8 Sustainable Forest Management for Smallholder Farmers in the Brazilian Amazon

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The conventional forest management system in effect for the Brazilian Amazon is not widely applied because of political and technical constraints (Hummel 1995). On the technical side, there is a lack of appropriately trained foresters with the necessary skills. On the political side, a legal document (Forest Management Project) approved by the federal authority (Brazilian Institute for the Environment and Natural Resources [IBAMA]) is required to practice forest management. Acquiring this document can be a complex and lengthy process. In addition, the existing forest management system requires substantial investment, which is worthwhile only for large areas of forest. By contrast, most properties in the settlement projects have forest reserves areas of only 30 to 50 ha. The 20- to 30-year felling cycles discourage owners from implementing forest management. Forest conversion yields large volumes of timber, whereas managed forest produces less timber with higher costs. Timber from both practices competes in the same market, with the result that timber prices are low. In addition, policy for the Amazon was originally focused on agricultural systems, especially cattle (*Bos taurus* L.) ranching, and effectively encouraged forest clearance. The net result is that smallholders are more likely to convert their forest area to nonforest use. A change in the dominant paradigm governing forest management is needed if the small producers, such as colonists and rubber tappers, are to become involved. This change is needed to allow the implementation of techniques and levels of intervention appropriate to the scale of the production and the availability of investment capital for smallholders.

According to the forest code, 50 percent of the area of properties with less than 100 ha must be preserved as a legal forest reserve in the Brazilian Amazon. The only legal commercial uses of this land are extractivism and sustainable forest management. Despite the government's efforts to control land use, some of those forest reserve areas have already been converted to traditional shifting cultivation and pastures. In 1994, 40 percent of the area was deforested on farms sampled in Colonization Project (PC) Peixoto and Theobroma in Rondônia state, representing a mean deforestation rate of natural forest of 2.4 ha/yr per farm (Witcover et al. 1994). Assuming the same deforestation rate in 1999 as in 1994, the farmers in these settlement projects are reaching the 50 percent limit that they can legally slash and burn. It is likely that they will not stop, or even reduce, the deforestation rate on their properties unless they can find an economic and ecologically sound use for their forests.

Riverine populations of the flooded areas (*várzeas*) of the Amazon Basin have been harvesting timber for generations. In Amazonas state, the production of timber by riverine populations represents a significant proportion of total wood production (Santos 1986; Bruce 1989; Oliveira 1992). The harvesting intensity is low because only a few species are used and because of the high-diameter felling limit, making the practice as a whole environmentally sound (Oliveira 1992). This practice is also found in the *terra firme* (upland) forest but varies in intensity according to access and market proximity. The sustainability of the system is determined by the farmers' capacity to extract wood and the opportunity that they have to sell it because of the absence of rules and control. In these systems, timber extraction is a seasonal activity and integrated with hunting, fishing, nontimber product extractivism, and subsistence agriculture.

The existence of these traditional forest exploitation methods is proof of the ability of local people in the Amazon to implement sustainable forest management activities. However, the practice has not yet been formalized as a silvicultural system and documented sufficiently to allow its application in a systematic way. The forest management model proposed here is a formalization of these traditional methods and was designed for small farmers to generate a new source of family income. An additional aim is to maintain the structure and biodiversity of the legal forest reserves, conferring more value on forest than alternative forest uses (Dickinson et al. 1996), thereby increasing their importance for conservation. Formalization helps to reduce ad hoc changes in the method when external conditions change, such as drops in the price of extractivist products, economic recession, or third-party greed. In the absence of formal procedures, short-term changes in economic circumstances undermine the long-term perspective needed for sustainable forest production by small producers and may lead to fluctuations in harvesting rates and damaging impacts on the forest.

The ecological basis for this sustainable forest management system, the components of the management system, and their application in a pilot project on smallholder farms in the PC Pedro Peixoto in Acre state in the western Brazilian Amazon are described in this chapter. Preliminary results from the pilot project on tree growth, mortality, and recruitment after an initial harvesting are also discussed.

RATIONALE AND ECOLOGICAL BASIS FOR THE FOREST MANAGEMENT SYSTEM

The proposed forest management system is based on low-intensity harvesting, low-impact disturbance, and short rotation cycles, which combined may alter the subsequent vegetation dynamics and composition compared with conventional forestry practices. Selective logging creates disturbances and canopy openings similar to those of natural tree falls that stimulate the growth of trees in advanced regeneration stages (Uhl et al. 1990). In contrast, conventional mechanized forest exploitation methods create significant simultaneous gaps (Johns et al. 1996). In addition, because mechanized logging operations usually are not planned, forest damage is greater, with the opening of unnecessary skid trails and excessive skidder maneuvering (Uhl and Vieira 1988; Oliveira and Bráz 1995; Johns et al. 1996). Large gaps may take longer to recover than small gaps because succession starts at the pioneer phase. Pioneer plants establish and grow rapidly, thus reducing the growth rate of desirable commercial species through competition. This pioneer effect imposes a longer cutting cycle and reduces yield. On the other hand, if the impacts of logging are distributed over time, a lower number of gaps will be created at the same time, and it is likely that the contribution of pioneer species to the natural regeneration will be lower.

Many factors affect decisions about the harvesting cycle length and intensity. The final choice is a balance of factors including financial needs, species composition, and site characteristics. Harvesting at low intensities but shorter intervals allows seed production and regeneration because most of the reproductively mature trees are retained in the residual stand. This is in contrast to long-rotation production systems in which entire populations of adult trees can be removed at harvesting. Retaining seed trees between harvesting events helps to maintain the genetic diversity of populations over time, particularly for species with intermittent reproduction and buffers the population against the possibility of stochastic disturbance events eliminating smaller size classes (Primack 1995). Shorter cutting cycles can also allow better biological control than longer cycles because diseased or infested trees can be cut more often. It is also easier to salvage dead trees if the smaller trees are marketable.

