Long-term effects of logging in a Neotropical rain forest in Suriname

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Summary

In a tropical rain forest in Suriname, the long-term impact of logging on biodiversity, the recovery of trees damaged during logging operations, the regrowth of tree species in gaps and on skid trails and the growth of the timber stand after logging were analysed in a logging and silvicultural experiment, where 15, 23 and 46 m^3/ha had been extracted in the late 1970s. It is shown that logging in this tropical rain forest did not lead to substantial changes in biodiversity. Furthermore, areas disturbed by logging recovered well and trees damaged during logging often survived and developed into good quality trees, especially when the extent of injury was modest. Logging led to faster tree growth, but due to a high variation in mortality it could not be proven whether or not this enhanced growth will result in a complete recovery of the commercial stand within one 25-year cutting cycle. The average commercial volume increment of all logging intensities combined amounted to 29.6 m^3/ha in 17 years or 1.7 m^3/ha.y., which is probably just insufficient to replace the volume lost during timber harvesting. It is therefore recommended to take measures to improve the commercial stand such as Reduced Impact Logging.

Keywords: tropical rain forest, timber harvesting, biodiversity, timber stand development, Suriname.

Introduction

Since the late 1970s, efforts are being made to develop sustainable methods for the management of tropical rain forests. Much attention has been given to Reduced Impact Logging (RIL), that is, to improvements in timber harvesting aimed at minimising damage to the forest and the environment. Short-term effects of logging are therefore well studied and documented. The long-term consequences of timber harvesting are less well known (see e.g. ter Steege, 2003; Silva *et al.*, 1995; Huth and Ditzer, 2001), however, and estimates are often based on indirect evidence. This is because research sites where the recovery of logged forest has been followed over a period of more than 10 years are extremely rare. As sustainable forest management deals by definition with short-term as well as long-term impacts, it is important that knowledge regarding long-term effects of logging becomes available to guide those involved in logging and forest management in their decision-making. This paper provides such information.

In Suriname (South America, see Figure 1), there exists a large-scale scientific experiment, where several logging and silvicultural treatment intensities were applied between 1979 and 1982 (Jonkers, 1987). This so-called MAIN experiment was meant mainly to test the Celos Silvicultural System (de Graaf, 1986; Jonkers, 1987), but it also provided part of the scientific basis for the Celos Harvesting System (Hendrison, 1990). It was part of a joint project of the Centre for Agricultural Research in Suriname (Celos) and Wageningen University. After this project closed in 1984, the experiment was neglected for many years. But it remained fully intact and in 1999-2000, Celos conducted another survey in the experiment to assess the impacts of the treatments. The data collected between 1978 and 1983 and in 1999-2000 form the basis for this paper.

Research subjects

This paper deals with the following aspects:

1) The long-term impact of logging on biodiversity (tree species only);
2) The recovery rate of trees damaged during logging operations;
3) The regrowth of tree species in gaps and on skid trails;
4) The growth of the timber stand after logging.

To answer the following questions:

1) Does biodiversity remain intact after logging?
2) To what extent do areas and trees damaged by logging recover?

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3) Is the growth of the timber stand such, that all timber harvested or killed by logging can be substituted within one cutting cycle of 25-30 years?

