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Sustainability of timber harvesting in Bolivian tropical forests

Erhard Dauber [a,c], Todd S. Fredericksen [b,*], Marielos Peña [a,b,c]

[a] *Proyecto BOLFOR, Santa Cruz, Bolivia*
[b] *Life Science Division, 212 Garber Hall, Ferrum College, Ferrum, VA 24088, USA*
[c] *Instituto Boliviano de Investigación Forestal, Santa Cruz, Bolivia*

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Abstract

Data from a total of 117 ha of small (0.25–4 ha) permanent plots in four ecoregions of Bolivia, along with information on harvest data, were used in a simulation model to determine the sustainability of timber harvesting in Bolivian tropical forests. Growth increments of future crop trees (averaging from 0.22 to 0.41 cm/year) in the principal forest ecoregions of Bolivia are currently not high enough to allow for similar wood volumes to be cut in the second next harvest using current cutting cycles and minimum cutting diameters, assuming that forest managers are cutting the volumes of wood that are stated in their management plans. Estimated recoverable volumes in the second harvest for regions varied from approximately 4 to 28% of the potentially harvestable volume in the first cycle considering all commercially marketable stems. It may be unrealistic to expect future yields equal to that of what is essentially primary tropical forest; however, forest managers should consider options that will allow for harvesting to move closer to sustainable wood production. These options include the implementation of silvicultural treatments to increase tree growth, focusing on fast-growing species with good regeneration, using fallow cycle rotations or a combination of these methods.

Keywords: Bolivia; Sustained timber yield; Permanent plot; Tropical forest management; Tree diameter growth; Cutting cycle

1. Introduction

The cutting cycle, or the return interval in years between timber harvests in the same area, is the most common method of regulating forest harvesting for uneven-aged management. If an appropriate cutting cycle is used, sustainable wood flow can be achieved by dividing the total area allowable for harvesting within a managed forest by the years of the cutting cycle (Davis and Johnson, 1987). In most tropical forests, harvestable trees are usually defined by a minimum cutting diameter (MCD) (Fredericksen, 1998). The appropriate cutting cycle is most accurately determined by the volume and growth rate of commercial trees below the MCD that remain after the first harvest, the volume harvested, and tree mortality rates.

Sustainability can only be achieved if residual trees left after the first harvest exist at sufficient densities

* Corresponding author. Tel.: +1 540 365 4360;
fax: +1 540 365 4375.
E-mail address: tfredericksen@ferrum.edu (T.S. Fredericksen).

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and grow at rates that are fast enough to provide a harvestable volume in the second cutting cycle that is similar to the amount of the first harvest. The harvestable volume of third and subsequent harvests will be determined mostly by the adequacy of regeneration (seedlings and saplings) and its subsequent survival and growth. New regeneration must also be secured to attain long-term sustainability.

According to the Bolivian Forestry Law of 1996, cutting cycles in Bolivian forests are required to be stated in each forest management plan and should be based on commercial tree diameter distributions from forest inventory data and tree growth rates obtained from permanent plots. The law also stipulates a minimum cutting cycle of 20 years. Since little growth data were available from Bolivian forests, growth increments used in the first round of forest management plans mandated by 1996 Forestry Law were usually estimated or, in some cases, growth data were used from other tropical forests. Forest managers were required to establish permanent plots as designated by mandatory best management practices so that local growth data could eventually be used to more accurately predict future yields in Bolivian forests.

Despite failures in the installation and measurement of permanent plots in the majority of forestry concessions and community forests, enough plots were established with the aid of international forestry projects to provide a reliable growth and yield database. The Bolivian permanent plot system is developing into one of the best existing growth and yield databases for natural tropical forests. The objective of this paper is to summarize results derived from analyses of permanent plot data and to make recommendations for timber harvest strategies in the tropical forests of Bolivia.

2. Methods

A total of 117 ha of small (0.25–4 ha) permanent plots in four ecoregions of Bolivia were considered to have sufficient data quality to be included in the analyses (Table 1). The four ecoregions include the dry forests of the Chiquitania, the humid forests in the transition region between the Chiquitania and Amazonia (Guarayos and Bajo Paragua), the humid forests along the base of the Andes (Pre-Andean Amazonia),