On the other hand, polycyclic silvicultural systems have been criticized for the damage they cause to the soil and residual trees because of the need to return to the forest at short intervals (Dawkins and Philip 1998). This damage can be minimized by reusing old logging roads and skid trails and through better-planned and -controlled logging operations (Silva et al. 1989; Bráz and Oliveira 1995). The use of mechanized logging in short-cycle systems probably is limited for both technical and economic reasons.

In summary, the proposed system is based on the hypothesis that low-impact disturbance at short intervals, combined with silvicultural treatments, will create gaps of different ages and permit the maintenance of a forest with a structure and biodiversity similar to those of the original natural forest. However, the longer-term ecological factors that are needed to ensure forest recovery of short-cycle systems must be balanced with the need for a minimum harvest volume intensity to make the activity economically viable.

METHODS

Site Description

The PC Pedro Peixoto was created in 1977 in an original area of 408,000 ha that was later reduced to 378,395 ha. It includes the municipal districts of Rio Branco, Senador Guiomar, and Placido de Castro and is planned for settlement by 3000 families (Cavalcanti 1994). The forest management pilot project is located in two trails on the road BR-363, 80 and 90 km from Rio Branco and involved eleven farms with 80 ha each. Because the forest management area represents 50 percent of the properties, each farm has about 40 ha for forest management.

The nearest meteorological station to the area is the Centro de Pesquisa Agroflorestal do Acre (CPAF/AC) meteorological station at 160 m altitude, 9°58′22″S, 67°48′40″W. The climate is classified as Awi (Koppen) with an annual precipitation of 1890 mm/yr and an average temperature of 25°C (all data from Embrapa–CPAF–Acre 1996a, 1996b).

Components of the Management System

The formalized systematic application of the forest management practices used by small farmers in the Brazilian Amazon entails the implementation of techniques for evaluating the production capacity of the forest (inventory), planning exploitation activities, and monitoring (Bráz and Oliveira 1996). The management system serves both harvesting and silvicultural treatments (Hendrison 1990). The basic components and operations of the proposed management system and the specifics of how they were applied in PC Pedro Peixoto are described in this section. Also refer to figure 12.6a in this volume.

Forest Inventory

A forest inventory is conducted 1 to 2 years before the first harvesting to characterize the structure and species composition of the forest and evaluate the potential for wood production.

A forest inventory was conducted in the managed forest areas of the PC Pedro Peixoto, the inventory was distributed among the 440 ha of the eleven farms, each with legal forest reserves of 40 ha. The inventory was performed using a systematic sampling design, with 10- by 100-m plots distributed along ten lines. There were twenty plots for each area, totaling 214 samples and a total sampled area of 21.4 ha, 4.87 percent of the total area. Later these lines were used as access routes for implementing all activities of the management plan.

All plants larger than 10 cm dbh were measured and identified. The natural regeneration (plants taller than 1.5 m and less than 10 cm dbh) were sampled in 10- by 10-m subplots located in the first 10 m of each plot. The species were identified by vernacular names by the Acre State Technological Foundation (FUNTAC), *mateiros* (local people with great experience in field identification of species), and herbarium work.

In 2000, Empresa Brasileira de Pesquisa Agropecuária (Embrapa) performed an inventory of the whole forest area of PC Pedro Peixoto (150,000 ha). This inventory will be used for future forest management planning in this site.

Forest Management Compartments

Compartments are established within the forest area that will delimit the areas for the harvesting intervals according to commercial timber volume and cutting cycle length.

In the case of the Pedro Peixoto, the decision on cutting cycle length must be based on the small forest areas, the short time to execute all operations, the limited labor availability, and the use of animal traction for extraction. The small size of the felling area prevents the creation of many compartments and eliminates the possibility of using long cycles (at least when annual incomes are desired). For small properties the cutting cycle may be shortened so that it equals the number of annual felling compartments to create an annual income that allows the owner to pay taxes and forest management costs (Leuschner 1992).

Figure 8.1 provides a layout of a typical farm in Pedro Peixoto and includes ten compartments, measuring 100 by 400 m, in the forest reserve that will be harvested during the 10-year rotation. The compartments are harvested sequentially, with only one compartment harvested per year.

Prospective Forest Inventory

A prospective forest inventory is performed in each targeted compartment 1 year before harvesting to allow planning of exploitation activities, defining the trees to be treated, logged, or preserved. The resulting map can include other information such as topographic features, the location of skid trails, and preservation areas.

All trees larger than 50 cm dbh are measured, identified, and plotted on a map. Usually only commercial species are measured in such inventories, but considering the small size of the plots in the Pedro Peixoto farms, all trees were mapped. This allows

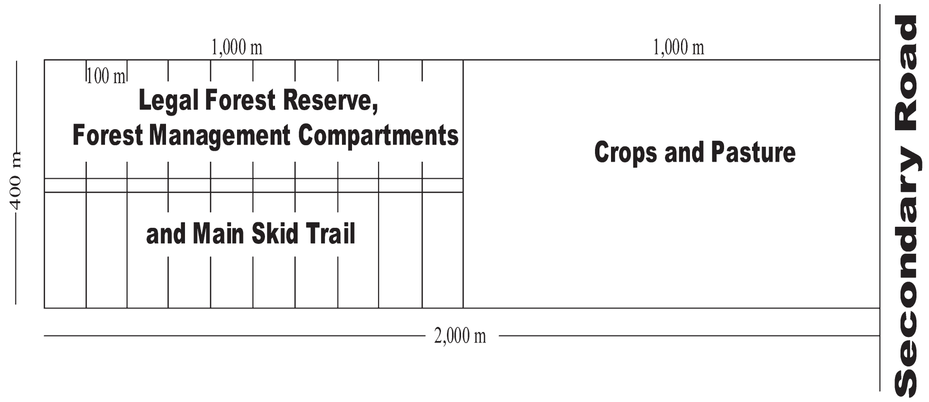

Figure 8.1 Layout of a typical farm in the Pedro Peixoto colonization project, showing the distribution of the agricultural land (crops and pastures) and the legal forest reserve. The forest reserve area shows the forest management compartments based on a 10-yr rotation.

future decisions about which trees might be included in silvicultural treatments. In addition, the list of commercial species is changing rapidly, and recording all trees on prospective inventories helps to locate the commercial stems at future harvests.