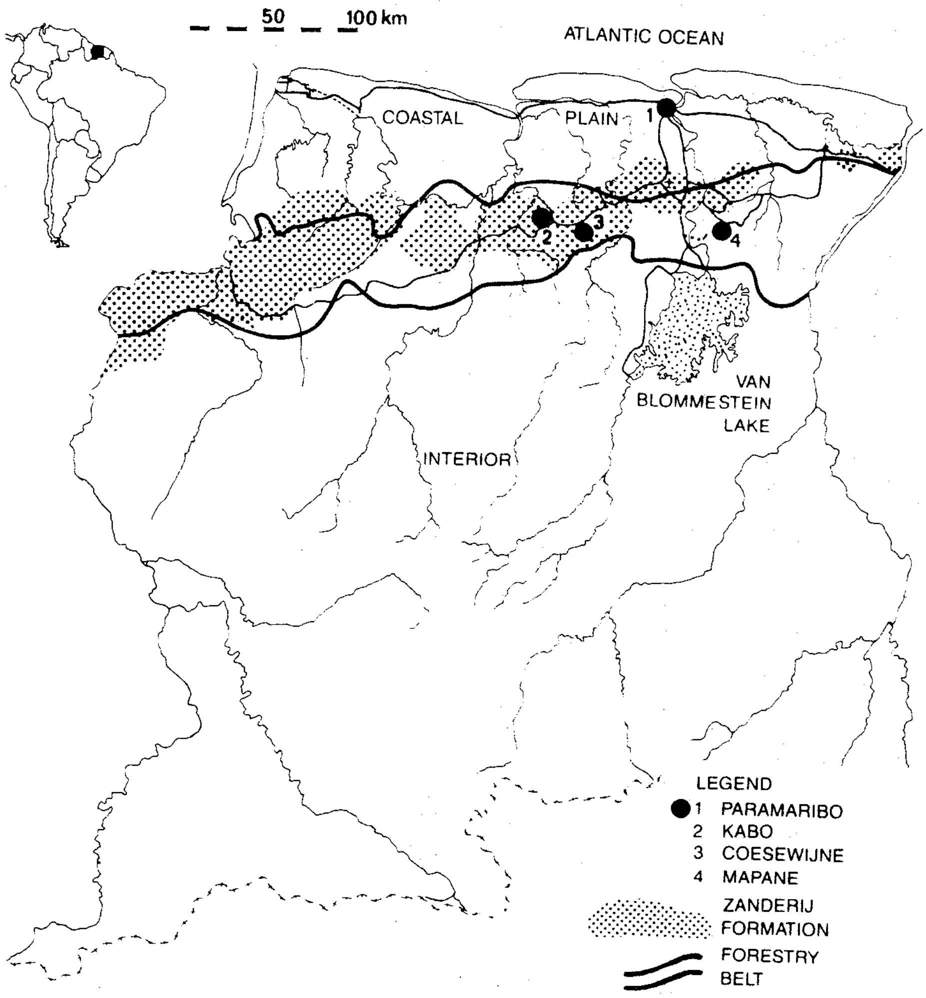

Figure 1. Map of Suriname

Methodology

The MAIN experiment is located at Kabo (see Figure 1) and was created in 1978 to determine which combination of logging intensity and silvicultural treatment would result in an optimal development of the commercial stand. Hence, only commercial species were enumerated initially. In 1981, after logging had been completed, it was realised that the experiment would be of much greater value if the focus were not on timber species only. The experimental design then was adjusted to allow the enumeration of other forest components.

Experimental design[3]

The MAIN experiment is a complete factorial block experiment with two factors, logging and silvicultural treatment, at three levels. The experiment originally consisted of three randomised blocks (replications), each of nine treatment plots, but three virgin forest plots were added in 1981 (Figure 2).

[3] For more details, see Jonkers (1987)

Individual treatment plots originally consisted of 2.25 ha assessment plot surrounded by a 25-m wide buffer zone (Figure 3). Six circular subplots of 750 m^2 each were located systematically within each assessment plot. Commercial species over 15-cm dbh were assessed in the 2.25 ha plot, and commercial trees larger than 5 cm were enumerated in the circular subplots[4].