Table 1
Permanent plots incorporated in analysis

Region	Site name	Ownership[a]	No. of plots	Plot size (ha)	Total area (ha)	Years measured[b]	N/ha (trees/ha)	G/ha (m^2/ha)
Chiquitano Dry Forest	Lomerío	I	180	0.1	18	94–02	439.94	23.42
	INPA	PP	25	0.25	6.25	98–02	411.04	21.40
	Cimal (Ex Lam. San Miguel)	TC	18	1	18	98–02	366.61	20.26
	Cimal Velasco	TC	3	1	3	98–02	372.07	20.81
	Cimal Angel Sandoval	TC	12	0.25	3	98–02	309.00	18.74
	Cimal ex Marabol	TC	4	1	4	02	450.75	20.49
	Sutó	TC	8	1	8	99–02	352.63	21.89
Transition Chiquitano–Amazonia	Cimal Guarayos (Ex concesión Vasber)	TC	17	1	17	98–01	317.44	18.33
	Taruma	TC	8	1	8	97–99	406.06	21.66
	San Luis	TC	6	0.25	1.5	99–01	445.33	23.90
Pre-Andean Amazonia	Jamanchi (Chimanes)	TC			10	95–02	510.40	28.45
	Aguas Negras (Chimanes)	PP			6	95–02	521.00	24.19
	Siete Palmas (Ixiamas)	CF	1	1	1	01	571.00	25.36
Lowland Amazonia	Imapa	TC	2	1	2	00–02	557.50	23.33
	Sagusa	TC	3	1	3	00–01	482.00	21.99
	Promab	RF	1	4	4	95–99	540.75	25.16
	Cinma	TC	2	1	2	99	357.00	24.40
	Mamoré	TC	2	1	2	99	367.00	22.84

[a] Ownership: TC, timber concession; PP, private property; I, indigenous lands; CF, municipal forest; RF, research forest.
[b] Periodicity of measurements normally is two years.

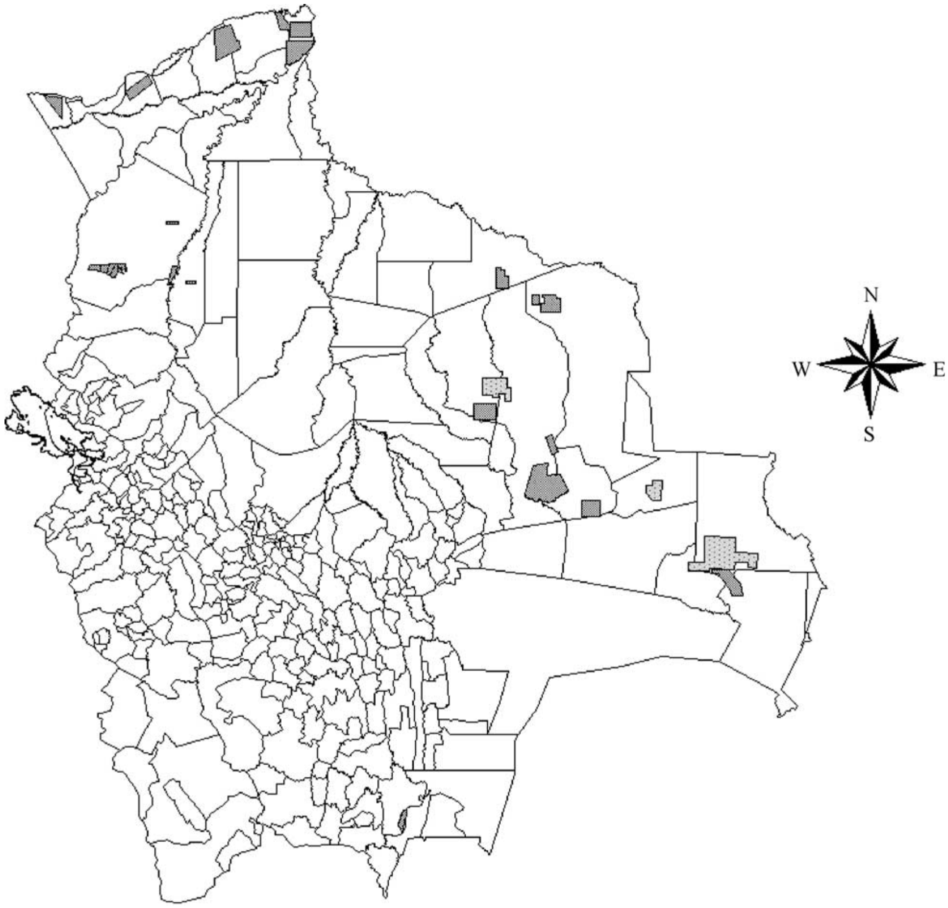

Fig. 1. Location of permanent forest inventory plots within Bolivia.

and Lowland Amazonia (Riberalta area and Pando). The area of permanent plots by ecoregion varied widely, with more than half of all plots established in the Chiquitania (52%). Most permanent plots were cooperative projects established by forest managers and international forestry projects, such as BOLFOR, FOMOBOL, PROMAB, and PANFOR. The data come mostly from forestry concessions, but also include some plots in privately owned forest and on lands owned by indigenous people. Most plots were located in areas of unharvested forest and have only been measured twice. Some plots, however, had as many as six measurements spanning a range of eight years. In addition to small-scale permanent plots, some data were derived from recently established unharvested control plots of the Long-Term Silvicultural Research Project installed by BOLFOR and the Bolivian Forestry Research Institute (Instituto Boliviano de Investigación Forestal (IBIF)) in the Guarayos Transition region. These plots cover an area of approximately 80 ha and include measurements of over 10,000 trees. The geographical location of all plots is shown in Fig. 1.

