GROWTH AND YIELD OF A TROPICAL RAIN FOREST OF THE BRAZILIAN AMAZON 13 YEARS AFTER LOGGING

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ABSTRACT

Diameter increment, volume production, recruitment and mortality were reassessed in a silvicultural experiment in the Tapajós National Forest, State of Pará, Brazil, 13 years after an experimental logging. The forest was left to regenerate with no subsequent silvicultural intervention to evaluate the behaviour of such an approach for forest management. Thirty-six permanent sample plots established in 1981 for monitoring stand development have been measured six times. The behaviour of the stand parameters was studied in three periods, *viz* 1981-1987, 1987-1992 and 1981-1992. From the first to the second observation period diameter growth of all species has decreased from 0.4 cm.year^{-1} to 0.2 cm.year^{-1}. The average for the second period is similar to an unlogged primary stand in the same forest. The annual mortality rate had a slight increase from 2.4% to 2.6% per year while recruitment rates fell from 5.4% to 1.8%. Recruitment of commercial species also fell from 5.4% to 1.3%; volume production fell from 6.1 m^3.ha^{-1} to 4.2 m^3.ha^{-1}. Similarly the average volume production of commercial species decreased from 0.9 m^3.ha^{-1}.year^{-1} to 0.7 m^3.ha^{-1}.year^{-1}. Considered as a whole, the stand had a positive balance, *i.e.*, basal area, volume and number of trees increased in the eleven-year studied period. The average values for diameter increment, ingrowth and mortality were, respectively, 0.3 cm.year^{-1}, 3.1% *p.a.* and 2.2% *p.a.* Only 6 trees per ha of the commercial group (32 species) of merchantable size (45 cm DBH) were available in 1992 corresponding to a volume of 18 m^3.ha^{-1}. However, updating the list of marketable timbers with 29 new species presently being utilized, the number of trees of a logging size increased to 15 trees per ha, corresponding to a volume of 54 m^3.ha^{-1}. These results support previous recommendations for application of silvicultural treatments at 10-year intervals to allow reasonable growth rates, to promote natural regeneration of valuable species and to replenish the volume extracted.

Keywords: diameter growth, volume growth, recruitment, mortality, forest dynamics

RESUMO

Foram reavaliados o incremento em diâmetro, a produção volumétrica, o recrutamento e a mortalidade em um experimento silvicultural na Floresta Nacional do Tapajós, Estado do Pará, Brasil, 13 anos após a exploração. A floresta foi deixada regenerando sem tratamentos silviculturais para estudar o comportamento do povoamento em função desta abordagem de manejo. Trinta e seis parcelas permanentes foram estabelecidas em 1981 para monitorar o desenvolvimento da floresta, sendo medidas seis vezes desde então. Observou-se o comportamento do povoamento em três períodos, 1981-1987, 1987-1992 e 1981-1992. O incremento em diâmetro decresceu de 0,4 $cm.ano^{-1}$, para 0,2 $cm.ano^{-1}$ do primeiro para o segundo período, neste, sendo similar às taxas de crescimento encontradas na mesma floresta em povoamento não explorado. As taxas de mortalidade tiveram um leve acréscimo, de 2,4% para 2,6% por ano, enquanto que o recrutamento caiu de 5,2% para 1,8%; o recrutamento das espécies comerciais também decresceu de 5,4% para 1,3%; a produtividade volumétrica caiu de 6,1 $m^3.ha^{-1}.ano^{-1}$ para 4,2 $m^3.ha^{-1}.ano^{-1}$; do mesmo modo, a produtividade média das espécies comerciais decresceu de 0,9 $m^3.ha^{-1}.ano^{-1}$ para 0,7 $m^3.ha^{-1}.ano^{-1}$. De um modo geral, o povoamento apresentou um balanço positivo, i.e., a área basal, o volume e o número de árvores aumentaram no período estudado. Os valores médios para o incremento em diâmetro, ingressos e mortalidade no período total observado foram, respectivamente, 0,3 $cm.ano^{-1}$, 3,1% *p.a.* e 2,2% *p.a.*. Somente 6 árvores por ha das espécies comerciais (32 espécies) da lista de 1979 com tamanho comercial (DAP 45 cm) existiam em 1992, correspondendo a um volume de 18 $m^3.ha^{-1}$. No entanto, adicionando-se 29 espécies hoje aceitas no mercado de madeiras, o numero de árvores com tamanho de corte cresceu para 15 por ha, correspondendo a um volume de 54 $m^3.ha^{-1}$, segundo a lista atualizada. Os resultados obtidos concordam com recomendações já feitas de aplicar tratamentos silviculturais em intervalos de 10 anos para permitir taxas razoáveis de crescimento, promover a regeneração natural de espécies valiosas e repor o volume extraído.

