Determination Of Sustainable Management Of Natural Tropical Forests Using SYMFOR Modelling Framework

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EXTENDED ABSTRACT

A permanent sample plot (PSP) data set was enumerated from primary forest in Jambi province, Indonesia. No silvicultural treatment (harvesting, thinning, poisoning) was applied to the plot during the period in which measurements were taken. The data set including individual tree information such as tree identity, diameter and position within the plot, was input into the Sustainable Yield Management for Tropical Forests (SYMFOR) model. The model has been calibrated for a Kalimantan PSP data set.

Prior to the simulation, the Jambi data set was compared to the Kalimantan data set in terms of diameter class distribution, the dominant tree species, and tree family distribution. It was concluded that both data sets are not significantly different. Moreover, both data sets are lowland tropical primary forest types. Hence, the model was readily applicable to this Jambi data set.

Using the SYMFOR computer model several harvesting methods were simulated. These were the conventional method TPTI (*Tebang Pilih dan Tanam Indonesia)*, RIL (Reduced Impact Logging) and a set of harvesting methods derived from the RIL namely RIL8, RIL50 and RIL60. The RIL8 means the maximum number of trees allowable to cut is 8 per hectare, while the RIL50 and RIL60 means the maximum volume of the allowable cut is 50 m^3 ha^{-1} and 60 m^3 ha^{-1} respectively. The RIL60 associated with the production forests category while the RIL50 with the limited production forests category.

The simulation was run over a long period of time in order to cover multiple harvest cycles, and were repeated for several times to capture the variability among the runs. These output results were manipulated to obtain the evolution of timber extracted as time went on.

Under a 35 year cutting cycle, the RIL50 and RIL60 performed better than other methods - the amount of timber extracted per hectare in the first harvest were successfully attained before the next harvest.

The simulation was also conducted by altering the length of cutting cycle within the TPTI, RIL and RIL8. The results showed that timber production increased with the cutting cycle. In particular, under the RIL8 on 45 years cycle, the quantity of timber extracted reached back its pre-first harvest level. This might be due to maximum allowable cut assigned for the RIL8 was less severe.

The effect of logging on residual stands was also simulated. It was found that both the RIL50 and RIL60 were consistently better than the other harvesting methods; the forest system could be revived almost to the condition of pre-first harvest level.

Upon the cutting cycle extension, it was found that under RIL50 and RIL60 methods, the level of residual stand beyond the 35 years cycle, were successfully returned to its pre-first harvest level. In contrast, both the TPTI and the RIL methods failed to reach its respective pre-first harvest level despite substantial extension of the cutting cycle applied. Notably, the RIL8 which is considered to be less severe logging compared to the RIL, still failed to reach the pre-first harvest level particularly if the cutting cycle less than 45 years. This suggests that in order to reach forest sustainability, careful logging operations as assigned within the RIL methods should be in conjunction with the reduction of logging level.

This study consistently suggests that the current forest management guidelines in Indonesia (the TPTI) would not lead our forest sustainably. Both RIL50 and RIL60 harvesting methods on 35 year cycle could be good alternatives for the TPTI.

1. INTRODUCTION

TPTI (*Tebang Pilih dan Tanam Indonesia*) is the current forest management guidelines for the management of natural tropical forests in Indonesia. Among the rules assigned in this selective cutting method are: individual trees above 50 cm in dbh (diameter at breast height) may be harvested, and may be re-harvested in the same area in the next 35 years. It is expected that a similar amount of timber will be obtained given this length of time for regeneration. However, the 35-year cycle was calculated based on an assumption that the dbh increment of individual trees was 1 cm per year and the volume increment was at least 1 $m^3ha^{-1}yr^{-1}$. Van Gardingen (1998) indicated that the above assumption lacks scientific basis. This might cause some doubt whether our natural tropical forests would be sustainable or not under this harvesting method. Here, the sustainability was defined as the extent to which the forest system could be restored back to the respective pre-first harvest level of timber extracted and the residual stand.

