compared to conventional logging). These methods will be all the more interesting as they will reduce damage and the number of injured trees (Sist *et al.* 1998). These are indeed stems of potentially poor quality as they are prone to develop distortion or rot. Silvicultural treatments such as thinnings prove to be interesting to boost the commercial stems and lead to a reduction of the recovery time but their application depends more on the implementation costs.

The growth and mortality rates of virgin forest calculated from the STREK project data and used for the simulation are consistent with those from many other sites of lowland mixed dipterocarp forest in Southeast Asia (Wyatt-Smith 1961, Nicholson, 1965, Tang 1976, Manokaran & Kochummen 1987, Swaine *et al.* 1987, Yong 1990). Some differences may be observed especially for growth rates after logging (Thang & Yang 1988, Thang 1989) but this is naturally due to the high variations of logging intensity (Nguyen-The *et al.* 1998). The scenarios detailed and the simulation results could be those of many other sites elsewhere in Malaysia.

The results obtained through this method are clearly influenced by the rates and more particularly the periods (t_1, t_2 and t_{ml}) used. We chose arbitrarily, yet in accordance with data from the literature, 5 y for the three periods. With longer periods, the results of the simulation would be shortened. There is obviously the need for a follow-up of the layout on the long term to refine and ascertain these results. Nevertheless, the TPTI characteristics as applied theoretically in a rather unrealistic way provide a maximum limit that is unlikely to be reached. All the scenario simulations in this study demonstrate that a felling cycle of 35 y as recommended in TPTI is clearly too short. This result is also confirmed by Mendoza and Setyarso (1986).

This approach must be considered with caution as it must be borne in mind that we make the simulation in terms of number of stems. Our simulation forecasts around 10 stems ha^{-1} with a diameter above 60 cm after 35 y. The corresponding volume will not be equivalent to that in primary forest conditions. Indeed, the volume will be made of trees that have just passed the 60 cm limit. Furthermore, the trees that are left during the first logging operation are likely to be misshapened or hollow and will keep a poor value for the second harvest.

The aim of this paper is, however, not only to provide estimation results but also to provide a basic and simple tool to be used by forest managers, should this tool be modified and adapted to local requirements. Given these results, the issue is now to know whether these scenarios can be considered as sustainable or not. According to this simulation, the forest will require more than 100 y to return to its initial state but this one corresponds often to the accumulation of old trees sometimes without any more commercial value. This state is not necessarily desirable for sustainable management. A forest can indeed be managed in a sustainable way with a cutting cycle shorter than 100 y or so, provided that a harvest, lower than the first one, is accepted. According to the model of Favrichon and Young Cheol (1998), the forest can be harvested often but with a low extraction rate. The definition of the most suitable cutting cycle will be a compromise between the production level, the subsequent benefit desired, and the cost of the intervention. The probable impoverishment of the species diversity should also be taken into account.

Acknowledgements

This study was carried out in the framework of the STREK project sponsored by the French institution FFN (Fond Forestier National), the Indonesian Government, and CIRAD-forêt. We wish to thank all the staff members of the STREK project who carried out the field measurements necessary to this study and PT. INHUTANI I for the collaboration in the field.

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