Skid trails are planned on the basis of the prospective forest inventory. For this system, a main skid trail 1.5 m wide crosses the middle of the compartment, perpendicular to the direction of the nearest secondary road (figure 8.1). This trail is opened from the first to the tenth compartment at a rate of 100 m (the width of the compartment) per year.

Some silvicultural treatments can also be applied at this time. The only silvicultural treatment currently incorporated into the management system is climber cutting. Climbers often bind trees together, and when one is felled others come down; cutting climbers sufficiently ahead of time may significantly reduce damage (Fox 1968; Liew 1973). Because of the low harvesting impact (no more than two trees per hectare) of this system, treatments such as protective tree marking (Chai and Udarbe 1977) are not necessary, and the residual trees will be protected using the prospective inventory information (i.e., map of trees) and the practice of directional felling.

Determination of Felling Rate

Species are selected and the felling rate determined on the basis of species diameter distribution, growth rate, and seed dispersal based on information obtained in the prospective forest inventory. The annual harvesting rate for Pedro Peixoto was determined on the basis of a minimum felling cycle of 10 years and harvesting intensity of 5 to 10 m^3 of timber per hectare. This recommendation is based on a conservative yield estimate of 1 m^3/ha/yr (Silva et al. 1996). The low yield predictions are based, in part, on the low level of silvicultural intervention that will be used, although it has been shown that usable timber volume can be increased silviculturally up to 5 m^3/ha/yr (Miller 1981; Silva et al. 1996). An additional harvesting rule will be applied whereby a maximum of one-third of the total commercial volume (stems of commercial species greater than 50 cm dbh) is taken. A similar harvesting rate was used in Osa Peninsula, Costa Rica, where all trees larger than 60 cm dbh were felled in three cycles of 10 years (Howard 1993). This rule guarantees that there will be at least three rotations of the management system. Predicted yields may increase in the future after the growth studies on permanent plots.

Selective Logging Operation

Logging is then conducted. Trees are directionally felled, when possible, to facilitate their transport and minimize damage to the forest. The logs are converted in the forest by chainsaw or one-person sawmills into planks, boards, or other products according to the characteristics of the timber and market demand. This phase is the most expensive and labor-intensive component of the entire system. Three different studies were conducted to determine the effectiveness and costs of the different phases of logging. These studies are described later in this section.

In upland forests, such as at Pedro Peixoto, it is also necessary to saw the logs so that animal traction can be used to skid them from the forest to the secondary roads. First the planks are carried to the main skid trail with the use of a zorra (an implement used regionally to skid planks), and then the planks are moved by wagon from the main skid trail to the secondary road. Haulage by animals has the advantage of generating less soil compaction and modification, and less damage to residual trees, than mechanical skidding equipment (Dykstra and Heinrich 1992; Ocaña-Vidal 1990; FAO 1995).

Artificial Regeneration

Desirable species are planted in the felling gaps and on skid trails after logging. One of the challenges of forest management is to promote the regeneration of species with high economic value, maintain their populations, and preserve their genetic variability. The regeneration of some desirable species is difficult to achieve without intervention (Evans 1986). This difficulty is characteristic of several species that are under strong exploitation pressure in tropical forests (e.g., *Swietenia* spp. in South America, *Khaya* and some *Entandrophragma* spp. in West Africa).

The implementation of artificial regeneration is strongly limited by economic factors and the heavy demand for labor (Thang 1980). Therefore, its adoption can be enforced only by the force of law (presupposing an effective policing) in very favorable economic conditions (e.g., financing, subsidies, fiscal incentives, or elevated return rates) or only at small or medium management scales (Ramos and del Amo 1992). The most common technique is enrichment planting (Ramos and del Amo 1992), but in practice the application of these techniques has not been effective in Amazon because growth and survival has been low (Verissimo et al. 1995).

The artificial regeneration technique proposed for Pedro Peixoto pilot project is to establish species such as *Swietenia macrophylla* King, *Torresia acreana* Ducke, *Ceiba pentandra* (L.) Gaertn., *Bertholletia excelsa* Humb. & Bonpl., and *Cedrela odorata* L. in gaps and skidding trails immediately after forest exploitation, using the planting techniques proposed by Oliveira (2000). The planting will be carried out using a spacing of around 5 by 5 m. Before planting, manual cleaning of the areas must be executed. The farmers plant seedlings about 30 cm in height at the end of the dry season between October and December. No cleanings or other silvicultural treatments are needed after planting.

Forest Monitoring

Monitoring of the forest responses to forest management is achieved through the study of the forest dynamics (growth, ingrowth, recruitment, damage, and mortality) in the permanent sample plots (PSPs) that were established during the prospective forest inventory. Forest dynamics are monitored in the PSPs 1 year before harvesting and then 1, 3, 5, and 10 years after logging to estimate logging damage and stocking of the residual stand.