INTRODUCTION

Forestry plays an important role in the Brazilian Amazon. From the enormous volume of wood estimated at about 45 billion cubic metres, *c.* 13 billion have commercial value (Nascimento & Homma 1984). This richness gives the region an unrivalled position to become the principal tropical timber supplier of the world, as African and Asian stocks become exhausted.

The socio-economic importance of the timber activity in the region is unquestionable: in Pará State, for example, timber ranks second in income generation, only surpassed by mining (Yared 1990); in Paragominas region, eastern Amazonia, it is estimated that forestry employs about one person for each 200 ha of forest, which is more than twice the number generated by cattle ranching (Silva & Uhl 1992). This advantageous situation, however, could worsen if boycot campaigns continue against the use of tropical timbers originating from non-sustainable sources, presently the case in the Brazilian Amazon. Sustainable forest management for timber production is therefore an important issue in the region.

The Brazilian Forestry Authority now requires that all timber companies consuming more than 12,000 cu. m. per year of logs must submitt and conduct a forest management project aiming at sustainably supplying timber to meet their needs.

One of the basic inputs for the management projects is information on growth and yield. Only recently data on growth and yield of tropical rain forests in the Brazilian Amazon became available (Silva 1989; Silva *et al.* 1989; Carvalho 1992; Higuchi 1987; Higuchi *et al.* 1993). Long term permanent plots date from 1956, but few data have been published (Moraes 1970; Pires 1978). Monitoring growth and yield in silvicultural experiments in Amazônia began in the early 80's. In 1989 about 105 ha of permanent plots had been established in the region, most of them (90%) in Pará State (Silva 1989).

This paper gives basic information on growth and yield of a tropical rain forest of the Brazilian Amazon, aiming at contributing to a better design of forest management projects in the region, and to the knowledge of tropical rain forests dynamics.

METHODS

The research was conducted in a sixty-four ha experimental plot denominated RP012, set up in the Tapajós National Forest, 67 Km South of Santarém City, in the State of Pará, Brazil, longitude 55°00' W and latitude 2°45' S (Fig. 1).

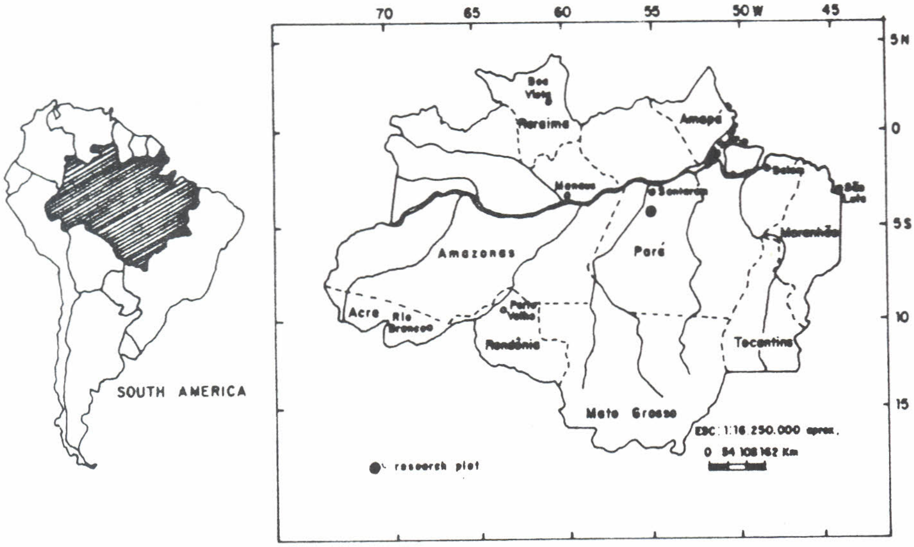


FIG. 1. Location of the research area

The forest is a typical dry land ("terra firme") high forest averaging about 150–200 $m^3.ha^{-1}$ over 45 cm DBH (Diameter at Breast Height). The climate of the region is Ami according to Köppen's system. The annual rainfall is about 1,900 mm. The heaviest of the rains occur from December to May. There is a short dry season of 2 to 3 months with less than 60 mm of precipitation. The monthly temperatures are fairly constant through the year, varying from 24.3 to 25.8 °C.

