THE EFFECTS OF LOGGING IN NATURAL FORESTS

By the magnitude of its impact, the harvesting process* defines a new stand structure to be managed for subsequent yield cycles. Controlling the harvesting process and minimizing the damage to the residual stand are therefore essential tasks for the silviculturist in any polycyclic system. Silvicultural activities will always have less effects than logging impacts. For example, for Southeast Asia, NICHOLSON (1979) estimated the total damage to residual stands of dipterocarps at 43.7 %, very close to assessments made in Latin America and Caribbean region (JONKERS, 1987 ; HENDRISON, 1989 ; COSTA FILHO, 1991).

Along with the development of reduced impact logging (RIL) techniques, a post-harvesting assessment is now required from concessionaires in accordance with Principle 25 of the ITTO** Guidelines for Sustainable Management of Natural Tropical Forests (1990). However, criteria to assess an acceptable level of damage to the ecosystem and which will protect against irreversible degradation, have yet to be defined. In this paper, we will refer to the results of the STREK Project***, a R & D Project launched in East Kalimantan (Indonesia) in 1989, where one component focuses on the assessment of damage to the residual stand under various logging practices and intensities, in a network of permanent sample plots (PSP). Following presentation of observed impacts, we will further consider ways to apply these estimations and recommendations at a concession scale of several tens of thousand of hectares.

* This is a less restricted expression than « logging operation » which is used mainly for the felling and skidding phases of the harvesting process (DYKSTRA and HEINRICH, 1992).
** International Tropical Timber Organization (ITTO).
*** See Bois et Forêts des Tropiques n° 232, p. 26-28 and n° 242, p. 77-81.

IMPACT OF LOGGING ON THE RESIDUAL STAND

Before logging, the study area was covered by primary lowland, mixed dipterocarp forest. Tree density (⩾ 10 cm dbh) and basal area were 530 stems/ha (SD = 63.3, N (plots) = 12) and 31.4 m²/ha (SD = 3.2, N = 12) respectively. Dipterocarps represented 25 % of the tree population (134 stems/ha, SD = 28.4, N = 12) and about 50 % (15.7 m²/ha, SD = 2.2, N = 12) of the basal area (SIST, 1994).

METHODS

Before logging commenced, 12 plots of 4 ha each were defined in a virgin forest. These were grouped into three blocks based on similarities in topography, species richness and tree density (BERTAULT *et al.*, 1993). In those plots all the trees ⩾ 10 cm dbh were measured, mapped and identified to at least the family level. Four different treatments were defined, each being replicated three times, once in each block of similar plots. They included two damage-controlled logging techniques, a conventional (CNV) logging method and, finally, a control treatment without any logging activities. The experimental logging treatments, E ⩾ 50 and E ⩾ 60, differed only in the minimum diameter of the trees to be felled, 50 and 60 cm respectively. Three months before logging, the climbers surrounding each tree to be felled were cut. The main skidtrails network was established according to the topographic features and the position of trees to be felled. Felling directions were defined in such a way that felled trees would lie in a position favourable for skidding. Felling and skidding damage were assessed separately using two complementary methods. In the first method, injured and dead trees (⩾ 10 cm dbh) were recorded at the end of each operation, using a code system that described the damage. The second method assessed the logging damage by delimiting the areas disturbed by each operation according to the position of injured or dead trees. Finally,three months after logging, a survey recorded the broken trees with regrowth as alive, whereas those without sprouts were regarded as dead.

RESULTS

□ Overview on logging damage

On average, logging damage affected about 40 % of the original tree population (Table 1). Injured and dead trees were recorded in roughly the same proportions (21 and 19 % respectively, Table 1). Felling mainly caused injury to trees whereas skidding was the primary cause of mortality (Fig. 1). The most common injury was crown damage caused mainly by felling, followed by bark and wood injuries resulting from skidding (Fig. 2). A Chi-square test was conducted to assess whether damage to each diameter class was distributed in accordance with the relative abundance of the class found in the original tree population. The difference between the injured and the original population was highly significant ($\chi^2 = 73.05$, df = 5, $\underline{P} < 0.01$) apparently because of the higher proportion of injured trees in the middle dbh classes, 30-50 cm (Fig. 3).