In the PC Peixoto management areas, tree growth, recruitment, mortality, and species richness and diversity were monitored in five permanent PSPs for 3 years, with measurements starting before logging and repeated 1 and 2 years after logging. The PSPs were installed in five different management areas, two on the Nabor Junior trail 400 m apart and three on the Granada trail (the first two 400 m from each other and the third one about 800 m from the second). The distance between the two trails is 10 km. Each PSP is a square 1-ha plot, divided into 100 subplots each of 100 m^2 (10 by 10 m). All trees larger than 20 cm dbh were tagged, identified, and measured. In twenty randomly selected subplots in each PSP, all trees larger than 5 cm dbh were also tagged, identified, and measured.

Tree crown exposure was assessed following the same classification as Silva et al. (1996): full overhead light, when the complete crown received direct sunlight; some overhead light, when the crown receives some direct sunlight; and shaded, when the crown does not receive direct sunlight.

Species groups were assigned to the following categories: pioneer species that included both short-lived pioneers and large pioneers, shade-tolerant species divided between understory trees and canopy trees, and commercial species that included all species that have been sold in Rio Branco market by the farmers.

Species richness was defined as the total number of species on plots (Kent and Coker 1992) and diversity was expressed using Fisher's α. This index was chosen because it is stable with changes in sample sizes and can be used to predict the number of species in larger samples (Condit et al. 1996).

Mean annual mortality rates (AMRs) were calculated using the formula of Sheil et al. (1995): $\text{AMR} = 1 - (N_1/N_0)^{1/t}$, where N_0 and N_1 are population counts at the beginning and end of the measurement interval, t.

Recruitment rate includes all plants that attained the minimum measurement diameter of 5 cm dbh. Recruitment rate was standardized by dividing the total number of recruits in one census by the number of adults in the previous census, then dividing by the census interval (Condit et al. 1996).

Growth rates were calculated using the formula $(\text{dbh}_2 - \text{dbh}_1)/t$, where dbh_1 and dbh_2 are diameters at the beginning and end of measurement interval t, respectively. Differences in growth rates were tested statistically using Tukey's test after one-way analysis of variance (ANOVA) for species groups and crown exposure. Where there was evidence that the residuals were not normally distributed, the data were transformed using the Box Cox transformation (Minitab 12.23).

Growth of Residual Trees

Growth of the residual trees and artificial regeneration of desirable species are assisted by removing badly formed or undesirable trees 5 years after logging.

Forest Exploitation Experiments

Tree Felling and Conversion of Logs to Planks

A study was conducted to determine the time needed for each phase of the logging operation (tree felling, cutting the log, and converting the logs to planks). The efficiency of the conversion to planks was determined as the final volume of planks relative to the initial volume of logs. The study took place in two managed areas, one off the Nabor Junior secondary road and the other off the Granada secondary road. The data were collected during four logging events, using trees of *Guarea pterorachis* Harms, *Hymenolobium excelsum* Ducke, and *Dipteryx odorata* (Aubl.) Willd. from 45 to 97 cm dbh. A total of twenty-eight logs, each 2.2 m long, were processed by a team of three men.

Plank Skidding

In this study, the time needed for the different steps in the skidding cycle were measured: the travel (unloaded) from the edge of the secondary road to the felling gap in the forest, loading of the planks, the time to travel back (loaded) to the secondary road, and the unloading of the planks. The time needed to rest the animals was considered wasted time. This study was carried out in two managed areas, both off the Granada secondary road. The data were collected in five skidding events and forty skidding cycles, where planks of four species were being skidded (*Couratari macrosperma* A.S. Smith, *Dipteryx odorata* (Aubl.) Willd., *Protium apiculatum* Swartz, and *Peltogyne* sp.). The skidding distances varied from 200 to 1400 m, and the planks were loaded onto a zorra. The skidding was performed with two teams of two men working with an ox on each team. The oxen used for skidding the planks were two individuals of the Melore breed of age 5 and 8 years and weighing around 500 kg.

Forest Management Costs and Economic Analysis

Costs were estimated on the basis of the minimum salary offered in Brazil in 1997 of US$100 per month, a working day of 6 hours, a 5-day working week, and a team of three people for all activities except the skidding of the planks, where the team consisted of only two men. The depreciation of the chainsaw was calculated as 25 percent per year and the useful life of the oxen 10 years. The harvesting and conversion of the logs to planks was performed with a Stihl 051 chainsaw.

RESULTS AND DISCUSSION

Forest Inventory

The vegetation is predominantly evergreen tropical forest with some deciduous species that included *Tabebuia serratifolia* (Vahl) Nichols., *Ceiba pentandra* (L.) Gaertn., and *Cedrela odorata* L. Structure varied from open (low-stature forest with a dense understory and high occurrence of lianas and palm trees) to dense (taller forest with greater standing timber volume and no dense understory). The structure depended on the drainage and topographic status of the site.

In total, 307 species were identified, from 185 genera and 54 families. The most common family was the Caesalpinaceae, with eighteen genera and twenty-three species sampled. The distribution of the species across the area was very irregular, with some species common (e.g., *Protium apiculatum* Swartz) and other rare species sampled only once in all 214 samples (e.g., *Macrolobium acaceifolium* Benth.).

The forest had an average of 375 trees/ha (trees larger than 10 cm dbh), an average basal area of 22 m^2/ha, and total volume of 180 m^3/ha. The volume of trees below commercial size of 50 cm dbh was 107.4 m^3/ha, and the volume of trees of commercial size was 73.1 m^3/ha (table 8.1).