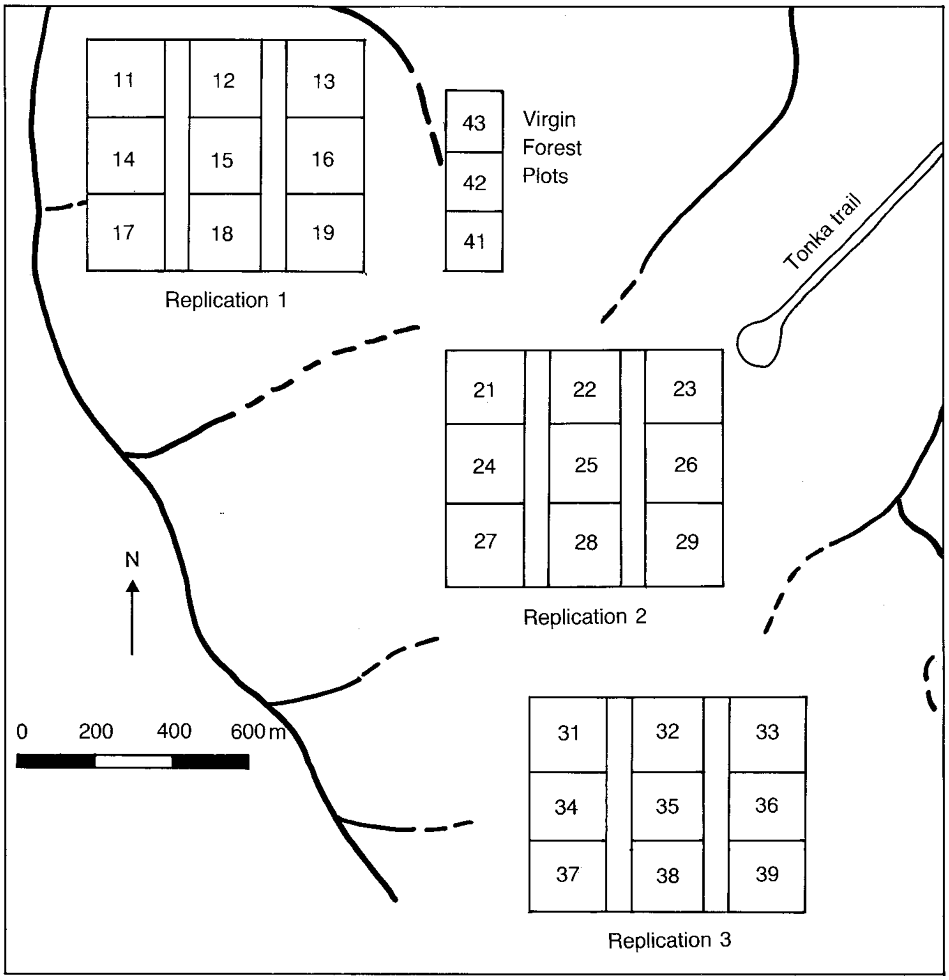

Figure 2. Layout of the MAIN experiment

In 1981, 1-ha assessment plots where established centrally within each treatment plot, consisting of 100 quadrats of 100 m^2 each (Figure 3). These were used mainly to enumerate both non-commercial and commercial trees with diameters larger than 15 cm dbh. Smaller individuals were assessed in systematic sub-samples (replications 1 and 2 only): all trees exceeding 2 m in height were tallied in 16 25-m^2 sapling subplots per treatment plot and seedlings in 16 quadrats of 4 m^2 each.

Treatments

Three levels of exploitation were applied in 1980, namely removing basal areas of about 1, 2 and 4 m^2/ha, which amounted to timber yields of 15, 23 and 46 m^3/ha (Table 1). These yield figures are reflected in the treatment codes used (E15, E23 and E46). Logging was done in a semi-controlled way. Trees to be felled were selected in such a way that a fairly even distribution over a treatment plot was achieved. Felling was

[4] Commercial species in the context of this paper are those species, which were considered to have commercial potential at the onset of the experiment (for a list, see Jonkers, 1987) and includes almost all species which are currently harvested.

done with a chainsaw without application of directional felling or other damage-reduction measures. Extraction was done by a contractor using wheeled skidders, which were allowed to enter each treatment plot at three points on the western side of the plot and three points at the eastern side. Maps were used to find the shortest routes to the logs and the operators had to remove all logs, but apart from these restrictions, no efforts were made to reduce skidding damage.