In order to conduct an assessment into the TPTI, extensive PSP datasets comprising of several experimental hectares, where continuous surveys have been conducted, for a substantially long period of time, are required (Alder and Synott, 1992). This is too expensive both in terms of labour, and financial resources required. Moreover, in terms of time interval required to complete the survey, it is almost impossible to assess the TPTI in the conventional way. In addition, natural tropical forests are known for their complex systems, both in terms of the size and the species of trees growing in them (Vanclay, 1994). This makes the task even more difficult. This is the reason why modeling becomes important, where models are built to represent natural phenomena.

The natural phenomena being modelled in SYMFOR are recruitment, tree mortality, and tree growth. In each phenomenon, particular mathematical equation was implemented, which was determined via nonlinear regression analysis using the Kalimantan data set. If some trees are removed from the forest under a particular harvesting regime, then some trees in the residual stand will be smashed and probably died. As a result, more light comes through into the forest floor. Hence, the growth of the existing trees improved. For every time step elapsed, individual trees might die, grow, and have the newly trees recruited. After some years elapsed, the hectare will be harvested again under the same harvesting regime and the process repeats.

SYMFOR is considered as a computer model framework, due to the modularity feature offered. It enables forest managers or policy-makers to assess whether a harvesting regime being practiced for their concessionary forests, could lead to forest sustainability or not (Young and Muetzelfeldt, 1998; Van Gardingen and Phillips, 2000). This was possible because users are allowed to alter parameter values such as length of harvest cycle, and minimum tree diameter may be cut. For instance, users could explore the effect of extending the 35 years harvest cycle within the TPTI into 40 years length; in terms of the quantity of timber could be obtained per unit hectare.

Using the Kalimantan data sets, a computer simulation using SYMFOR was conducted and concluded that the TPTI would not lead to sustainable forests (Phillips *et. al.*, 2003; van Gardingen *et. al.*, 2003). Therefore, the TPTI needs to be revised.

In order to check whether such a conclusion is site specific or not, the model needs to be tested. A PSP dataset gathered from Jambi Province in Indonesia has been utilised to conduct this test. The spread of the basal area means of both data sets were compared, and concluded that both data sets were not significantly different. Therefore, recalibration of the mathematical equations implemented in the SYMFOR software, were not necessary. Both diameter and family distributions of all trees suggested that the Jambi data set is appropriate for this purpose. The other reason being, both the Jambi and the Kalimantan plots are categorised as lowland forests.

2. MATERIAL AND METHODS

2.1. PSP datasets

Data of individual trees enumerated from a permanent sample plot (PSP) were made available in this study. This six hectare plot was located in Pasirmayang - Muarabungo, Jambi province of Sumatra. Laumonier (1997) indicated that the geographical location of the site is between $1^o1'35''$–$1^o5'55''$ South Latitude and $102^o4'35''$–$102^o6'45''$ East Longitude, at an elevation of about 30-40 meters above sea level. This 6 ha ((200x300) m^2) plot was established by BIOTROP – a research institute of Bogor Agricultural University (IPB), Bogor.

The details of individual trees gathered in each survey, were: tag number; co-ordinates, dbh, point of measurement, and the level of scientific family names were ascertained, with some to the species level. The point of measurement indicates the height of point above ground where the dbh was measured. In this data set, those greater than 30 cm in dbh were grouped as trees, while the smaller ones, with a dbh between 10 cm and 30 cm were grouped as poles.

2.2. Quality control of the dataset

Those categorised as poles ($10 \leq dbh \leq 30$) cm were listed and details noted in 1987, 1994, and 1998, while those categorised as trees (dbh>30) cm were listed and details noted in 1985, 1994, and 1998. In this study, both poles and trees groups were overlaid and considered as the initial condition of the stand, despite the measurement time for the first survey were spanned over two years, since the dbh increment were unlikely to be significant over such a short period of time.

In total, 4154 individual trees of both groups were enumerated in the first survey. In the second measurement, less than 90% of the trees were re-measured. The number of trees was slightly increased in the third measurement, simply because some individual trees were not measured in the second time but re-measured in the third measurement. This inconsistency was found to be mostly within the poles category.