The experimental plot was logged in 1979, using chainsaws and attempting at directional felling. A wheeled skidder was used in skidding trails previously opened by bulldozer. Logging removed about 75 $m^3.ha^{-1}$ from an average of 16 trees per ha with minimum DBH felling limit of 45 cm.

In 1981, 36 permanent sample plots of 0,25 ha each (9 ha in total), square in shape, were laid out at random over the area. The plots are composed of 25 quadrats of 10 m x 10 m to allow a better control of the measurements.

In each quadrat all trees ≥ 5 cm DBH were number tagged and a set of variables were measured according to the methodology described in Silva & Lopes (1984) and Silva (1989). Seedlings and saplings were measured in special plots but are not considered in the present study. For the purpose of this study, three variables were used from the set of variables measured. These were the DBH, the Stem Identity Classes (SIC) and the Crown Illumination Classes (CIC).

The DBH were always measured on the point of measurement (POM) using a diameter tape. The POM was always set up at breast height or just above buttresses. In both cases the places should be free of defects.

Stem Identity Classes are three digit codes used to describe the various situations in which a tree can be found. For example, a tree can be found standing and alive, with complete trunk, broken or even cut. Or else it can be found alive but fallen, dead standing or dead fallen. Trees which died or disintegrated between two measurements were also assigned a special CIC.

The Crown Illumination Classes are modifications of the Crown Illumination Scores originally proposed by Dawkins (Dawkins 1958). Class 1 was used to identify trees receiving full overhead light. Class 2 for trees partially shaded *i.e.* receiving some overhead light, and class 3 was assigned to trees receiving only side light or completely shaded. Simplification of the scores (formerly 5) has proved to be very useful for the correct evaluation of this important variable.

Stand parameters were calculated using a special package of computer programmes, SINFCON (Continuos Forest Inventory System) which have been developed for permanent sample plot data analysis.

RESULTS AND DISCUSSION

Stand structure

In 1981, two years after logging, 22 species, 14 shade tolerant (ST) and 8 light demanding (LT) comprised *c.* 60% of the stand basal area over 5 cm DBH. From this group, ten (45%) are commercial (Table 1). Dominance was also in terms of bole volume.

Rinoria guianensis (Violaceae) had the highest basal area. This is a shade tolerant species, frequently found in Tapajós Forest forming the undergrowth, rarely reaching 50 cm DBH. In 1992, the same group of species still composed 60% of the stand basal area but dominance changed: *Rinorea* ranked 5th. Benefiting from canopy opening *Bixa arborea* (Bixaceae), a fast growing light demander, ranked first in basal area followed by two other pioneer, *Inga* ssp.(Leguminosae) and *Cecropia sciadophylla* (Moraceae). Carvalho (1992) studying the changes in species dominance before and after logging in another trial 47 Km South of RP012 in the same forest and where 90 $m^3.ha^{-1}$ had been extracted, reported no important changes in species dominance. Shade tolerant species, *viz*. Sapotaceae (9 species) and *Rinorea guianensis* ranked 1st and 2nd before logging and the same Sapotaceae and *Minquartia guianensis* (Olacaceae) dominated 7 years after logging. Common pioneer species such as *Cecropia* and *Inga* ranked 3rd. *Bixa arborea* in spite of being present in the stand is not among the most dominant as in the case of RP012.

TABLE 1: Stand parameters in two assessments, rank of the dominant species and dynamics of RP012, in the Tapajós Forest.