The forest contained a high volume of commercial species, (46.5 m^3/ha above 10 cm dbh). This volume is composed of hardwood species used in construction, such as *Dipteryx odorata* (Aubl.) Willd. and *Hymenaea courbaril* L., and species with an inter-

Table 8.1 Results of the Forest Inventory at Pedro Peixoto Colonization Project Showing Mean Values of Tree Density, Basal Area, Volume, and Standard Deviation (SD) and 95% Confidence Interval for Estimates of Total Volume

Average number of trees (dbh > 10 cm)/ha	375.4
Basal area	22.0 m^2/ha
Total volume of timber (dbh > 10 cm)	180.4 m^3/ha
Standing volume (dbh > 50 cm)	73.1 m^3/ha
Standing volume (dbh 10–50 cm)	107.4 m^3/ha
Volume confidence interval ($p > .05$)	
Minimum	171.0 m^3/ha
Maximum	189.7 m^3/ha
SD	71.6
SE (%)	4.8

mediate commercial value, such as *Aspidosperma vargasii* A.D.C., *Protium apiculatum* Swartz, and *Peltogyne* sp. However, highly desirable species such as *Cedrela odorata* L. and *Torresia acreana* Ducke were present but with low commercial volume.

The volume of commercial timber in the study site is around 20 to 30 m^3/ha. Although the conventional forest management system in the Amazon uses a harvesting rate of 30 to 60 $m^{3/}$ha on a 30-year cycle, it does not usually exceed 30 m^3/ha (Johns et al. 1996). Thus, the outcome in terms of yield will be equivalent to the standard rotation of 25 to 30 years established by IBAMA for mechanized management. The annual felling rate should not fall below 5 m^3/ha/cycle; otherwise, harvesting is likely to be uneconomic, returning less than the minimum salary practiced in Brazil around US$100.

Some species were very common in the natural regeneration such as *Trinorea publifora* (Benth.) Sprang & Sandwith, but others were rare, such as *Chrysophyllum* spp. Some species were recorded only in the regeneration and not in the adult population (e.g., *Piper hispidinervum* C.D.C.) because they have a low maximum size or are shrubs. Almost all commercial species were found in the regeneration. Some of the species not present in the inventory samples (e.g., *Torresia acreana* Ducke) were later sampled in the natural regeneration areas of the felling gaps study.

Monitoring Permanent Sample Plots

Mean Diameter Growth Rate

During the study period, diameter increment varied from 2 cm/yr (e.g., *Jaracatea spinosa* Aubl.) to 0.1 cm/yr and even less for some understory species (e.g., *Quaribea guianensis*). The pioneer and shade-tolerant species groups showed significant differences in mean relative growth (table 8.2). The large difference in the mean diameter increment of canopy species and understory species indicates that even after group-

Table 8.2 Annual Diameter Increment (mean and *SE*) for Species Groups of the Trees in the Five Permanent Sample Plots in Pedro Peixoto

Group	Growth Rate[a] (cm/yr)	SE
Short-lived pioneer species	0.63a	0.25
Big pioneer species	0.57ab	0.29
All pioneer species group	0.61a	0.25
Canopy species	0.29b	0.03
Understory species	0.21b	0.03
All tolerant species group	0.26b	0.28
All trees	0.28	0.04

[a]Means followed by the same letter are not significantly different (Tukey test, $p < .05$).

ing into shade-tolerant and pioneer species, there are still species with very different growth patterns in the groups.

Crown exposure had a strong influence on diameter increment, independent of ecological grouping. On the PSPs, the variation in mean diameter increment resulting from crown exposure was from 0.47 cm/yr (trees with full overhead sunlight) to 0.19 cm/yr (shaded trees). Trees that only received some direct sunlight had a mean growth rate of 0.34 cm/yr (table 8.3).

Diameter increment was not affected by diameter class when analyzed within crown exposure classes. The expectation that diameter increment increases with tree size may exist because most of the slow-growing trees die when they are small and because the big tree class includes no understory species (Swaine et al. 1987).

Table 8.3 Mean Annual Diameter Increment by Diameter Class and Crown Illumination on the Permanent Sample Plots at Pedro Peixoto

Diameter Class	Full Overhead Light		Some Overhead Light		Shaded	
	Growth Rate (cm/yr)	SE	Growth Rate (cm/yr)	SE	Growth Rate (cm/yr)	SE
5–10	0.42	0.05	0.29	0.06	0.20	0.02
10–19.9	0.57	0.11	0.43	0.04	0.21	0.01
20–29.9	0.38	0.03	0.32	0.02	0.25	0.02
30–39.9	0.50	0.05	0.30	0.02	0.32	0.04
40–49.9	0.40	0.06	0.37	0.05	0.36	0.10
50–59.9	0.55	0.07	0.34	0.01	0.22	0.08
>60.0	0.45	0.04	—	—	—	—
Average for all plants[a]	0.46a	0.18	0.34b	0.06	0.20c	0.03

[a]Means followed by different letters are significantly different (Tukey test, $p < .05$)

The annual diameter increments recorded here were similar to other values obtained in tropical forests (e.g. Okali and Ola-Adams 1988; Chiew and Garcia 1989; Rai 1989; Silva et al. 1996), showing an average of 0.27 cm/yr for the plants measured on all PSPs in the period (CPAF/AC and PC Peixoto).

The effect of crown exposure on the growth rate of trees is well known and has been reported before (e.g., Silva et al. 1989; Silva and Whitmore 1990). However, the results presented in this work demonstrate that a large increase (of up to 100 percent) in the mean annual diameter increment can be expected after a change of the crown exposure of a tree (table 8.3). This finding provides strong support for the application of silvicultural treatments in the region.