In all plots, trees $\geq$10 were marked with metal tags and the diameter-at-breast-height (dbh) was measured with a diameter tape over a period of years. The exact location of dbh measurements was marked with red paint to minimize error due to measurement location. For each tree measured within the plot, observations were also made on tree canopy position, crown form, stem quality, and vine loads (Appendix A). Plot establishment and measurement methods closely followed those outlined by Alder and Synnott (1992).

2.1. Growth model specifications

The model used was a simulation model based on single tree increments of trees remaining after harvests. Computer simulations (based on a Turbo Basic program written for this purpose) were carried out to compare the timber harvesting possibilities of first and second cutting cycle in four different ecoregions of Bolivia. In the first cycle of logging, all commercial species over the MCD are removed, with the exception of 20% of residual seed trees as prescribed by forest law.

Prediction of future basal areas and volumes is based on diameter growth of individual trees using the mean diameter increments of three species groups (corresponding to low, medium, and high increments). Group means are use instead of individual species means because of the small sample sizes of individual species (Appendix B).

Only future crop trees (trees of good stem and crown forms), of the current commercial species, are considered for second cycle yield predictions. Natural mortality and mortality caused by logging activities are taken into account by percentages, where logging mortality is defined as a logarithmic function of logging intensity.

Diameter growth and mortality of future crop trees are observed until the basal area of those trees, which already reached or surpassed MCD corresponds to the basal area to be substituted. The latter is defined by a certain percentage of the original basal area of harvested trees plus the basal area to be replaced due to mortality of seed trees. The time necessary to reach the basal area to be substituted corresponds to the cutting cycle. Variation of cutting cycles therefore can be realized by variation of the mentioned percentage, which together with the MCD is defined as an input parameter.

The model considers two main scenarios: one including the mean diameter increments of future crop trees, the other optimum diameter increments, which refer to trees in optimum growing conditions (trees in dominant or co-dominant canopy positions and without vines in the tree crown). Alvira et al. (2004) found that trees with vines grow, on average, only at one-third the rate of trees without vines. Comparison of the two scenarios permits evaluation of the influence of liberating future crop trees from vines and competing trees.

The reliability of simulation results depends on the reliability of the main model parameters given by:

- Mean increments of the three commercial species groups of small, medium, and high increments.
- Diameter distributions of these species.
- Natural mortality and mortality caused by logging activities.

Essential improvements of the diameter distributions can be expected if more extensive forest inventory data become available in each region. Estimation of mean increments and mortality will improve with the extension of sample sizes and observation periods.

First year mortality after logging (defined as a logarithmic function of logging intensity) is based on view estimates available from a treatment trial with different logging intensities, established by the former mentioned Long-Term Silvicultural Research Project. Mortality caused by high intensity logging is based on an estimation sustained by some results in moist tropical forests in Australia (Nicholson et al., 1988). The decrease of logging mortality from 100% in the first year after logging to 0% in the 10th year is based on an assumption.

Although model simulations fundamentally consider basal area estimates, corresponding volumes were calculated by use of mean commercial height and form factor. An estimation of available volumes was carried out for various combinations of MCDs and cutting cycles.

2.2. Assumptions of the model

One important assumption of the model is that all of the species listed in the management plan will be harvested during each cutting cycle and that current non-commercial species will not become marketable in the future. In fact, most companies currently harvest only a small portion of the species listed in their management plan because of a lack of markets for many species and there is great uncertainty regarding what species will be marketable in the future. The list of species harvested often changes each year depending on varying demands in the export market. The model also indirectly assumes a static harvesting and milling efficiency, whereas these efficiencies are likely to increase in the future and will therefore increase the volume of wood extracted per each tree.

As a result of these assumptions, yields in the second cycle may be underestimated on the scale of an entire forest, particularly if the forestry sector and markets adapt to lesser-known tree species, but they may be accurate for those species that are currently harvested each year.

3. Results and discussion

In general, it is clear from Tables 2 and 3 that growth increments of forest trees in the principal forest regions of Bolivia are not high enough to allow for similar wood volumes to be cut in the second harvest using current cutting cycles and DMCs. Recoverable volumes in the second harvest for regions vary from approximately 4 to 28% of the potentially harvestable volume in the first cycle considering all commercially marketable stems.

Few comparative data are available in other logged neotropical forests. However, Kammesheidt (1998) found that logged humid forests in Venezuela only recovered one-third of their original basal area after 19 years, a scenario which is similar to results obtained in Bolivia with 20-year cutting cycles. If the growth rates of ''free-to-grow'' trees only are used (the ''optimum'' scenario), harvestable volumes increase in the second cycle by 9–64% depending on the region. It is likely that most of the trees that survive to the second harvest will be these free-to-grow trees, since vine-covered trees in the forest understory should experience high mortality rates.