The main cause of mortality was uprooting during skidding and felling (76.5 and 10.1 % respectively). Mortality caused by stem breakage mainly occured during felling (8.1 vs 3.7 % during skidding). Small trees were more likely to be killed than large trees ($\chi^2 = 178.91$, df = 5, $\underline{P} < 0.01$, Fig. 3). The skidder's blade easily uprooted small trees (10-20 cm dbh) whereas the larger ones were naturally more resistant, and skidder damage on these larger trees was usually restricted to bark and wood injuries. Also, small trees were easily broken during felling, whereas bigger trees mostly suffered crown injuries. These results support the concept that the damage caused by felling and skidding operations is different. Felling primarily injured trees 30-50 cm in dbh whereas skidding caused mortality of small trees, 10-20 cm dbh.

Table 1. Proportions of trees injured and killed by logging in the three treatments
Mean (SD) are for 3 plots except for E ⩾ 60 which is for 2 plots only

	E ⩾ 50 ± SD	E ⩾ 60 ± SD	CNV ⩾ 60 ± SD
# Trees/ha before logging	537.5 ± 97.6	568 ± 101.1	494.4 ± 27.6
# Trees felled/ha	10.3 ± 3.8	6.5 ± 2.1	10.3 ± 1.1
% Injured trees	19.2 ± 0.5	16.9 ± 0.6	25.2 ± 0.6
% Dead trees	17.6 ± 0.5	13.6 ± 0.5	23.2 ± 0.5
% Felling damage	16.4 ± 0.5	11.8 ± 0.5	17.3 ± 0.5
% Skidding damage	19.0 ± 0.5	16.9 ± 0.6	29.9 ± 0.6
% Trees injured twice	1.4 ± 0.1	1.8 ± 0.2	1.2 ± 0.1

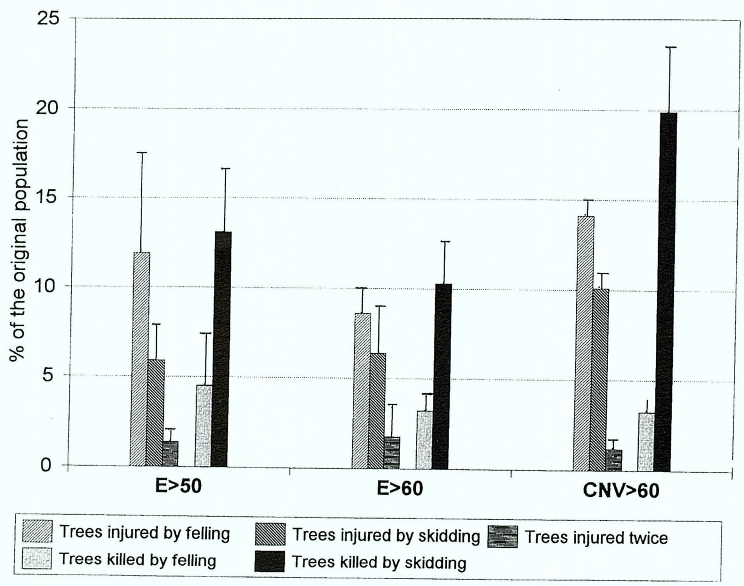

Figure 1. Mean percentage (bars = + SD) of trees damaged (i.e. injured or killed) by felling, skidding or both according to the treatments. E ⩾ 50, E ⩾ 60 : selective controlled-damage logging with a minimum cutting of 50 and 60 cm dbh respectively ; CNV : conventional selective logging.