Stand Basal Area Increment

The total stand basal area in the PSPs before logging was 24.28 m^2/ha, and that of the commercial species was 5.96 m^2/ha. The logging of the areas caused a reduction in these to 22.93 and 4.89 m^2/ha, respectively. Two years after logging the mean total stand basal area was 23.12 m^2/ha, with 5.33 m^2/ha for the commercial species. These changes represent a mean annual increment of 0.09 m^2/ha/yr (0.76 m^3/ha/yr) for the total stand basal area and 0.13 m^2/ha/yr (1.06 m^3/ha/yr) for the commercial species.

The greater volume increment of the commercial species (1.06 m^3/ha/yr) in the PSPs at PC Pedro Peixoto compared with the total volume increment (0.76 m^3/ha/yr) can be interpreted as an increase in the population of the commercial species in the total volume in the forest. This might be an affect of directional felling, which aimed to reduce the environmental impact of logging and the protection of residual trees of commercial and potential species. The volume increment of commercial species was compatible with the logging intensity and cycle length proposed.

Mortality and Recruitment Rates

Tree mortality immediately after logging was 3.7 percent and 2 years after was 3.2 percent per year. The average for the period was 3.0 percent per year. A peak in the mortality was observed from 1998 to 1999 (4.0 percent), which might have been influenced by the El Niño event that year because 1 year after logging the mortality was only 2.2 (figure 8.2).

High recruitment rates of thirty-six plants per hectare per year in the first 2 years after logging were found in the pilot project. This rate is high partly because it included all trees above 5 cm dbh. Because recruitment considered only trees larger than 5 cm dbh, the time of the study was insufficient to include the cohort of trees that germinated immediately after the logging. Thus, an increase in the recruitment rates in those areas may be expected in the next few years.

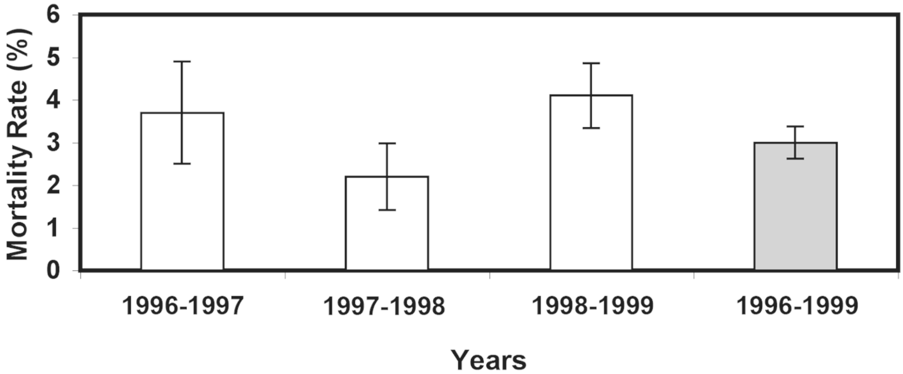

Figure 8.2 Mortality of trees >5 cm dbh in the five permanent sample plots immediately after logging (1996–1997), 1 yr (1997–1998), and 2 yr (1998–1999) after logging, and the mean rate *(gray bar)* for the 2 yr after logging (1996–1999). Lines indicate *SD*.

Damage by Timber Exploitation and Natural Causes

In this study, logging damage for all trees was estimated from the basal area of trees that fell or had their crowns destroyed in or around felling gaps (Oliveira and Bráz 1995). Therefore, it includes even the trees that fell as a result of natural causes (e.g., high winds and storms); logging operations were considered responsible by increasing the tree's crown exposure.

The damage caused by the low-impact forest management logging operations (*sensu* Oliveira and Bráz 1995) affected 1.21 m^2/ha or 5.1 percent of the stand basal area 1 year after logging. The damage caused by natural causes (e.g., wind and storms) in the same period was 1.02 m^2/ha, or 4.3 percent of the stand basal area (figure 8.3). The canopy opening caused by the harvesting was minimized by the low harvest intensity (two trees per hectare) and the use of oxen to skid the planks. The damage caused by logging was greater in the first years after logging, probably because of the death of damaged trees. Two years after logging there were still some effect of the logging, but the damage to the forest from natural causes was higher. The damage produced by natural causes showed a tendency to increase after the harvesting, from 0.61 m^2/ha 1 year before to 1.61 m^2/ha 2 years after logging (figure 8.3). The increased damage can be associated with the logging impact but was probably also associated with the fact that 1998 was an El Niño year, with more frequent and stronger storms in the area.

Species Richness and Diversity

Two years after logging the number of species was lower in the managed area than before harvesting (235 and 259, respectively). The density of stems of commercial species larger than 5 cm dbh was similar before and 2 years after logging and therefore