In order to show the quality control of this data set, the individual tree growth was calculated. It was noticed that 87% of the total individuals showing positive dbh increment within the first growing interval i.e. between the first and the second measurements; and 74% of the total individuals were showing positive dbh increment in the second growing interval i.e., between 1994 and 1998.

In this study, the data set obtained in the first measurement was utilized into SYMFOR computer framework, as the number of measured trees was the largest compared to the following time of measurements. Also, the percentage of trees with positive dbh increments was the highest within the first growing interval i.e., between the first and the second measurements.

2.3. The dbh class distribution

The dbh class distribution of individuals within the plot in each measurement is shown in Figure 1. This reversed-J shape commonly occurs in primary tropical forests - the number of trees decreased with the diameter class (Whitmore, 1998). As shown in Figure 1.a, the number of poles within the 10-15 dbh class is rapidly decreased with time of survey. This captured the unmeasured poles beyond the first measurement, as previously explained. Those above 50-55 diameter (dbh) class were extracted from Figure 1.a, and zoomed (see Figure 1.b.).

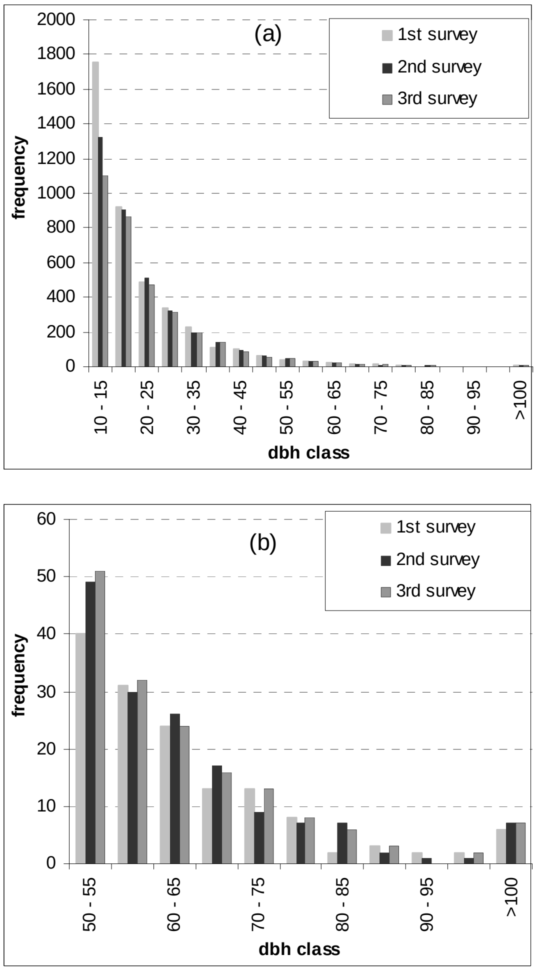

Figure 1. Diameter (dbh) class distribution of all individuals (a), and those above 50 cm in dbh (b).

2.4. The distribution of scientific families

There are more than 95% of the total individuals were identified as being from 58 scientific families. In Figure 2, tree families containing less than 20 individuals were denoted as “Others”, while the “Unknown” are those with scientific family names could not be identified (the second top bar). The cross-section area of each tree was calculated at the point where the diameter was measured, presuming its circular shape. This is defined as basal area (BA). In Figure 2, the total basal area for each family in the whole plot is presented. The Dipterocarpaceae family dominates the plot, with its total basal area almost 8 m^2 ha^{-1}, which is almost 25% of the stand. This is a typical of primary topical forests in South East Asia

(Whitmore, 1998). Sist and Saridan (1999) reported that the Kalimantan PSP data set (was used to calibrate SYMFOR) is also dominated by the Dipterocarpaceae family.