□ Comparison of logging damage between treatments

For the same logging intensity, as recorded in E ⩾ 50 and CNV ⩾ 60, the total damage from controlled logging (E ⩾ 50) was significantly lower than when using conventional methods (CNV ⩾ 60) ($\chi^2 = 169$, df = 1, $\underline{P} < 0.01$, Table 1). For these two treatments, felling damage was not significantly different ($\chi^2 = 1.82$, df = 1, $\underline{P} > 0.01$), whereas skidding impact was lower in E ⩾ 50 than in CNV ⩾ 60 ($\chi^2 = 201.07$, df = 1, $\underline{P} < 0.01$). These results suggest that controlled logging mainly reduced skidding damage but failed to decrease those of felling (Table 1). This phenomenon was the result of the poor success of directional felling, as only 30 % of the trees were felled in the planned direction (pers. obs.). Although the size, crown shape and the abundance of lianas and epiphytes influenced the success of this operation, fellers often failed to accurately apply felling techniques to direct fall because of their inexperience and lack of training. Logging damage in E ⩾ 60 was significantly lower than in the other treatments (E ⩾ 60 vs E ⩾ 50, $\chi^2 = 47.06$, df = 1, $\underline{P} < 0.01$; E ⩾ 60 vs CNV ⩾ 60, $\chi^2 = 324.36$, df = 1, $\underline{P} < 0.01$). This results from a significant reduction of both felling (E ⩾ 60 vs E ⩾ 50, $\chi^2 = 46.92$, df = 1, $\underline{P} < 0.01$; E ⩾ 60 vs CNV ⩾ 60, $\chi^2 = 61.62$, df = 1, $\underline{P} < 0.01$) and skidding damage (E ⩾ 60 vs E ⩾ 50, $\chi^2 = 8.70$, df = 1, $\underline{P} < 0.01$; E ⩾ 60 vs CNV ⩾ 60, $\chi^2 = 242.11$, df = 1, $\underline{P} < 0.01$) in E ⩾ 60 (Table 1). The lower damage recorded in E ⩾ 60 compared with E ⩾ 50 must be attributed to the lower logging intensity which occurred in E ⩾ 60 (only 6 stems/ha vs 10 in E ⩾ 50, Table 1). Impacts of logging can be significantly reduced by (1) close supervision and plannning of the operations and (2) reduction of the felling intensity, which should not exceed 6 to 7 stems/ha. In this study, logging damage, in terms of trees injured or killed, was reduced from 48.5 % in conventional logging to 30.5 % in logging using reduced impact logging (RIL). This reduction of 18 % represents 95 trees/ha > 10 cm dbh that remained undamaged and have the potential to grow into future crop trees.

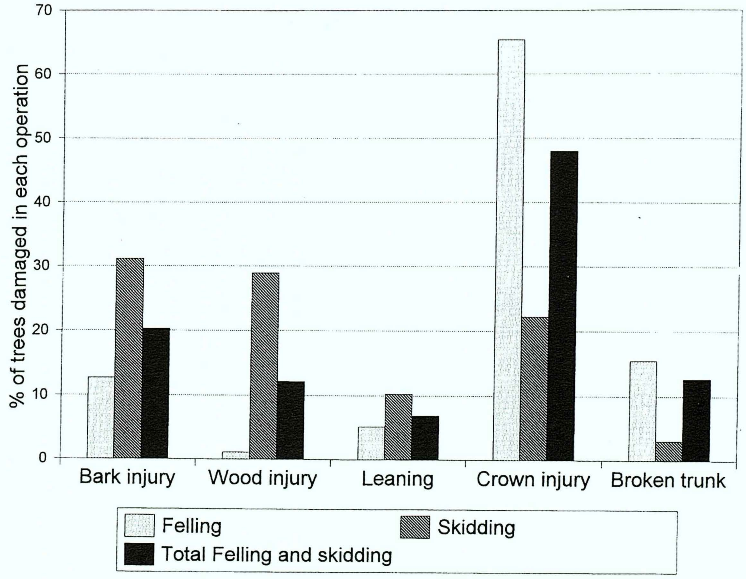

Figure 2. Percentages of trees injured by felling and skidding by general damage classes. All treatments and damaged trees combined (N = 3,993 damaged trees for the 9 plots).