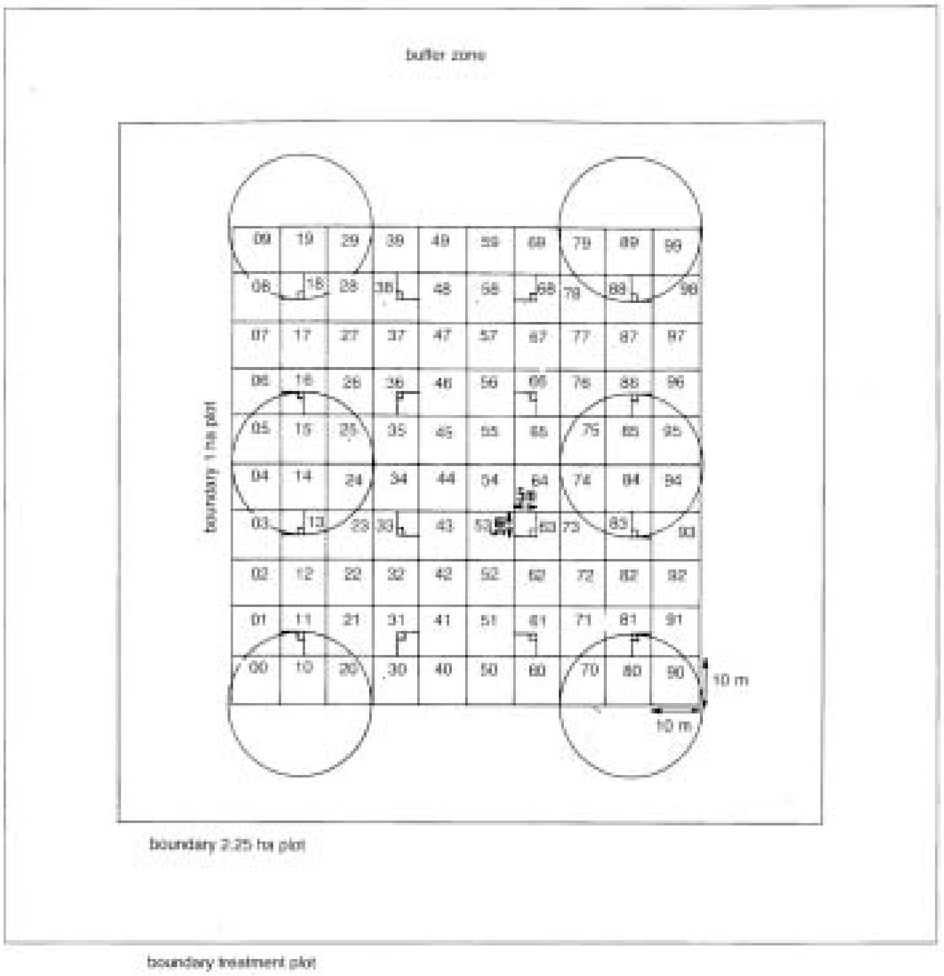

Figure 3. Layout of a treatment plot

The silvicultural treatments used are beyond the scope of this paper (for a description, see Jonkers, 1987), and plots were such treatments have been applied were not included in the analyses.

The virgin forest plots remained untouched.

Table 1. Treatment schedule (in part).

Replication	**Plot number per exploitation level**		
	E15	**E23**	**E46**
1	19	14	12
2	28	26	22
3	34	38	32

Data collected[5]

Five enumerations have been carried out: one prior to logging (1978-1979); three after logging between 1980 and 1983; and one in 1999-2000. However, this does not apply for all plots (see Table 2).
A large number of parameters were assessed. In the 2.25-ha plots, 1-ha plots and circular plots, tree characteristics recorded included among others: the vernacular species name, stem diameter (dbh), the quality of the stem, and the amount of crown damage and stem injury. In the sapling and seedling subplots, tree species were tallied per species and per size class.
In addition, the so-called “forest class” was assessed for the 100-m^2 quadrats and seedling and sapling subplots. The forest class qualifies the subplot as “gap” or “skid trail” if gaps and trials together occupied more than half of the subplot, and in other cases as “residual forest” or “secondary forest”[6].