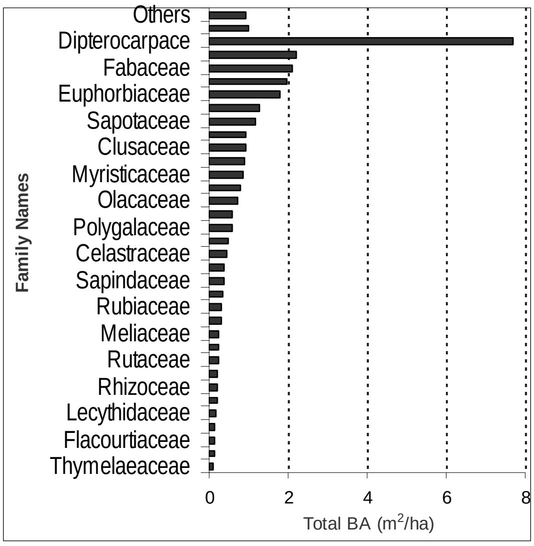

Figure 2. The total basal area per hectare of each family in the whole plot. The family names were alternately omitted.

Further, each individual was allocated into a member of particular ecological species group and commercial species group. The commercial groups were based on timber marketing in East Kalimantan (Rombouts, 1998; Phillips *et. al.*, 2002), while the ecological groups were established for SYMFOR using the Kalimantan PSP data set via nonlinear regression. The ecological grouping was intended to capture that each species group response differently to environment change followed to logging. For instance, the light demanding species were plausible to be clustered into different group with the shading tolerant species – tree species that are still growing in the absence of light (Whitmore, 1998). Phillips, *et. al.*, (2003) established 10 species groups for Kalimantan PSP data set. These 10 ecological groups were adopted into the Jambi data sets given that both data sets were not significantly different. See the following section.

2.5. Test of similarity

This test was conducted to test the similarity between Jambi and Kalimantan datasets, provided both plots were categorised as primary forests (Phillips, *et. al.*, 2003) and had not been logged over the measurement period. The data set of both sources, which were enumerated in the first survey were utilized in this test.

The average basal area of living trees per hectare was calculated in conjunction with its standard error for each data set. It was concluded that Kalimantan and Jambi data sets are not significantly different, since error bars overlap the means. This indicates that the confidence limits overlap. Hence the difference between both datasets is considered to be non significant (Parker, 1979). See Figure 3.

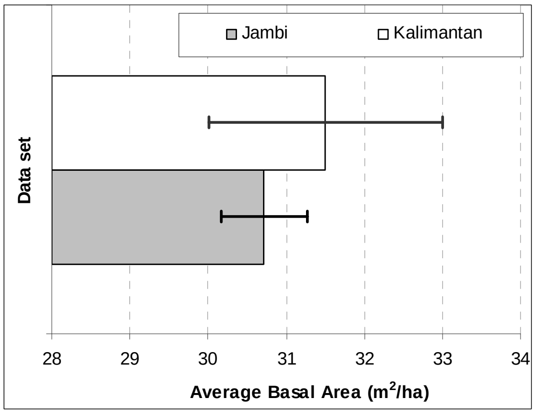

Figure 3. The comparison of basal area means between both data sets.

2.6. Setting up the modules in this simulation

The harvesting methods simulated were TPTI, RIL, RIL8, RIL50, and RIL60. Unlike in the conventional TPTI, in those RIL descendant methods pre-harvesting plan exist, the harvesting process are more careful, and felling was directed. Also, the damage to residual stands was expected to be lower for the RIL descendants given a shorter Skid prepared radius, narrower Skid width and less damage to surrounding trees (Max dbh likely to damage). Therefore, those RIL descendants are considered more ecologically sound than the conventional TPTI. See Table 1.

Table 1. Specification of harvesting regimes set up in this simulation (adapted from van Gardingen *et. al.*, (2003)).

	TPTI	RIL	RIL8 max. 8 stems/ha	RIL50 max. 50 m^3/ha	RIL60 max. 60 m^3/ha
Management modules					
Felling	Undirectional	Directional	Directional	Directional	Directional
Plan skidtrails	Straight	Branched	Branched	Branched	Branched
Management parameters					
Logging specifications					
Dbh threshold (cm)	50	50	50	50	50
Proportion of commercial trees in the plot	0.3	0.3	0.3	0.3	0.3
Max. number of trees extracted	500	500	8	500	500
Max. volume extracted (m^3)	500	500	500	50	60
Skidding (extraction)					
Max dbh likely to damage (cm)	40	30	30	30	30
Skid prepared radius (m)	5	3	3	3	3
Skid width (m)	7	5	5	5	5

The maximum allowable cut assigned for TPTI and RIL was 500 m^3 ha^{-1} while for the RIL50 and RIL60 were assigned at level 50 m^3 ha^{-1} and 60 m^3 ha^{-1} respectively. For the RIL8, the maximum allowable cut was assigned 8 trees ha^{-1}. The RIL8 is considered to be moderately severe logging compared to the conventional TPTI, but more intense than RIL50 and RIL60 (Priyadi, *et. al.*, 2002).