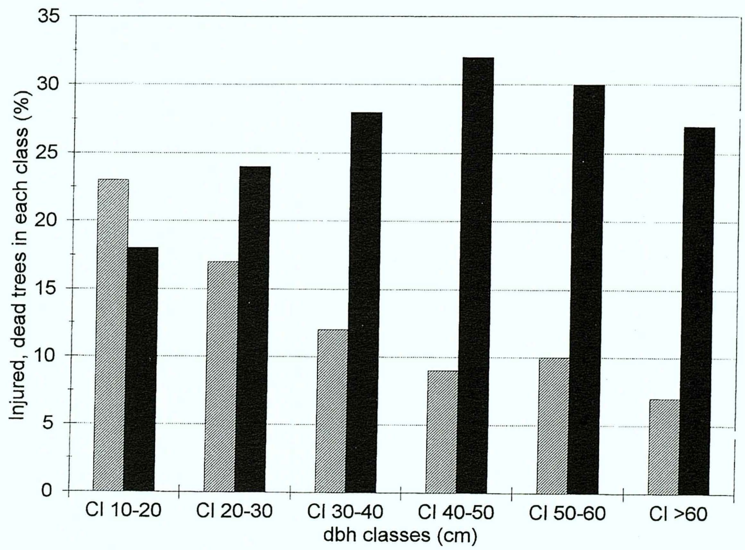

Figure 3. Proportions of injured (filled black bars) and dead trees (hatching) in relation with the tree density before logging in each dbh class. All plots and treatments combined (N = 19,149 trees before logging and N=7,706 damaged trees, injured and killed after logging).

□ Disturbed areas

Total disturbed areas naturally varied according to treatments and logging intensities and ranged from 26.3 % to 45.5 % of the plot area (Fig. 4, p. 18). For a logging intensity below 10 trees/ha, areas damaged by felling were quite comparable, varying only from 12 to 16 %. However, when the logging intensity reached more than 10 trees/ha, this rate could be more than 25 %,