Table 2
Average diameter growth increment rates (cm/year) for future crop trees (commercial tree species with good stem and crown forms) in different ecoregions of Bolivia including Chiquitania, Transition Chiquitania–Amazonia (Guarayos and Bajo Paragua), Pre-Andean Amazonia and Lowland Amazonia (Riberalta and Pando)

Diameter increments of future crop trees				
Region	All trees		Trees in ''optimum'' conditions	
	Average annual increment (cm)	Minimum–maximum	Average annual increment (cm)	Minimum–maximum
Chiquitania	0.22	0.08–0.35	0.26	0.10–0.32
Transition Chiquitania–Amazonia	0.41	0.24–1.34	0.70	0.36–1.55
Pre-Andean Amazonia	0.26	0.10–1.46	0.41	0.17–1.82
Lowland Amazonia	0.32	0.21–0.49	0.36	0.21–0.63
Chiquitania	0.22	0.08–0.35	0.26	0.10–0.36
Transition Chiquitania–Amazonia	0.41	0.24–1.34	0.70	0.19–1.65
Pre-Andean Amazonia	0.26	0.10–1.46	0.41	0–1.82
Lowland Amazonia	0.32	0.21–0.49	0.36	0.21–0.63

Growth rates include rates for all trees and those in ''optimum'' growing conditions. Optimum conditions include trees in dominant or co-dominant canopy positions and without vines in the tree crown.

Table 3
Current (first cut) and projected (second cut) available volumes for different ecoregions in Bolivia

Ecoregion	CC	MCD	first cut (m^3/ha)	Second cut (m^3/ha)	Percentage	Second cut optimum (m^3/ha)	Percentage
Chiquitania	25	40	18.87	2.40	13	2.95	16
Transition Chiquitania–Amazonia	25	50	13.71	3.80	28	8.70	64
Pre-Andean Amazonia	25	50	16.68	0.58	4	1.43	9
Amazonia	25	50	11.82	2.52	21	2.62	22

The second harvest is based on overall growth rates of future crop trees (commercial tree species with good stem and crown forms) and growth rates of trees in ''optimum'' growing conditions. Optimum conditions include trees in dominant or co-dominant canopy positions and without vines in the tree crown. Models are based on a 25-year cutting cycle and MCDs typical for each region. Percentages (%) are expressed as the amount available in the second harvest relative to the first harvest.

3.1. Regional differences

Large differences in tree growth rates were observed among regions probably due to differences in precipitation, soil fertility, vine loads, and disturbances, such as fire, wind, and history of anthropogenic influence. Growth rates in the transition region between the Chiquitania and the Amazonia were much higher than in other regions. Tree growth rates in this region also responded better to liberation than in most other areas due to higher vine loads. The region with the slowest growth rates was the Chiquitania, probably due to low precipitation in this zone. The response to liberation in this zone was low as well, perhaps due to the open nature of the canopy of this forest.

Yields in the second cycle are not only influenced by tree growth rates, but also by relative tree density in classes below the MCD. The extremely low volume recovery rates for the Pre-Andean Amazonia region is largely due to extremely poor recruitment in lower size classes. In a study of mahogany (*Swietenia macrophylla*) regeneration and growth in this region, Gullison et al. (1996) found that slow growth and poor regeneration would likely require an increase in the MCD of mahogany from 50 to 80 cm. The structure of this forest is very different from the forests in other regions and consists of very large canopy trees and a very sparse understory. Once large canopy trees are removed, there are few smaller trees available to take advantage of the open canopy. Under normal conditions in tropical forests, especially considering current growth rates, the second harvest will have to be obtained from existing trees below the MCD and not from new regeneration (Dawkins and Philip, 1998). In the Pre-Andean Amazonia region, there are few trees available to comprise the second harvest. Accordingly, only a 9% recovery of original volume would be expected in the second cutting cycle even under optimum growing conditions.

In the Amazonia and Chiquitania regions, the recovery under the ‘‘optimum’’ scenario is 16–22%. This may be due to a scarcity of stems of commercial species in the understory. Non-commercial stems are particularly predominant in the forests of Lomerío in the Chiquitania, where approximately two-thirds of logging gaps are likely to be filled by stems of non-commercial species (Fredericksen and Licona, 2000). Forests closest to recovering full volume are in the Transition region, where high growth rates and a relative abundance of commercial stems in the understory allow recovery in the second harvest of 90% of the original volume of the first cut using the optimum model conditions for a cutting cycle of 30 years.

3.2. Species differences

Large differences exist in diameter growth and abundance among species within ecoregions. For example, within the transition region, diameter growth rates among species differ by an order of magnitude. The fastest-growing species, *Schizolobium parahyba*, averages 1.3 cm/year, while *Terminalia oblonga* and *Pseudolmedia laevis* are growing at rates closer to 0.2 cm/year. Examples from other regions are not quite as dramatic, but in all ecoregions the fastest-growing species exceeded the slower growing species by a factor of three or more (Appendix B). One implication of these differences in growth rates among species is that species composition needs to be closely evaluated within each forest management plan and that species-specific growth rates should be used rather than regional growth rate means for all species. A company that manages its forest mostly for the fastest-growing species will probably be able to cut similar volumes in the second harvest at the current harvest levels, assuming that there is an adequate density of stems below the MCD. Unfortunately, the situation for nearly all other Bolivian timber species is less optimistic.