Table 2. Enumeration schedule

	Plot type	1978-1979	1980	1981-1982	1982-1983	1999-2000
Replications	2.25 ha	x	x	x	x	x
	circular	x	x	x	x	x
	1 ha	-	-	x	x	x
	Sapling/seedling	-	-	-	x*	x*
Virgin forest plots	2.25 ha	-	-	x	x	x
	circular	-	-	x	x	x
	1 ha	-	-	-	x	x
	Sapling/seedling	-	-	-	-	-

*In replications 1 and 2 only.

Data analysis

Data were analysed using Microsoft Access version 8 (Microsoft, 1997) and SPSS version 9 (SPSS Inc., 1999). Statistical methods used include Analysis of Variance (ANOVA), Student’s t test and Correspondence Analysis. ANOVA and the t test were used in analysing the development of the commercial stand and Correspondence Analysis in determining the impact of logging on the biodiversity. Correspondence Analysis is basically a method to depict plots in a multi-dimensional space in such a way, that the distances between plots reflect the dissimilarity in species composition, whereby a maximum of the variation is concentrated in the first few dimensions. The Correspondence Analysis used in the standard SPSS one (distance measure Chi-square, standardisation by removing species and plot means, symmetrical normalisation).

Impact of logging on biodiversity

In the entire MAIN experiment, a total of 259 tree species were recorded in the subsequent enumerations. Many of those occur in frequencies of less than one individual per ha, and one may therefore expect that after a few decades, some of those species have disappeared due to mortality. This was indeed the case. The number of species, which disappeared per 3 ha between 1983 and 2000, was assessed for the virgin jungle plots and for the three logging intensities. Surprisingly, almost exactly the same number of species had disappeared in each of the four cases: six in the virgin jungle plots and five in each of the logging treatments. The lost species were replaced by others. Again, there was a striking similarity between the untouched and logged plots: the number of new species per three hectares varied from 13 to 20 in the logged areas, compared to 17 in the virgin forest plots. Apparently, logging had very little impact on the loss or gain of tree species within this 17-year period.

Jonkers (1987) analysed the species composition in the entire experiment, based on the 1981-1983 data and concluded that the experiment was rather uniform in tree species composition for a tropical rain forest, but that there was nevertheless a clear north-south gradient. Part of this analysis was repeated for the plots

[5] For more details, see Jonkers (1987); for tree categories enumerated in the various plot types, see under “Experimental design”
[6] The forest class “secondary forest” was not used in the 1981-1982 enumeration to allow estimation of the areas under felling gaps and skid trails. Due to the establishment of secondary species, these openings might have otherwise been classified as secondary forest.

where no silvicultural treatment had taken place, and also for the 1999-2000 data of the same plots. In both cases, the result was similar: a fairly obvious north-south gradient and no evidence of a pronounced impact of logging intensity (Figure 4). A closer examination of the data revealed a positive relation between the number of pioneer trees and logging intensity, but no other important changes in species composition. In 2000, 6% of the trees in the virgin forest plots belonged to a pioneer species, compared to 17% in plots with logging intensity E46.