For each of this six hectare plot, the simulation run for 350 years with 20 replicates, so that multiple harvests were covered and the variability among the runs captured.

3. RESULTS AND DISCUSSION

3.1. Comparison among harvesting regimes

The total basal area of timber extracted per hectare for each harvesting methods on 35-year cutting cycle, is presented in Figure 4. It was observed, the total quantity of timber is rapidly dropped starting from the 2nd cycle to the 4th cycle (year-35 to year-105), then rise again.

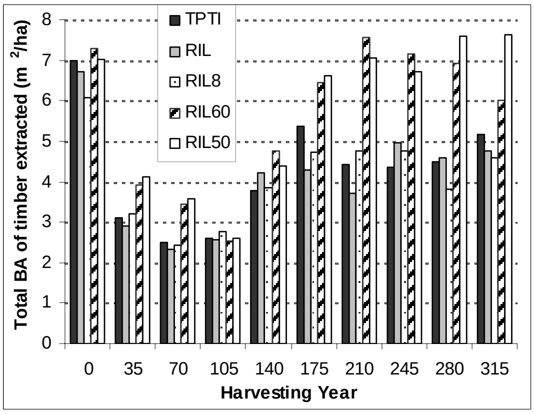

Figure 4. Total basal area (BA) of timber extracted per hectare.

Under the TPTI method, the basal area of timber has never reached its first harvest level, despite having run the simulation 10 harvest cycles. This is because logging was too severe in the first iteration. In other words, the maximum allowable cut assigned for this conventional TPTI was too high. As a consequence it will be very difficult to get back to its first-harvest levels, although the simulation was carried out for a substantial long period of time. A similar pattern was depicted for the RIL and RIL8 methods.

In contrast, the RIL50 and RIL60 could be considered as "good" alternatives for the TPTI since the basal area of timber extracted is higher under these methods compared to the three methods just mentioned, in most harvesting years. In fact, under these methods, the first harvest level has been slightly exceeded starting from the 7th cycle onwards (year 210 onwards). This was due to the more ecological-sound harvest plan assigned in both methods, compared to the conventional TPTI, and less severe logging compared to the other RIL methods.

It was anticipated, that by extending the cycle length the amount of timber extracted would increase as more time allowed for regeneration process. A simulation was conducted particularly for the less performed harvesting methods i.e., TPTI, RIL and RIL8 with choices of cutting cycles were 25, 30, 35, 40 and 45 years long. The system behaves as expected – the amount of timber extracted is gradually increased as the cutting cycle lengthens. In particular, the RIL8 method on 45 years cycle is successfully exceeding its first harvest level. Again, this was due to the less severe logging assigned in this method compared to the TPTI and the RIL methods. See Figure 5.

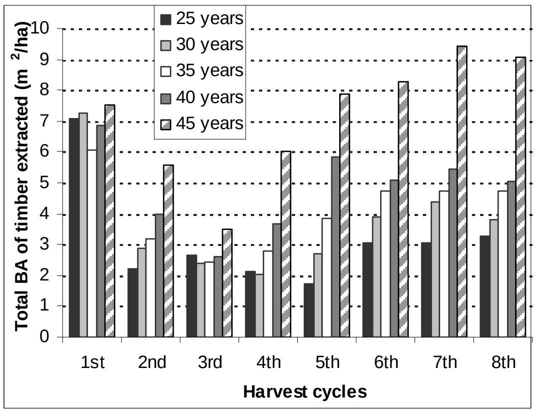

Figure 5. Total basal area (BA) of timber extracted in the RIL8 method with cutting cycle altered.