Species	1981			1992			1981 - 1992				
	B.A	V	N	B.A	V	N	Ingrowth N	Mortality N	Balance N	AB/V	EC
Rinorea guianensis (Aubl) Schum	1.26	8.3	51.0	1.16	7.9	43.1	2.6	10.5	–	–	ST
Pouteria sp.	1.18	8.0	51.9	1.25	9.6	46.8	4.1	9.2	–	+	ST
Bixa arborea Huber	0.98	7.6	39.7	1.71	14.0	64.4	36.0	11.3	+	+	LD
Protium apiculatum Swartz	0.95	4.6	58.8	1.16	7.0	62.2	13.2	9.8	+	+	ST
Couratari oblongifolia Ducke	0.86	9.1	18.7	0.92	9.9	17.7	1.1	2.1	–	+	ST
Carapa guianensis Aubl	0.79	7.4	18.8	1.12	11.8	18.4	1.8	2.2	–	+	ST
Ocotea sp.	0.64	4.5	29.2	0.71	5.5	29.4	6.8	6.6	+	+	ST
Sloanea froesii C. E. Smith	0.55	2.9	78.0	0.79	3.8	69.0	38.7	47.7	–	+	LD
Inga sp.	0.51	2.1	59.8	1.39	6.7	90.1	52.7	22.4	+	+	LD
Eschweilera blanchetiana Miers	0.46	3.7	13.4	0.46	3.8	12.6	0.7	1.5	–	+	ST
Hevea sp.	0.42	4.6	5.9	0.47	5.1	6.7	1.1	0.3	+	+	ST
Virola melinonii (R. Ben.) A.c. Smith	0.41	3.8	10.9	0.52	5.0	16.0	6.2	1.1	+	+	ST
Eschweilera amara Ndz.	0.39	3.4	12.2	0.44	4.1	12.2	1.0	1.0	+	+	ST
Eperua bifuga Mart. ex Bth	0.31	2.3	16.1	0.33	3.0	12.4	0.9	4.6	–	+	ST
Swartzia corrugata Benth	0.31	3.7	2.2	0.29	3.5	2.3	0.6	0.5	+	+	ST
Sclerolobium chrysophyllum Poepp. & Endl	0.26	2.3	9.1	0.61	6.7	13.2	6.8	2.7	+	+	LD
Goupia glabra Aub.	0.24	2.9	1.4	0.22	2.7	1.6	0.4	0.2	+	+	LD
Jacaranda copaia (Aubl) D. don	0.23	2.1	9.0	0.47	4.0	17.1	10.3	2.2	+	+	LD
Licaria canella (Meissn.) Kostermos	0.22	1.8	8.4	0.27	2.4	9.7	2.5	1.2	+	+	ST
Manilkara huberi Stanlley	0.21	2.3	3.3	0.24	2.8	2.8	–	0.5	–	+	ST
Cordia bicolor D. C.	0.19	1.5	9.2	0.28	1.8	18.9	11.2	1.5	+	+	LD
Cecropia sciadophylla Mart	0.15	0.7	19.8	1.35	12.2	28.2	13.3	4.9	+	+	LD
Remaining Species	8.77	71.2	404.8	9.76	79.5	455.1	152.9	80.9	+	+	–
Total	20.30	160.8	931.6	25.92	212.8	1,050.1	364.9	224.9			

EC = Ecological Group; BA = Basal Area ($m^2.ha^{-1}$), DBH ≥ 5 cm; V = Volume ($m^3.ha^{-1}$), DBH ≥ 20 cm; N = Number of trees per ha, DBH ≥ 5 cm.

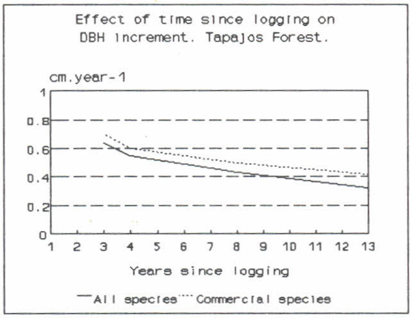
In general terms the forest had a positive balance, *i.e.*, the stand parameters Basal Area, Volume and Number of Trees increased in the studied period. Three hundred and sixty five trees per ha were new recruits in 1992 and about 225 trees per ha died in the period studied. Eight dominant species showed a negative balance in number of trees, but only one species (*Minquartia* sp.) decreased Basal Area and Volume. The remaining species having a negative balance in number of trees, growth compensated the loss of individuals by death. It is worth noting that *Manilkara huberi* (Sapotaceae) had no ingrowth into the 5 cm DBH in the period studied showing that this species has very slow growth rates when very young.

Diameter increment

TABLE 2: Periodic annual increment (cm.year^{-1}) in diameter in three periods of observation in Tapajós Forests. Trees standing and complete.

Observation period	All species	commercial
1981–1987	0.4	0.5
1987–1992	0.2	0.3
1981–1992	0.3	0.4

Periodic annual increment (PAI) was calculated for all species (195) and for the commercial group (32 species) in three periods, *viz* 1981–1987, 1987–1992 and 1981–1992. PAI of all species and of the commercial group has shown a considerable decline as result of canopy closure. The former halved while the latter decreased about 40% (Table 2). In the eleven–year observation period, PAI of all species and of the commercial group averaged 0.3 cm.year^{-1} and 0.4 cm.year^{-1} respectively. Carvalho (1992) in another research plot in the same forest reported growth rates of 0.4 cm.year^{-1} eight years after logging and 0.2 cm.year^{-1} for the unlogged stand. The growth rates found in the present study nearly approaches the rates of a primary unlogged forest.