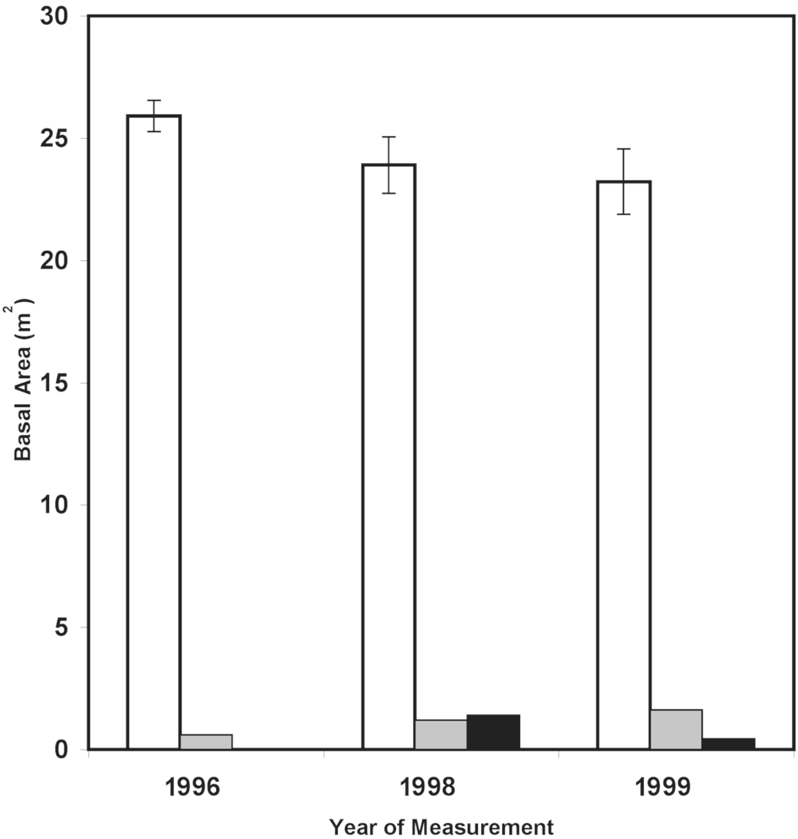

Figure 8.3 Mean basal area of nondamaged *(white bars),* damage caused by natural causes *(dark bars),* and damage caused by logging *(light bars),* before logging (1996), 1 yr (1998), and 2 yr (1999) after logging. Lines indicate *SE.*

apparently was not affected by a harvesting intensity of one or two trees per hectare. Fisher's index varied from around 84 before harvesting to 81 after logging (table 8.4). The variation in species richness and diversity before and after logging was too low to be considered significant. It is possible that diversity will increase above that before management started because opportunities for invasion by pioneer species increases with canopy opening.

Forest Exploitation Experiments: Preliminary Results

Tree Felling and Conversion of Logs to Planks

The efficiency of conversion (in volume terms) of logs to planks was between 61 and 41 percent for the biggest and smallest trees, respectively, with an average of around 50 percent. The total time to convert 1 m^3 was 5.1 work-hours. For a 6-hour work day,

Table 8.4 Species Richness and Diversity in the Permanent Sample Plots of Colonization Project Pedro Peixoto Before and 2 Years After Logging

	Total Number of Stems	**Number of Stems of Commercial Species**	**Total Number of Species**	**Number of Commercial Species**	**Fisher's α Based on All Species**
Before logging	1737	265	259	35	84.3
Two years after logging	1390	225	235	32	81.1

a team of three people produced 3.6 m^3 of sawn timber, which represents a very low productivity even when compared with that of a small sawmill (around 10 m^3/day). On the other hand, because the annual potential production of these farms is only about 40 m^3 (10 m^3/ha × 4 ha/yr), the maximum annual labor requirement therefore is only about 18 work-days to convert this unsawn timber into about 20 m^3 of planks (table 8.5).

Skidding the Planks

The number of skidded pieces varied between one to four per ox per trip according to their shape and weight. The load therefore varied from around 0.19 m^3 (*Dipteryx odorata* [Aubl.] Willd.) to 0.39 m^3 (*Couratari macrosperma* A. S. Smith), with an average of 0.28 m^3. The loading and unloading of the zorra also were strongly affected by the shape and specific weight of the wood. The pace of the oxen was approximately 4 km/hr and was kept constant even when the skidding distance increased from 200 to 1200 m. However, when the distance increased to 1400 m the time needed to load and unload the zorra was not long enough to rest the animals for continuous operation. The total volume skidded in 1 day by a team of two men and one ox varied according to skidding distance, from 1.14 m^3 (skidding distance 1400 m) to 3.36 m^3 (skidding distance 250 m) (table 8.6).

Table 8.5 Work-Hours Needed to Complete Each of the Phases Involved in Felling Trees and Converting the Timber into Planks

Phase	**Time for the Complete Tree (work-hours, mean [SD])**	**Time for 1 m^3 (work-hours, mean [SD])**
Cutting the tree	0.5 (0.20)	0.1
Cutting the logs	1.0 (0.07)	0.2
Converting logs to planks	23.0 (0.80)	3.5
Chainsaw maintenance	6.0 (0.88)	0.9
Wasted time	1.8 (0.32)	0.4
Total time	32.3 (1.97)	5.1

Table 8.6 Breakdown of the Performance and Volumes Skidded by Two Teams of Two Men with One Ox per Team over Three Skidding Distances (200, 1200, and 1400 m) in the Managed Forest of the Pedro Peixoto Colonization Project

Performance and Volume	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Skidding Distance (m)	**200**		**1200**		**1400**	
Effective work day average (work-hours)	13.7		11.00		12.3	
Total wasted time per day (work-hours)[a]	0.5		1.0		2.0	
Average time for complete cycle (work-hours)	1.1	0.19	1.7	0.13	1.1	0.45
Number of cycles per day	12		6		6	
Average volume skidded per cycle (m^3)	0.28	0.07	0.28	0.04	0.19	0.07
Average volume skidded per hour (m^3)	0.43		0.26		0.13	
Total volume skidded per day (m^3)	3.36		1.68		1.14	

[a]The time to rest the ox was counted as wasted time.

Costs and Economic Analysis of the Proposed Forest Management System

The production costs were between US$33.5 and US$35.5/m^3 of sawn planks at the roadside before transport to the market (table 8.7). Considering the costs of transportation, at around US$15/$m^3$, the total costs would be around US$50/$m^3$. The current market price for wood in Rio Branco varies between US$100 and 150/$m^3$, according to species and the quality of the planks. Therefore, even with the low level of technology and experience available to the farmers for this activity, it was possible to achieve ratio of benefits to costs of around 2:1 (table 8.7). In a similar small-scale forest management system in Nicaragua, Castañeda et al. (1995) found a return of US$47 per work day and production costs around US$43 to US$65/m^3.