3.2. Effect of logging on residual stands

The response of residual stand on logging could give an indication of forest sustainability under a particular harvesting regime. In this simulation, the total basal area of the residual stand per hectare is calculated every year for 350 years simulation long. The simulation was conducted by applying the conventional TPTI and consecutively with the RIL descendant methods. All of them were based on 35 years cutting cycle applying to the Jambi PSP data set. The results are presented in Figure 6.

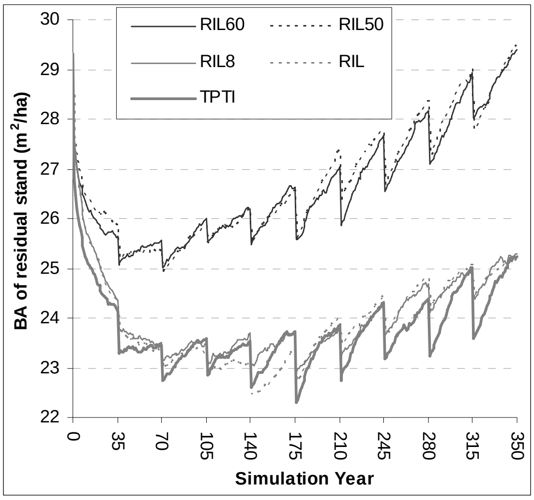

Figure 6. The residual stand's response of several harvesting method on 35-years cutting cycle.

As discussed previously, both RIL50 and RIL60 are considered to be performing well in terms of the quantity of timber extracted. The same conclusion is drawn here. The total basal area of the residual stand under both harvesting methods could reach its pre-first harvest stand level, despite a long period of time is required.

In Figure 6, total basal area of the residual stand under the TPTI method is lower than RIL50 and RIL60. This was expected, due to the less ecological sound harvesting modules assigned for the conventional TPTI. Please refer to Table 1. Moreover, the RIL and RIL8 methods tend to be clustered with the TPTI diverged from the pre-first harvest stand level. Despite both RIL and RIL8 were assigned to be more careful logging operations compared to the conventional TPTI, but the maximum allowable cut assigned in both methods are still too severe compared to the RIL50 and RIL60. This seems to be largely affecting the pattern. The same conclusion was drawn in the simulation of timber extraction, previously discussed.

It is widely accepted that the RIL method is more ecological sound than the conventional TPTI. Van der Hout, (1999) indicated that the number of small trees damaged is higher under the conventional logging compared to the RIL method. But, in terms of total basal area of residual stand the difference between both methods are not significant. This finding is consistent with the simulation results obtained in this study. Bertault and Sist, (1997) indicated that under RIL8 which is considered to be a high felling intensity, the proportion of injured and dead trees was similar to those recorded in conventional logging TPTI. This conclusion was obtained from the 24 ha plots established in Malinau, East Kalimantan province. In Figure 6, the residual stand graph of RIL8 tends to be clustered with the TPTI graph – meaning that the total basal area of the residual stand obtained under both methods is not very different. This simulation result is consistent with Priyadi, *et. al.*, (2002).

3.3. Effect of cutting cycle extension on residual stand

Here, a simulation was conducted to assess the effect of extending the length of cutting cycle on residual stand, with one expectation that if the cutting cycle extended then the residual stand level would eventually approach its pre-first harvest stand level, as more time provided for forest regeneration between two successive harvests.

Under the TPTI methods, it was observed that the extension of the cycle length has no effect to bring back the residual stand into the pre-first harvest stand level, despite the cycle length having been extended up to 45 years. See Figure 7. The same pattern observed for the RIL method. But, for the RIL8, the forest could get revived, under 45-years cutting cycle (see Figure 8). This relates to the maximum allowable cut assigned in RIL8 was lower than TPTI and RIL. Apart from anything else, the severity of logging is very important to be assigned down to a moderate level, in order to achieve sustainable forests.