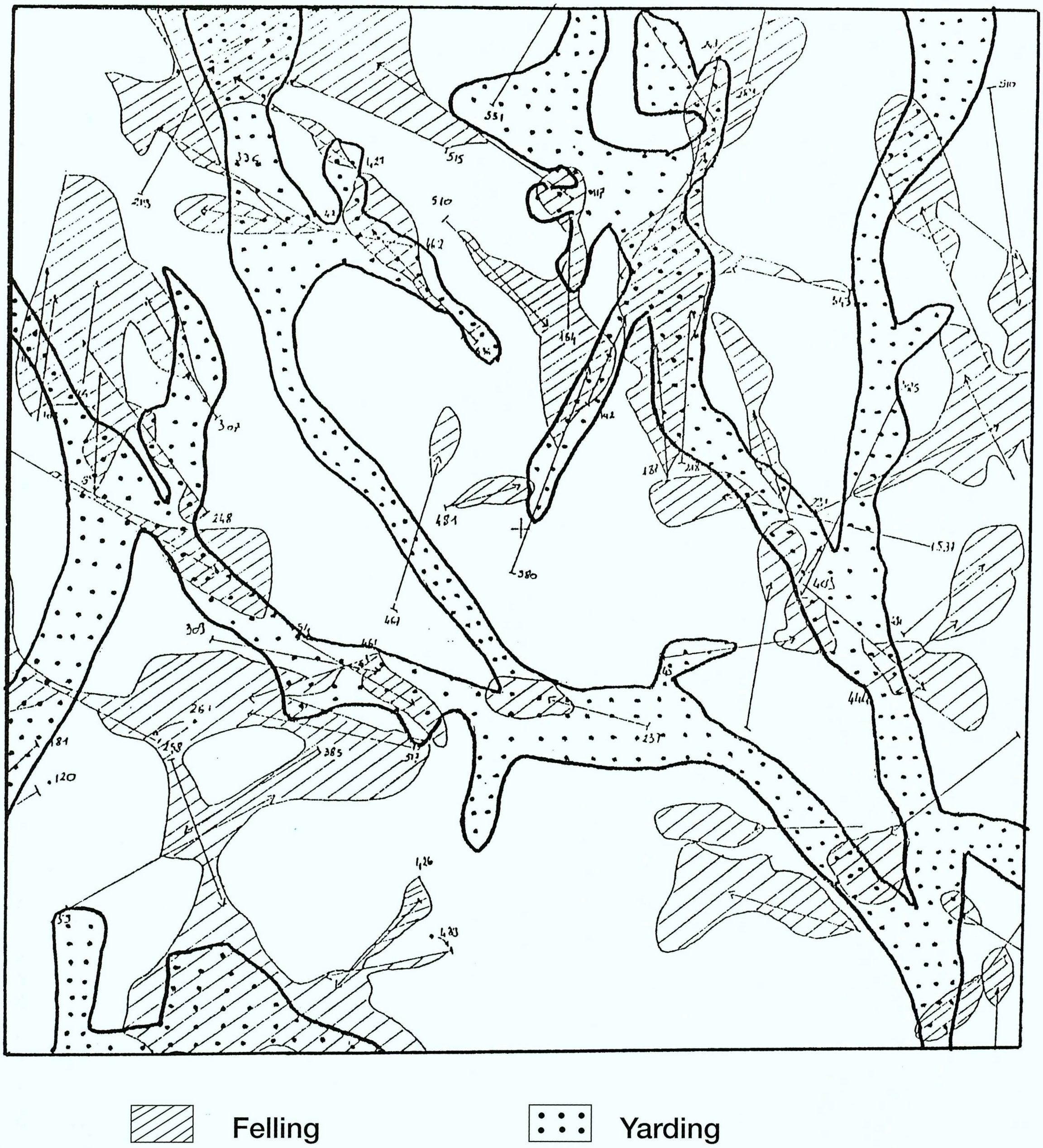

Figure 4. Map of disturbed areas in plot 12, E ⩾ 50. Felled volume : 173.8 m³/ha. Hatched zone : area disturbed by felling : 26.5 %. Dotted zone : area disturbed by skidding : 26 %. Total disturbed area in the plot : 41.5 % (with the overlapping effect decreasing the cumulative impact of each phase).

increasing significantly the area damaged by felling by about 10 %. Areas damaged by skidding ranged from 13.7 to 35.7 %. RIL reduced skidding damage by about 10 % in terms of affected areas, but had no influence on reduction of felling damage, which was mainly determined by the logging intensity. The limited overlap between felling and yarding damage confirms the specificity of felling and skidding impact.

□ Proposal for an acceptable rate of damage

Table 2 summarizes the main characteristics of the logging impact displaying the status of three main indicators recorded during STREK experimentation : trees above 10 cm ∅, saplings (2 to 9.9 cm ∅) and disturbed area. From these data, we can see that conventional practices have a significant impact on the residual stand, whether on the trees above 10 cm ∅ (27.6 to 56.1 %), the saplings (varying from 30.2 to 48.2 %) or the disturbed areas (28.4 to 41.5 %). This latter figure is also an easy way to assess the seedling destruction*. In the damage-controlled areas the impact is relatively constant with damage of 27.6, 30.2 and 28.4 % respectively for the three selected parameters. Consequently, it may be proposed as a first and realistic objective that the concessionaire achieves a rate of 33 % (one third) maximum damage as an acceptable target initially. Progressively, the objective might be fixed at 25 % damage with a final target of 20 % when all the conditions are met to pass from the logging system to the harvesting concept.

THE LOGGING IMPACT ON A CONCESSION SCALE

After determining an acceptable level of damage by use of standards, the second step requires a reliable method to assess these data in the field. At the present time, there are no practical tools such as a « quick harvesting diagnostic » designed for evaluation on the concession scale to serve as a norm. On the other hand, the logging evaluation has to encompass, at the macro (concession) level, a way to relate the theoretical programme and the cutting area, whereas field operations have to assess the impact on the residual stand in the cutting area. In the past, to conduct these surveys at the field level, numerous statistical inventories were carried out in tropical forests and these techniques may be adapted to the present situation in combination with remote sensing and aerial photos, statistical inventories and GIS.

* The ratio of seedlings richness per m^2 derived from permanent plots/area disturbed.