The effect of increasing competition on DBH increment as canopy closes is clearly seen in Fig. 2. The beneficial effect of logging on growth lasted only for 3 years and then started to decline. The same effect is seen when considering two growth periods (Table 2). The fact that logging improves only briefly growth conditions is widely accepted as reported by several authors (e.g Graaf 1986, Jonkers 1987, Silva 1989). Log and leave as an approach for forest management (see Poore *et al* 1989) would require far longer cutting cycles to replenish the volume removed than forests periodically treated to improve growth conditions.

TABLE 3: PAI per crow illumination classes in three periods of observation. Trees standing and complete.

CIC	1981–1987	1987–1992	1981–1992
1	0.7 a	0.6 a	0.6 a
2	0.5 b	0.3 b	0.4 b
3	0.3 c	0.2 c	0.3 c

CIC = 1: Emergent trees or receiving full overhead light
CIC = 2: Trees partially shaded or receiving some overhead light
CIC = 3: Trees receiving only sidelight or completely shaded.
Means followed by different letter are significantly different by the Tukey's test at 0.05 probability level.

Crown illumination had a strong influence on tree growth. Table 3 shows the average DBH increment per crown illumination classes (modified Dawkins' Crown Illumination Scores). Trees receiving full overhead light grow faster than trees partially shaded and completely suppressed or receiving only sidelight. These results corroborate previous findings (e.g Bryan 1981; Korsgaard 1986, 1992; Silva 1989). Monitoring crown illumination is therefore, an important tool to help decision making about the timing and/or the need for application of silvicultural treatments. In the present study a considerable proportion (nearly 66%) of the crowns of the commercial species were receiving full or some overhead light. To improve even further growth conditions of those trees, a treatment to release crowns with CIC 2 (partially shaded) would be advisable.

Due to different physical and environmental conditions in which trees can be found and also intrinsic factors such as species' growth habits and different genotypes among others, variability in diameter increment is often very high in tropical forests. Table 4 shows that in all DBH classes, the coefficients of variation are very high. High variability in DBH increment in tropical forests has also been reported elsewhere (e.g. Weaver 1979, Swaine *et al* 1987, Silva 1989, Carvalho 1992).

Eleven years after the first assessment, there were still trees with zero increment or the growth was so small that it was not detected by the diameter tape. Diameters were always rounded to the nearest lower millimeter and therefore trees which grew less than one millimeter were considered as zero growth. The faster increments occurred in the medium and larger trees, but even in these classes some trees presented very slow growth rates.

TABLE 4: PAI of diameter per diameter classes in the Tapajos forest in the period of 1981–1992. Trees standing and complete.

CD	N	MIN	MAX	MEAN	SD	CV
10	2919	0.0	0.9	0.2	0.2	100
20	1189	0.0	1.8	0.5	0.4	80
30	576	0.0	2.6	0.8	0.7	87
40	254	0.0	3.3	0.8	0.7	87
50	149	0.1	2.2	0.8	0.5	62
60	40	0.1	2.6	0.7	0.5	71
70	27	0.1	3.5	1.1	0.9	82
80	9	0.1	3.3	1.1	1.1	100
90	3	0.9	2.0	1.3	0.6	46
100	7	0.2	1.0	0.7	0.3	43

Ingrowth and mortality

Following the general trend of the forest, ingrowth of new recruits into the stand table (DBH ≥ 5 cm) has shown a sharp decrease over the time either in absolute or in relative terms for all species and for the commercial group (Table 5). At this stage of development of the stand after logging, growth conditions at the lower canopy layer are no longer adequate to promote fast growth of the seedlings and saplings. In another silvicultural experiment in the Tapajós Forest, Carvalho (1992) reported an ascending percentage of ingrowth 8 years after logging which removed 90 $m^3.ha^{-1}$. In this study 75 $m^3.ha^{-1}$ have been logged. It seems that in the former case the gaps created by logging still allow enough light in the lower canopy layer as seen by the ingrowth behaviour.

TABLE 5: Ingrowth and mortality rates in three observation periods in the Tapajos Forest. All stem identity classes.