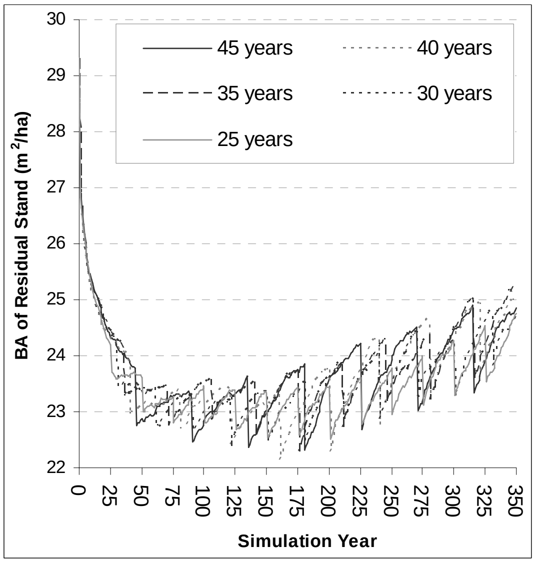

Figure 7. The residual stand's response on altered cutting cycle in the conventional TPTI method.

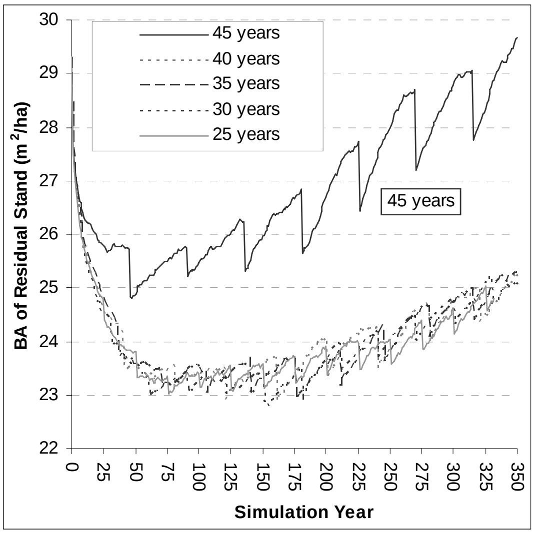

Figure 8. The residual stand's response on altered cutting cycle in the RIL8 method.

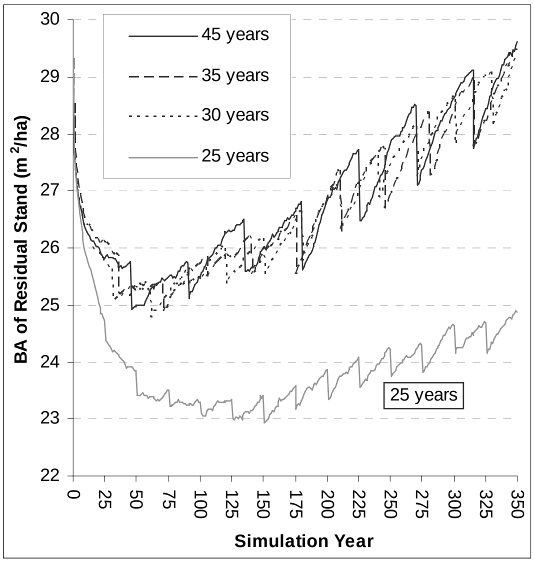

Figure 9. The residual stand's response on altered cutting cycle in the RIL50 method.

In fact, under the RIL50 method, the system has been successfully recovered back to its pre-first harvest stand level starting from the 30-year long of harvest cycle. This cycle length is even lower than the cycle length assigned in TPTI. Again, the severity of logging plays a key-role to achieve sustainable forests. See Figure 9. The same pattern was observed for the RIL60 method (not shown).

4. CONCLUSIONS

In order to manage our natural forest in a sustainable manner, the current guidelines TPTI need to be revised. The logging intensity assigned in the guidelines was found to be too severe. The harvesting methods namely RIL50 and RIL60 are found to be the best alternative to the conventional TPTI, since the quantity of timber extracted per hectare could reach back its pre-first harvest level, after a long period of time. It was shown that 35 years harvest cycle is adequate for both alternatives.

Moreover, in terms of the residual stand affected by logging, it was found that under the conventional TPTI the forest system has never reached its pre-first harvest stand level even after a long period of time has elapsed. The main reason was too much timber extracted in the first harvest. The reason seems to be valid for RIL8 method, a more ecological sound harvest procedure but logging was still too intense. The severity of logging is found to be the key factor affecting the failure to reach sustainability. The simulation on extending harvest cycle has shown that the forest system fails to be restored back to the pre-first harvest level of timber extracted and the residual stand.