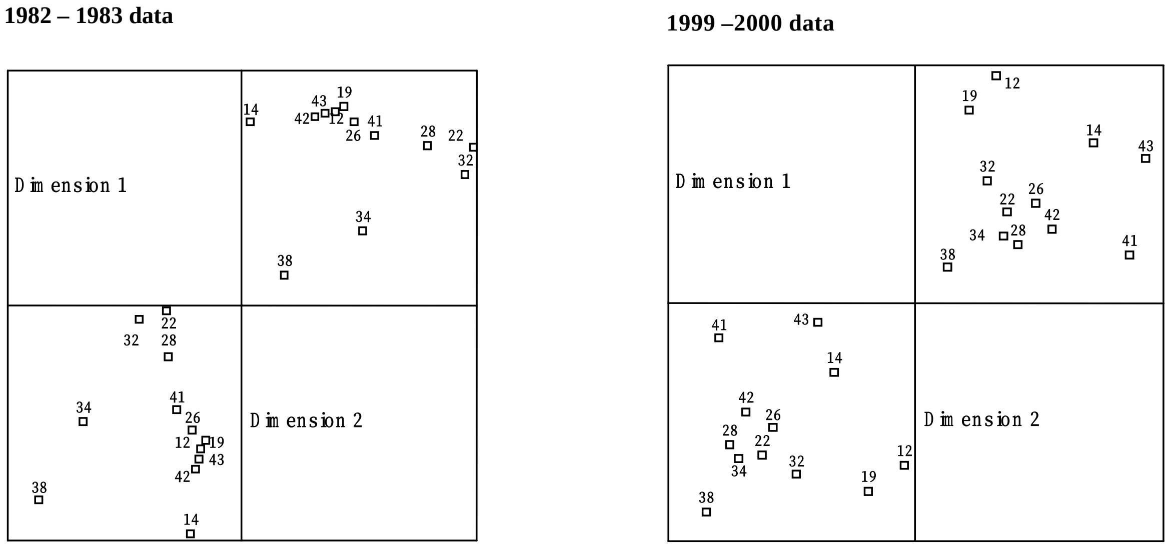

Figure 4. Results of two Correspondence Analyses on species frequencies in the 1-ha plots

Vegetation recovery in gaps and on skid trails

Vegetation recovery in logging gaps and on skid trails can be shown by a simple comparison of the 1999-2000 stocking in sapling subplots classified as residual forest, gaps or trails during the 1981-1982 enumeration. Because of the small sample size (see Table 3), the three logging intensities could not be evaluated individually and were lumped in the analysis.

Table 3. Density of trees per size class and species category in the year 2000 in relation to the 1981-1982 forest classes (seedling and sapling subplots; replications 1 and 2)

Forest class (1981-1982)	**Area (ha)**	**Species category***	**Number of trees per ha (1999-2000)****		
			2m high-5 cm dbh	**5-15 cm dbh**	**>15 cm dbh**
Residual forest	0.1525	Commercial	387	151	125
		Secondary	459	85	26
		Other	1154	302	111
Gaps	0.0625	Commercial	368	112	176
		Secondary	496	144	64
		Other	928	256	176
Skid trails	0.025	Commercial	600	160	120
		Secondary	960	360	120
		Other	600	320	80

* Commercial species as classified at the onset of the project; secondary species: all pioneer species except those with timber of commercial potential.
** Highest values per species category are underlined.

Table 3 shows clearly that the densities of commercial species in former gaps, on former skid trails and in (former) residual forest were comparable. Pioneer species were common on former skid trails and to a lesser extent also in former gaps, but they were not very numerous in the forest as a whole (see also Dekker and de Graaf, 2003). This evidence would suggest that former trails and gaps have regenerated well. This applies indeed for gaps and also for the branch trails in the sample, but not for the more intensively used trail sections further from the middle of the treatment plots. Many of these were still without any tree regeneration 20 years after logging.

Recovery and mortality among trees damaged during logging

Logging damage comprises, among others, a loss of timber trees for future harvests. This kind of loss includes not only trees which are instantaneously destroyed during felling or skidding, but also the trees, which initially survive their injury but do not recover. The extent of this loss therefore depends on the potential of injured trees to restore their physical condition.

Table 4 shows to what extent commercial trees in the MAIN experiment recovered from logging damage. The findings are presented for all logging intensities combined, as it had become clear during the analysis that the relation between the recovery rates per injury class and logging intensity was at best very weak. The results presented show that trees with mild forms of injury usually recovered. But trees with severe logging injury had almost twice as much chance either to die within 19 years or to develop a defective stem as compared to trees with minor or no damage. The number of trees with severe injury was rather modest, but since injury in the MAIN experiment was much more common among large trees than among small ones (Jonkers, 1987), it may still lead to substantial losses of standing timber. On the other hand, Table 4 shows also that even trees with severe crown or stem injury often developed into good-quality timber trees. So, injured trees often have the potential to contribute to future harvests and can be considered as part of the timber resource.