LOCATION OF LOGGING ACTIVITIES : REMOTE SENSING (RS) CONTRIBUTION

Space remote sensing for tropical forest analysis is now in full development. As well as the high resolution, optical multispectral data provided mainly by Landsat and Spot which observe in the visible and infrared spectral ranges, a new generation of satellite utilizing the radar technology as ESR-1, JERS-1 and soon Radarsat, has been appearing since 1991. The synthetic aperture radar or SAR images al-

Table 2. Impact on the residual stand (%)

	Trees above 10 cm Ø			Saplings (2 to 9.9 cm Ø)			Disturbed area		
Types of Logging	Injury	Mortality	Total	Injury	Mortality	Total	Felling	Skidding	Total area
Heavy Logging (15/ha) E ⩾ 50 (Plot 12)	29	27.1	56.1	14	34.2	48.2	26.5	26	41,5
CNV Logging (8-10/ha) CNV (Plot 9)	24.9	19.7	44.5	8.7	30.6	39.3	12.9	27.8	36.6
Damage-Controlled (RIL) (8-10/ha) E ⩾ 50 (Plots 2-3)	15.4	12.2	27.6	6.9	23.3	30.2	16.4	13.9	28.4

ready show significant application with the use of the microwave range (sensitive to roughness and moisture), thus overcoming the high cloud cover incidence in tropical countries. Therefore, the applicability of remote sensing for forestry will increase significantly. Even before being able to use these soon-to-be available new outputs, the false colour composite images (FCC) are very useful for acquiring a general view of the study zone. VSB colour composite images created with three indexes, vegetation index (VI), shadow index (SI) and bare soil (BS) allow easy identification of the logged-over areas which appear on the images in red. To identify these logged-over forests, it is also conceivable to utilize a VST composite image built with three indexes (vegetation index, shadow index and thermal index) which records high temperature on the bare soils and lower temperature in the forest areas. In the case of concession monitoring, the remote sensing technology is a valuable tool for this macrolevel evaluation because of its regular observation frequency.

FIELD DAMAGE ASSESSMENT

As explained above, damage can be summarized in three main categories : trees above 10 cm dbh, the saplings and the area disturbed. The ideal post-harvesting assessment technique would be to establish, before logging, a network of permanent and temporary sample plots with the required density and to come back after harvesting in these plots to compare the different impacts. By simultaneously using temporary and permanent plots, a reliable assessment can be achieved at this field level : calculating the trees and saplings destroyed by logging compared with the data recorded in the PSP in untouched forest will allow a decision of whether damages are, for example, less than or above the 30 % threshold required.

WHAT TYPE OF ASSESSMENT DEVICE FOR IMPLEMENTATION ?

Selection of the optimal statistical device for implementation will depend on many factors :

- Number of degrees.
- Type of stratification.
- Choice of systematic, random or cluster device in the cutting area.
- The intensity by stratum based on the coefficient of variation (CV) to calculate for a given threshold of confidence (0.95 or 090) with an acceptable error (10 or 15 %) ; the configuration of the plots, circular or rectangular.
- The type of observations to be recorded.

Following this, the data-processing phase and the software required to generate the outputs will have to be defined (tables, graphs, maps) together with their relevant costs. This inventory configuration has to be closely studied by preliminary testing in terms of both implementation and cost-effectiveness. At this stage, it is suggested that the theoretical annual cutting area be used as the forest unit for inventory and on this scale to assess, at the selected sampling intensity, the three main components : stands above 10 cm ∅, the saplings (2 to 9.9 cm ∅) and the disturbed areas which can indirectly indicate the proportion of destroyed seedlings. Utilization of GIS, integrating remote sensing capacities, cartography application and data analysis correlated to spatial observations, should readily facilitate this work where a full-scale approach is necessary for a reliable assessment.

CONCLUSION

As confirmed by this study, damage during the harvesting process significantly shapes future structure and stand composition. RIL techniques represent concrete ways to translate the concept of sustainability to production forests. In addition to the first damage reduction objective, a further target is a significant decrease of the non-utilized wood abandoned in the cutting area. Specific efforts have to be made to value the existing timber resource at a time when questions arise about the adequacy of the resource and the timber industry. Based on STREK experiments, it was proposed to rapidly reduce the damage to a rate of 30 % and in the near future to 25 %. Close monitoring of more than 20,000 trees, before and after logging, has clearly demonstrated that it is possible to reach this objective if some basic rules are respected. Thus, implementing a low-impact harvesting regime should always be a prerequisite in a sustainable management policy. Therefore, accurate estimation of the impact has to be accepted as an essential component of any polycyclic management system. This post-harvesting assessment, clearly outlined in ITTO guidelines, will also provide the silviculturist with information for a better design of any silvicultural treatments required after exploitation. □

For bibliography, see the French version.