3.3. The potential of silvicultural treatments for improving regeneration and tree growth

The ‘‘optimum’’ scenario might be achieved or perhaps even enhanced by active silviculture, such as liberating future crop trees from vines or overtopping non-commercial tree species. Many potentially useful silvicultural treatments are available in Bolivia for testing at the operational level (Fredericksen and Peralta, 2001). For example, liberation of future crop trees in La Chonta increases diameter growth increments by a factor of 2–3 and at relatively low cost (US$ 1/ha) (Peña et al., 2003). Marking of future crop trees can also be added to vine cutting treatments with little additional cost and will reduce damage or mortality from 17 to 4% (Peña et al., 2003). Fewer future crop trees damaged by harvesting during the first harvest results in more volume available for the second cut.

The third and subsequent harvests require new regeneration (seedlings and saplings). A scarcity of regeneration has been observed for many Bolivian commercial tree species (Mostacedo and Fredericksen, 1999). For some species, there are no known practical solutions for providing new regeneration. However, for many other species providing regeneration is as simple and inexpensive as scarifying soil in logging gaps (Fredericksen and Pariona, 2002).

3.4. Residual tree considerations

Currently, 20% of harvestable trees of each species above the MCD must be retained as a security factor of management plans. These trees, apart from producing seed for new regeneration, also will provide some volume that can be recovered during the second cut.

Residual seed trees are required to be representative of harvested trees with respect to form and size. It is possible, however, that large-diameter residual trees may be overmature or dead by the time of the next harvest. Therefore, it might be wise to select residual trees that have diameters near the MCD.

3.5. Limitations of the model

Although the models applied to Bolivian permanent plot data appear to contradict sustainable forest management for timber, some important assumptions of the model obviously do not apply to the current situation in the Bolivian forestry sector. Most importantly, many tree species assumed to be harvested in the model because they appear in management plans are, in reality, not being harvested because of a lack of market for their wood. Although some of the unharvested stems of these species will die, many will still be available for the next cutting cycle, assuming that markets appear for these species. Applying fallow cycle rotations with different groups of species harvested in subsequent cycles, therefore, may lead to sustainable yields.

On the other hand, current timber harvest projections were estimated assuming that these species would be harvested. This fact underscores the large magnitude of error in the overestimation of future yields or underestimation of cutting cycles in the first round of Bolivian forest management plans. This kind of problem is not unique to Bolivia. Optimistic polycyclic cutting cycles have been routinely applied in forests throughout the tropics (Dawkins and Philip, 1998). The overestimation of growth rates in the first Bolivian management plans is largely due to a lack of permanent plot data. However, data now exist that can be used to revise management plans. Bolivian forest managers should not be able to completely disregard current growth and yield projections and still expect to meet certification standards for sustainability.

Appendix A. Definitions of stem quality, canopy position, crown form and vine loads

A.1. Stem quality

1. Healthy and straight without any sign of defects.
2. With signs of fungus attack, decay, sores, crookedness, twisted growth, and other deformations.
3. Crooked and other serious defects, possibly useful for firewood.

A.2. Canopy position (using the Dawkins system with inverted scale of values)

1. Emergent: crown plan fully exposed vertically and free from lateral competition at least within the 90° inverted cone subtended by the crown base.
2. Full overhead light: crown plan fully exposed vertically, but adjacent to other crowns of equal or greater height within the 90° cone.
3. Some overhead light: crown plan partly exposed vertically, but partly vertically shaded by other crowns.
4. Some side light: crown plan entirely vertically shaded, but exposed to some direct side light due to a gap or edge of overhead canopy.
5. No direct light: crown plan fully shaded vertically and laterally.

A.3. Crown form (using the Dawkins system with inverted scale of values)

1. Perfect: the best size and development generally seen, wide, circular in plan, symmetrical.
2. Good: very nearly ideal, silviculturally satisfactory, but with some slight defect of symmetry or some dead branch tips.
3. Tolerable: just silviculturally satisfactory, distinctly asymmetrical or thin, but apparently capable of improvement if given more room.
4. Poor: distinctly unsatisfactory, with extensive die-back, strong asymmetry and few branches, but probably capable of surviving.
5. Very poor: definitely degenerating or suppressed, or badly damaged, and probably incapable of increasing its growth rate or responding to liberation.

A.4. Vine loads

1. Tree free of vines.
2. Vines present on the stem; crown is free of vines.
3. Stem and crown are infested with vines, but without affecting terminal growth.
4. Crown totally covered with vines, and terminal growth is seriously affected.