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6. REFERENCES

Alder, D. and Synott, T.J., 1992. Permanent sample plot techniques for mixed tropical forests. Tropical Forestry paper 25. Oxford Forestry Institute, Department of Plant Sciences, University of Oxford, UK.

Bertault, J., and Sist, P., 1997. An experimental comparison of different harvesting intensities with reduced-impact and conventional logging in East Kalimantan, Indonesia. For. Ecol. Manage. 94, 209-218

Brash, T.E., Phillips, P.D., van Gardingen, P.R., 2000. Species groups for use with the SYMFOR modelling framework. (http://meranti.ierm.ed.ac.uk/g&y/speciesgroups)

Laumonier, Y., 1997. The vegetation and physiography of Sumatra (Geobotany; v. 22). Kluwer Academic Publishers.

Parker, R.E., 1979. Introductory statistics for biology. 2nd ed. Institute of Biology. Studies in Biology: No. 43. Cambridge University Press.

Phillips, P.D., Yasman, I., Brash, T.E., and van Gardingen, P.R., 2002. Grouping tree species for analysis of forest data in Kalimantan (Indonesia Borneo). For. Ecol. Manage. 157, 205-216.

Phillips, P.D., Brash, T.E., Yasman, I., Subagyo, P. and van Gardingen, P.R., 2003. An Individual-based spatially explicit tree growth model for forests in East Kalimantan (Indonesian Borneo). Ecol. Modelling 159, 1-26.

Priyadi, H., Kartawinata, K., Sist, P., and Sheil, D., 2002. Monitoring Permanent Sample Plots (PSPs) after Conventional and Reduced – Impact Logging in the Bulungan Research Forest, East Kalimantan, Indonesia. In: Shaharuddin bin Mohammad Ismail, Thai See Kiam, Yap Yee Hwai, Othman bin Deris and Svend Korsgaard (Eds). Proceedings of The Malaysia-ITTO International workshop on growth and yield of managed tropical forest 25-29 June 2002, Pan Pacific Hotel, Kuala Lumpur, Malaysia. Forestry Department Peninsular Malaysia.p 226-235.

Rombouts, J., 1998. Species grouping based on diameter increment in East Kalimantan. GTZ Sustainable Forest Management project, Samarinda Kalimantan Timur, 47 pp.

Sist, P. and Saridan, A., 1999. Stand structure and floristic composition of a primary lowland Dipterocarp forests in East Kalimantan. J. Trop. For. Sci. 11, 704-722.

Vanclay, J.K., 1994. Modelling Forest Growth and Yield: Application to Mixed Tropical Forests. CAB International, Wallingford, UK.

Van der Hout, P., 1999. Reduced impact logging in the tropical rain forest of Guyana : ecological, economic and silvicultural consequences. -- Georgetown, Guyana: Tropenbos - Guyana Programme. (Monograph) 335p.; ill. (Tropenbos - Guyana Series; no. 6)

Van Gardingen, P.R., 1998. TPTI implementation by Inhutani I Labanan: options for improving sustainable forest management. European Union, Berau Forest Management Project, Jakarta, 40 pp.

Van Gardingen, P.R, and Phillips, P.D., 2000. Growth and Yield Modelling: Application of SYMFOR to evaluate silvicultural systems. (DFID FRP Training Document). University of Edinburgh, UK.

Van Gardingen, P.R., McLeish, M.J, Phillips, P.D., Fadilah D., Tyrie, G. and Yasman, I., 2003. Financial and ecological analysis of management options for logged-over Dipterocarp forests in Indonesia Borneo. For. Ecol. Manage. 183, 1–29.

Whitmore, T.C., 1998. An Introduction to Tropical Rain Forests. Oxford University Press, Oxford, 226 pp.

Young, A.C. and Muetzelfeldt, R.I., 1998 The SYMFOR tropical modelling framework. Commonwealth Forestry Review, 77, 11-18.