Table 4. Recovery and mortality among trees with various degrees of logging damage (commercial species; trees >15 cm dbh)

Logging damage (1981)		**Number of trees (=100%)**	**Tree condition in 1999-2000**				
Stem injury*	**% of crown broken off**		**Stem quality (%)**				**Dead / not found (%)**
			Excellent	**Adequate**	**Poor**	**Broken**	
None	0%	1360	12.2	60.9	3.8	3.1	20.0
	up to 50%	120	9.2	55.8	8.3	6.7	20.0
	50-99%	48	8.3	43.8	4.2	16.7	27.1
	100%	42	4.8	35.7	0.0	14.3	45.2
	All	*1570*	*11.7*	*59.3*	*4.1*	*4.1*	*20.9*
Minor	0%	58	12.1	62.1	10.3	1.7	13.8
	up to 50%	11	9.1	54.5	9.1	27.3	0.0
	50-99%	7	42.9	28.6	0.0	14.3	14.3
	100%	5	0.0	40.0	20.0	0.0	40.0
	All	*81*	*13.6*	*56.8*	*9.9*	*6.2*	*13.6*
Major	0%	25	4.0	44.0	24.0	4.0	24.0
	up to 50%	6	0.0	33.3	33.3	16.7	16.7
	50-99%	4	0.0	0.0	25.0	0.0	75.0
	100%	1	0.0	0.0	0.0	0.0	100.0
	All	*36*	*2.8*	*36.1*	*25.0*	*5.6*	*33.3*
All	0%	1443	12.1	60.6	4.4	3.0	19.8
	up to 50%	137	8.8	54.7	9.5	8.8	18.2
	50-99%	59	11.9	39.0	5.1	15.3	28.8
	100%	48	4.2	35.4	2.1	12.5	45.8
	All	**1687**	**11.6**	**58.7**	**4.8**	**4.2**	**20.8**

* Major stem injury means that the stem has split, or that the bark has been ripped off over either at least one third of the circumference of the stem or over more than least 20 cm of the stem circumference or over a length of at least 2 meters. Minor stem injury means that a smaller piece of the bark has been ripped off.

Development of the commercial stand

In theory, the growth of the commercial stand should be such, that the stem volume lost during the logging operation is replaced within one cutting cycle. This loss is more than the volume extracted, as the stump, the top end and defective parts of the felled stems are not hauled out and remain in the forest to rot. In addition, some trees of commercial species die during the logging operation due to felling damage. Table 5 summarises the main statistics regarding trees felled or destroyed during logging in the MAIN experiment. The volumes to be replaced add up to about 23.5 m^3/ha for the lowest felling intensity to 58.7 m^3/ha for the highest felling intensity. Assuming a 25-year cutting cycle, this would mean that the required annual volume growth would be about 1 m^3/ha.y for the lowest logging intensity (E15) and about 2.4 m^3/ha.y for the highest one (E46).

Table 5. Trees felled or destroyed during logging: numbers, basal areas and volumes

Logging treatment	Felled trees			Destroyed trees*		
	N/ha	**Basal area (m^2/ha)**	**Volume (m^3/ha)**	**N/ha**	**Basal area (m^2/ha)**	**Volume (m^3/ha)**
E15	3.11	1.43	19.80	2.52	0.30	3.68
E23	6.67	2.51	34.41	3.11	0.27	3.16
E46	11.56	3.79	51.64	6.07	0.59	7.02

* Commercial trees > 15 cm dbh only

The growth of the commercial volume is a function of the diameter growth, mortality and recruitment of commercial species. The bulk of the volume increment has to come from diameter growth. Average growth rates per logging intensity and their standard deviations are shown in Table 6. The differences between the means were rather small and standard deviations were high; it is therefore not surprising that differences in diameter growth could not be proven with ANOVA. However, the t-tests conducted showed significant differences between the highest logging intensity (E46) on the one hand and the virgin forest plots (untouched; $p < 0.001$) and the lowest logging intensity (E15; $p = 0.036$) on the other hand and insignificant differences ($p > 0.05$) for all other comparisons of logging intensities.