Appendix BDiameter increments of commercial tree species calculated from permanent plots in Bolivia (increments of individual trees were calculated from time series by means of linear regressions)

Diameter increments of commercial species in Chiquitania

Increment category	Species	cm/year (number of trees)					Increase (%)
		1[a]	2[a]	3[a]	4[a]	5[a]	
Low	*Aspidosperma* spp.	0.052 (678)	0.054 (482)	0.080 (348)	0.108 (159)	0.104 (95)	
	Calycophyllum multiflorum	0.051 (33)	0.054 (30)	0.089 (25)	0.084 (10)	0.220 (5)	
	Tabebuia impetiginosa	0.093 (280)	0.084 (223)	0.099 (191)	0.126 (126)	0.162 (66)	
	Phyllostylon rhamnoides	0.114 (268)	0.105 (205)	0.119 (176)	0.137 (91)	0.118 (34)	
	Gallesia integrifolia	0.155 (58)	0.135 (15)	0.135 (15)	0.132 (9)	0.228 (1)	
	Astronomium urundeuva	0.145 (161)	0.153 (152)	0.155 (110)	0.172 (80)	0.207 (36)	
	Mean of species	0.085 (1478)	0.084 (1107)	0.103 (865)	0.129 (475)	0.140 (237)	37
Medium	*Schinopsis brasiliensis*	0.174 (32)	0.168 (30)	0.181 (26)	0.180 (19)	0.227 (9)	
	Copaifera chodatiana	0.155 (125)	0.158 (99)	0.181 (84)	0.182 (54)	0.186 (30)	
	Sweetia fructicosa	0.129 (69)	0.155 (56)	0.187 (43)	0.222 (21)	0.223 (14)	
	Ceiba samauma	0.225 (38)	0.240 (22)	0.235 (18)	0.263 (15)	0.270 (8)	
	Machaerium scleroxylon	0.237 (110)	0.241 (84)	0.253 (73)	0.271 (52)	0.273 (28)	
	Cariniana ianeirensis	0.257 (24)	0.259 (15)	0.259 (15)	0.282 (13)	0.330 (8)	
	Mean of species	0.187 (398)	0.192 (306)	0.211 (259)	0.228 (174)	0.239 (97)	13
High	*Caesalpinia pluviosa*	0.231 (689)	0.243 (533)	0.263 (424)	0.268 (255)	0.248 (116)	
	Anadenanthera colubrina	0.271 (1154)	0.272 (976)	0.285 (872)	0.299 (675)	0.313 (519)	
	Centrolobium microchaete/ *Platymiscium ulei*	0.302 (94)	0.271 (48)	0.287 (44)	0.312 (35)	0.359 (17)	
	Amburana cearensis	0.309 (101)	0.312 (95)	0.316 (91)	0.316 (72)	0.317 (64)	
	Cedrela fissilis	0.299 (90)	0.308 (86)	0.347 (56)	0.365 (33)	0.319 (23)	
	Mean of species	0.263 (2128)	0.267 (1738)	0.283 (1487)	0.295 (1070)	0.305 (739)	8
Totals	Mean of commercial species	0.190 (4004)	0.195 (3151)	0.216 (2611)	0.243 (1719)	0.262 (1073)	21
	Mean of non-commercial species	0.167 (4818)	0.158 (3031)	0.177 (2228)	0.218 (872)	0.200 (533)	13
	Mean of all species	0.177 (8822)	0.177 (6182)	0.198 (4839)	0.234 (2591)	0.242 (1606)	22

[a] Filter: 1, overall mean; 2, stem quality 1–2; 3, stem quality 1–2, crown form 1–3; 4, stem quality 1–2, crown form 1–3, crown position 1–2; 5, stem quality 1–2, crown form 1–3, crown position 1–2, vine loads 1–2.

Appendix B (*Continued*)