Spec. Group.	Ingrowth N	Ingrowth R.p.a (%)	Mortality N	Mortality R.p.a (%)
	1981 - 1987			
All Species	370.1	5.2	134.8	2.4
Commercial	34.0	5.4	5.7	1.2
	1987 - 1992			
All Species	95.9	1.8	151.2	2.6
Commercial	6.7	1.3	7.7	1.5
	1981 - 1992			
All Species	364.9	3.1	224.9	2.2
Commercial	35.1	3.2	10.4	1.3

N = nr. of trees per ha; R.p.a. (Rate per annum) = proportion of the number of trees which were new recruits or dead at the end of the observation period,

The rates of ingrowth found in this study are compatible with figures reported elsewhere. For example, Weaver (1979) reported ingrowth rates ranging from 1.3% *p.a.* to 2.0 % *p.a.* for several tropical forests in Puerto Rico; in pristine forests ingrowth was nearly balanced with mortality. Swaine (1990) reported ingrowth and mortality rates of 1.3% and 1.5% in Kade, Ghana over an observation period of 17 years. These parameters were also balanced in La Selva, Costa Rica, as reported by Lieberman *et al*. (1985) where in a 13-year observation period, 1302 dead stems and 1293 new recruits were recorded.

The length of the observation period seems to be critical when analyzing ingrowth and mortality. Higuchi *et al*. (1993) have reported unbalanced figures for ingrowth and mortality in a virgin tropical rainforest near Manaus, Brazil.

In a 5-year observation period, the rates of mortality and ingrowth were, respectively, 9% and 4%.

Forest types and or species composition also influence the rates of ingrowth and mortality in tropical rain forests. In mixed dipterocarp forests in Peninsular Malaysia, Koon (1990) reported slightly higher mortality rates for non-dipteropcarps (2.53%) as compared to dipterocarp species (2.36%); conversely, dipterocarps had higher mean annual ingrowth percent (3.78%) compared to non-dipterocarps (3.29%) over the 14-year monitoring period.

In the present study, the rates of mortality had a small increase from the first to the second period of observation while ingrowth decreased (Table 5). In the first period ingrowth was higher than mortality but in the second period the balance was reversed. However, considering the overall monitoring period, the stand kept a positive balance .

Volume increment

The forest grew 38% in volume from 1981 to 1992 (Table 6). The group of commercial species augmented about the same proportion (37%) in bole volume. As it would be expected the periodic annual increment in volume followed the general declining trend as it was observed for the PAI in DBH

TABLE 6: Stand volume increment and periodic annual increment in three periods after logging in Tapajos Forest.

Species Group	Increment(%) 1981–92	PAI ($m^3.ha^{-1}.year^{-1}$) 1981–87	1987–92	1981–92
All species	38.4	6.1	4.2	5.2
Commercial				
Old List	37.0	0.9	0.7	0.8
Updated List	31.8	2.0	1.7	1.8

In 1992, the stand table of the commercial species according to the 1979 species list revealed only 6 trees.ha^{-1} and 18 $m^3.ha^{-1}$ of trees ≥ 45 cm DBH which is the commercial size according to the Brazilian forestry regulations. Analysis of the same stand in 1987 (Silva 1989) revealed also a very small number of trees of commercial species with potential size for the next harvest.

However, since the forest was logged, many species considered only as potential at the time of the first harvest were introduced to the timber market. Therefore, a revision of the species list revealed that 29 new species could be promoted to the commercial group.

Recalculating the stand tables according to the updated list, the commercial volume available in 1992 increased to 54 $m^3.ha^{-1}$ from 15 trees.ha^{-1}. Ingrowth of new species in the market raised the present yield of commercial timbers from 0.8 $m^3.ha^{-1}.year^{-1}$ to 1.8 $m^3.ha^{-1}.year^{-1}$ (Table 6). Even though the logging intensity had been considered too heavy for the region's standards, the performance of the forest so far indicates that a new cut at least similar to the first harvest may be possible at the end of the estimated cutting cycle (30–35 years). Continued assessments of the forest will confirm this assertion.

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ACKNOWLEDGMENTS

This research has been receiving logistic support from IBAMA–Brazilian Institute for Environment. World Wildlife Fund–WWF has given financial support for the past three years through the grant #2266. We thank Erly Pedroso, Nilson Carvalho and Argemiro, our tree spotters for their patient and important work of species identification in the forest. Luiz Parente de Souza has been helping on organizing and supervising the field activities. Thanks is also due to Svend Korsgaard and to Ana Mirtes Fouro for their help on development of computer programs for data analysis. Raimundo Parente de Oliveira has assisted on statistical analysis. Thanks to Milton Kanashiro and Vicky Schreiber for reviewing the manuscript.