Table 6. Diameter growth of commercial trees > 15 cm dbh (between 1982-1983 and 1999-2000 enumerations; 2.25 ha plots)

Logging treatment	Number of trees	Diameter growth (mm/y)	
		Mean	**Standard deviation**
Untouched	452	3.86	2.86
E15	528	4.22	3.29
E23	400	4.40	2.90
E46	484	4.64	3.04

The average mortality for all logging treatments combined was modest; about 21% over a 17-year period (see Table 4). The rates recorded in individual virgin forest plots were comparable, but the differences in mortality between logged plots were enormous (see Table 7). Two plots in the intermediate logging intensity (E23) had very high rates, while mortality in two plots with high logging intensity (E46) was negligible. It is unlikely that these differences were caused by the treatments applied, and a thorough statistical analysis was therefore considered redundant.

Recruitment, or rather ingrowth of trees, which had reached the 15-cm dbh level, contributed little to the volume increment. Although the values were incorporated in the total volume growth figures given below, they are not discussed separately here.

Due to the high variation in mortality, the volume growth differed considerably from plot to plot (Table 8). In the virgin forest plots, there was hardly any change in commercial volume, as one would expect. However, the volume increment after logging varied from less than – 8 m^3/ha or – 0.5 m^3/ha.y to more than

54 m^3/ha or 3.2 m^3/ha.y. This variation is probably mainly due to causes of mortality, which are not directly related to logging intensity.

Table 7. Mortality among commercial trees > 15 cm dbh (between 1982-1983 and 1999-2000 enumerations; 1-ha plots)

Logging intensity	**Replication**						**Mean**	
	1		**2**		**3**		**Number of trees/ha**	**Volume (m^3/ha)**
	N/ha	**m^3/ha**	**N/ha**	**m^3/ha**	**N/ha**	**m^3/ha**		
Untouched*	13	31.96	16	45.59	18	38.02	15.67	38.52
E15	9	16.84	17	12.17	19	24.31	15.00	17.78
E23	30	55.24	24	66.64	15	22.38	23.00	48.09
E46	9	4.92	17	31.72	8	3.89	11.33	13.51

* Plot 41: Replication 1; Plot 42: Replication 2; Plot 43: Replication 3

Table 8. Volume increment among commercial trees > 15 cm dbh (between 1982-1983 and 1999-2000 enumerations; 1-ha plots)

Logging intensity	**Replication**			**Mean**
	1	**2**	**3**	
	Volume increment in 17 years (m^3/ha)			
Untouched*	15.49	9.16	-15.72	2.98
E15	34.65	47.92	46.22	42.93
E23	-24.50	-36.19	34.82	-8.62
E46	44.68	40.38	78.10	54.39

* Plot 41: Replication 1; Plot 42: Replication 2; Plot 43: Replication 3

Discussion and conclusions

In this paper, it has been shown that logging in this tropical rain forest did not lead to substantial changes in biodiversity. Furthermore, areas disturbed by logging recovered well and trees damaged during logging often survived and developed into good quality trees, especially when the extent of injury was modest. Logging also led to faster tree growth, but due to a high variation in mortality it could not be proven whether or not this enhanced growth will result in a complete recovery of the commercial stand within one 25-year cutting cycle. The average commercial volume increment of all nine logged plots combined amounted to 29.6 m^3/ha in 17 years or 1.7 m^3/ha.y. That annual growth rate may seem just sufficient to secure another harvest at the end of the 25-year cutting cycle. However, 9% of the growing stock consists of poor-quality trees (see Table 4), so the mean volume growth of good quality trees was just about 1.5 m^3/ha.y. Moreover, as the growth of trees depends, among others, on the density of the stand, which has increased greatly during these 17 years, it is likely that the current annual increment in the last years of the cutting cycle will be slower than before. It is therefore recommended to take measures to improve the commercial stand such as Reduced Impact Logging (RIL). RIL is expected to leave more good-quality trees after logging and to have a positive impact on mortality after logging has been completed.

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