Diameter increments of commercial species in Transition Chiquitania–Amazonia

Increment category	Species	cm/year (number of trees)					Increase (%)
		1[a]	2[a]	3[a]	4[a]	5[a]	
Low	*Ormosia nobilis*	0.179 (71)	0.208 (54)	0.238 (43)	0.262 (25)	0.360 (11)	
	Pseudolmedia laevis	0.229 (2589)	0.236 (2132)	0.249 (1824)	0.378 (428)	0.478 (185)	
	Tabebuia spp.	0.192 (27)	0.231 (23)	0.251 (19)	0.341 (10)	0.394 (5)	
	Swartzia jorori	0.280 (60)	0.283 (58)	0.301 (50)	0.428 (9)	0.674 (4)	
	Pouteria nemorosa	0.252 (113)	0.281 (84)	0.310 (70)	0.397 (26)	0.653 (9)	
	Terminalia oblonga	0.264 (544)	0.276 (438)	0.311 (332)	0.316 (191)	0.512 (44)	
	Ficus spp.	0.311 (81)	0.317 (54)	0.319 (45)	0.177 (31)	0.191 (9)	
	Aspidosperma cilyndrocarpon	0.261 (82)	0.308 (69)	0.345 (50)	0.354 (15)	0.308 (5)	
	Mean of species	0.238 (3567)	0.247 (2912)	0.263 (2433)	0.350 (735)	0.473 (272)	80
Medium	*Sweetia fructicosa*	0.250 (53)	0.278 (38)	0.345 (28)	0.631 (9)	0.947 (4)	
	Heisteria nitida	0.360 (63)	0.344 (57)	0.370 (49)	0.402 (39)	0.397 (20)	
	Batocarpus amazonicus	0.366 (209)	0.392 (181)	0.414 (158)	0.460 (119)	0.539 (76)	
	Spondias mombin	0.412 (65)	0.414 (63)	0.434 (45)	0.461 (35)	0.579 (8)	
	Virola peruviana	0.461 (14)	0.464 (13)	0.487 (9)	1.292 (2)	1.652 (1)	
	Calycophyllum spruceanum	0.453 (29)	0.462 (28)	0.488 (25)	0.577 (11)	0.413 (7)	
	Cariniana spp.	0.422 (238)	0.439 (219)	0.489 (186)	0.505 (142)	0.675 (73)	
	Hura crepitans	0.496 (340)	0.514 (303)	0.526 (259)	0.541 (158)	0.802 (35)	
	Mean of species	0.423 (1011)	0.441 (902)	0.470 (759)	0.502 (515)	0.622 (224)	32
High	*Cordia alliodora*	0.461 (59)	0.481 (52)	0.528 (45)	0.623 (32)	0.811 (16)	
	Centrolobium microchaete	0.500 (39)	0.502 (37)	0.593 (28)	0.576 (21)	0.639 (3)	
	Ocotea spp./*Nectandra* spp.	0.503 (1162)	0.575 (889)	0.603 (775)	0.729 (304)	0.876 (158)	
	Gallesia integrifolia	0.492 (144)	0.625 (63)	0.678 (47)	0.518 (27)	0.225 (6)	
	Erisma unicinatum/ *Qualea paraensis*	0.633 (127)	0.657 (118)	0.682 (105)	0.736 (88)	0.858 (49)	
	Aniba aff. guianensis	0.699 (107)	0.708 (94)	0.736 (84)	0.775 (26)	0.828 (11)	
	Zanthoxylon sp.	0.676 (62)	0.725 (53)	0.784 (46)	0.839 (29)	1.022 (17)	
	Schizolobium parahyba	1.312 (51)	1.312 (51)	1.335 (50)	1.398 (47)	1.545 (40)	
	Mean of species	0.552 (1751)	0.622 (1357)	0.658 (1180)	0.771 (574)	0.950 (300)	44
Totals	Mean of commercial species	0.354 (6329)	0.379 (5171)	0.406 (4372)	0.525 (1824)	0.695 (796)	71
	Mean of non-commercial species	0.428 (5680)	0.465 (4125)	0.504 (3566)	0.649 (1438)	0.755 (782)	50
	Mean of all species	0.389 (12009)	0.417 (9296)	0.450 (7938)	0.580 (3262)	0.724 (1578)	61

[a] Filter: 1, overall mean; 2, stem quality 1–2; 3, stem quality 1–2, crown form 1–3; 4, stem quality 1–2, crown form 1–3, crown position 1–2; 5, stem quality 1–2, crown form 1–3, crown position 1–2, vine loads 1–2.

Diameter increments of commercial species in Pre-Andean Amazonia

Increment category	Species	cm/year (number of trees)					Increase (%)
		1[a]	2[a]	3[a]	4[a]	5[a]	
Low	*Guarea* spp.	0.103 (243)	0.103 (236)	0.104 (231)	0.173 (2)	0.173 (2)	
	Unonopsis floribunda	0.107 (48)	0.108 (46)	0.109 (45)	0.060 (2)	0.000 (1)	
	Terminalia spp./*Buchenavia* spp.	0.173 (114)	0.180 (100)	0.181 (99)	0.185 (69)	0.268 (35)	
	Ficus spp.	0.201 (109)	0.208 (98)	0.210 (97)	0.148 (66)	0.126 (25)	
	Sloanea obtusifolia	0.248 (18)	0.235 (12)	0.235 (12)	0.260 (5)	0.407 (2)	
	Mean of species	0.143 (532)	0.143 (492)	0.145 (484)	0.169 (144)	0.210 (65)	45
Medium	*Hura crepitans*	0.283 (237)	0.299 (212)	0.304 (207)	0.324 (163)	0.346 (80)	
	Calophyllum brasiliense	0.318 (16)	0.318 (16)	0.318 (16)	0.443 (7)	0.622 (4)	

Appendix B (*Continued*)