Table 8.7 Mean Cost of Each Phase of the Forest Management System per Cubic Meter of Harvested Timber

Forest Management Phase	**Cost (US$)**
Trail opening	4.2
Prospective inventory	1.4
Silvicultural treatment	0.8
Felling and converting logs to planks	19.9
Skidding with animals	7.1
Transportation	15.0
Total	48.4

IMPLICATIONS FOR THE FOREST MANAGEMENT SYSTEM

Forest Exploitation and Dynamics After Logging

Production is generally quite low in lightly exploited forests without silvicultural treatments (De Graaf 1986). The increased growth of the trees remaining after harvesting tends to disappear after only 3 to 4 years after the harvesting (Silva et al. 1989). Therefore, harvesting timber in a simple polycyclic system and leaving the forest to regenerate without further silvicultural assistance, such as enrichment plantings and refinement, is not a satisfactory approach for maintaining forest productivity (De Graaf 1986).

The implementation of liana cutting, directional felling, and planning the skid trails in this management system reduces the damage caused by logging and extraction and contributes to the maintenance of forest productivity (Pinard and Putz 1996). Additional silvicultural treatments should be considered, such as the elimination of badly formed trees, refinement of undesirable species, crown liberation (for commercial species), and gap liberation (*sensu* Kuusipalo et al. 1996). The goal of refinement should not be to eradicate undesirable species but to reduce their proportion and competitiveness in the stand (De Graaf 1986).

The proposed system will facilitate the application of silvicultural treatments, which are planned as part of the conventional system. Because of their high labor, demand and costs usually are not executed. Farmers regularly enter the forest management area on their properties during the work day for hunting, fishing, and rubber tree tapping. Therefore, it would be a simple matter to carry out the silvicultural treatments proposed here as part of the daily work schedule.

The use of the zorra over long distances reduces the productivity of the skidding phase. Alternatively, a small wagon pulled by one ox for the primary transport of the planks from the main skid trail to the edge of the secondary roads limits the skidding by zorra to the distance from the felled tree to the main skid trail, or a maximum journey of 200 m. This does not compromise the productivity of the overall operation.

Acquisition of more data from PSPs will allow the system to be fine-tuned by calculations of future harvest rates and the length of future felling cycles. This phase may be executed by a partnership between research and teaching institutes and the local people. The system also allows ongoing modifications of the basic model according to feedback provided through monitoring and data acquisition.

Economic and Social Benefits: Limitations and Strengths of the Proposed System

It must be recognized that the system has a low profitability when compared with the yields obtained by mechanized forest management. A low profitability is to be expected for a system designed to be applied in communities with a shortage of investment capital. In this case, the social benefits obtained by returning low profits to the colonists rather than higher profits to forestry companies can be used to justify the application of the system. On the other hand, the other available land use options for small farmers and colonists (shifting cultivation, extractivism, and small-scale cattle ranching) also usually return low profits (Vosti et al. 2001).

The price of timber is likely to increase in the future because of the rise in the demand for tropical timber worldwide and the restriction in supply, especially of the more valuable timbers. The constant restrictions on the availability of the timber of certain highly valued species, combined with international pressure for preservation of some of these species, has created a strong incentive for introducing new species to the market. There is also a potential market for plywood species (e.g., *Ceiba* spp.), which was not considered because of the low prices in the local market for the wood sold in logs. The group of commercial species is changing quickly. Therefore the current standing stock of timber represents an investment rather like a savings account.

The small property, as a unit of production, does not prevent collective or cooperative agreements between neighboring proprietors. Indeed, the aggregation of producers into larger units may facilitate the acquisition of new technologies (e.g., one-person sawmills, oxen, and small tractors), result in increased prices in local markets, and reduce the cost of overheads such as transport. Collective working might generate a substantial increase in the yields from forest management, and within a short time the profits generated by the forest management as proposed here will increase significantly.

A potential problem with forest management is the effects it can have on the fauna, changing the abundance of individual species, their food availability, the distribution of microclimate or other environmental conditions and changes in competitive relationships. These changes also could affect pollination, seed production, and seed dispersal (e.g., mahogany in Budongo forest in Uganda; Plumptre 1995), which are usually correlated with logging intensity (e.g., seed predators in Gorupi Forest Reserve). These effects usually tend to decrease over time (e.g., number of species of understory birds in Kerala National Park in Uganda; Drauzoa 1998).

In the case of PC Peixoto, the impact of the management on the fauna probably will be minimized by the low harvesting intensity, the high number of commercial species (diluting the effect of reducing the density of a single species, such as the exploitation of mahogany in Pará State East Amazon; Verissimo et al. 1995), and the use of animal traction instead of mechanized log extraction. In addition, hunting throughout the year is a common practice among most of the farmers, which might have a much higher impact on the fauna and seed dispersal (Guariguata and Pinard 1998) than the forest management, which is restricted in space (the compartment) and time (the cycle length of 10 years).

Future Prospects

Small-scale forest management provides an opportunity to fill a gap in land use in the Amazon by allowing small farmers to use the forest reserves on their properties in an economical and sustainable way. Forest management will help to maintain and preserve these reserves, which are currently under strong pressure to be converted to pastures and shifting cultivation.

It will be necessary to invest in farmer training to improve future yields. Additional time and work rationalization studies are needed and can be achieved by monitoring of the forest management activities involved in the forest management system. All forest management activities must be performed by the farmers themselves and, where possible, collectively. This avoids the costs of contracting the work to a third party.

To consolidate this proposal, some changes to forest legislation will be necessary, and policies must be implemented to enforce and promote these changes. A specific legislative framework covering inspection and implementation of management plans on small properties was approved in 1998. This legislation established the use of short cycles and animal traction by IBAMA agencies and provides promise for future sustained forest management by smallholders.

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