Diameter increments of commercial species in Pre-Andean Amazonia

Increment category	Species	cm/year (number of trees)					Increase (%)
		1[a]	2[a]	3[a]	4[a]	5[a]	
	Calycophyllum spruceanum	0.305 (17)	0.327 (14)	0.327 (14)	0.411 (8)	0.411 (8)	
	Virola spp.	0.358 (184)	0.358 (184)	0.364 (177)	0.475 (47)	0.483 (36)	
	Dipteryx odorata	0.368 (15)	0.368 (15)	0.368 (15)	0.414 (13)	0.414 (13)	
	Mean of species	0.317 (469)	0.328 (441)	0.332 (429)	0.366 (238)	0.399 (141)	20
High	*Ocotea* spp./*Nectandra* spp.	0.368 (62)	0.371 (61)	0.387 (58)	0.567 (14)	0.693 (10)	
	Swartzia jorori	0.406 (60)	0.398 (49)	0.415 (47)	0.576 (23)	0.653 (19)	
	Cedrela odorata	0.456 (9)	0.456 (9)	0.456 (9)	0.442 (6)	0.578 (4)	
	Zanthoxylon sp.	1.459 (7)	1.459 (7)	1.459 (7)	1.717 (5)	1.819 (4)	
	Mean of species	0.446 (138)	0.448 (126)	0.465 (121)	0.675 (48)	0.782 (37)	68
Totals	Mean of commercial species	0.252 (1139)	0.256 (1059)	0.260 (1034)	0.334 (430)	0.407 (243)	56
	Mean of non-commercial species	0.293 (4846)	0.298 (4609)	0.302 (4522)	0.416 (1091)	0.453 (741)	50
	Mean of all species	0.285 (5985)	0.291 (5668)	0.294 (5556)	0.393 (1521)	0.442 (984)	50

[a] Filter: 1, overall mean; 2, stem quality 1–2; 3, stem quality 1–2, crown form 1–3; 4, stem quality 1–2, crown form 1–3, crown position 1–2; 5, stem quality 1–2, crown form 1–3, crown position 1–2, vine loads 1–2.

Diameter increments of commercial species in Amazonia

Increment category	Species	cm/year (number of trees)					Increase (%)
		1[a]	2[a]	3[a]	4[a]	5[a]	
Low	*Tabebuia* spp.	0.185 (13)	0.210 (11)	0.210 (11)	0.247 (9)	0.210 (7)	
	Iryanthera spp./*Otoba* spp./*Virola* spp.	0.229 (103)	0.240 (94)	0.247 (84)	0.239 (35)	0.249 (29)	
	Heisteria spp.	0.233 (15)	0.247 (12)	0.247 (12)	0.344 (3)	0.344 (3)	
	Clarisia racemosa	0.253 (24)	0.276 (22)	0.280 (21)	0.340 (15)	0.378 (9)	
	Pouteria sp.	0.221 (35)	0.229 (25)	0.286 (19)	0.289 (11)	0.297 (7)	
	Mean of species	0.228 (190)	0.241 (164)	0.254 (147)	0.272 (73)	0.276 (55)	9
Medium	*Hymenaea* spp.	0.294 (7)	0.294 (7)	0.294 (7)	0.374 (5)	0.374 (5)	
	Aspidosperma vargasii	0.258 (14)	0.303 (11)	0.314 (10)	0.335 (8)	0.324 (6)	
	Tetragastris altissima	0.313 (238)	0.324 (207)	0.326 (192)	0.330 (97)	0.324 (76)	
	Cedrela odorata	0.340 (3)	0.340 (3)	0.340 (3)	0.511 (2)	0.511 (2)	
	Swietenia macrophylla	0.345 (3)	0.345 (3)	0.345 (3)	0.345 (3)	0.517 (2)	
	Mean of species	0.310 (265)	0.323 (231)	0.325 (215)	0.336 (115)	0.335 (91)	3
High	*Rinoreocarpus ulei*	0.305 (92)	0.320 (73)	0.346 (55)	0.419 (25)	0.390 (16)	
	Ocotea spp./*Nectandra* spp.	0.338 (57)	0.382 (45)	0.385 (44)	0.526 (15)	0.595 (12)	
	Spondias mombin	0.464 (6)	0.357 (4)	0.470 (2)	0.564 (1)	0.564 (1)	
	Apuleia leiocarpa	0.429 (28)	0.458 (25)	0.473 (24)	0.463 (22)	0.537 (13)	
	Terminalia spp.	0.472 (8)	0.472 (8)	0.486 (7)	0.486 (7)	0.634 (2)	
	Mean of species	0.345 (191)	0.369 (155)	0.391 (132)	0.464 (70)	0.504 (44)	29
Totals	Mean of commercial species	0.296 (646)	0.312 (550)	0.321 (494)	0.353 (258)	0.357 (190)	11
	Mean of non-commercial species	0.376 (1581)	0.399 (1342)	0.419 (1134)	0.503 (605)	0.535 (454)	27
	Mean of all species	0.353 (2227)	0.374 (1892)	0.390 (1628)	0.458 (863)	0.482 (644)	24

[a] Filter: 1, overall mean; 2, stem quality 1–2; 3, stem quality 1–2, crown form 1–3; 4, stem quality 1–2, crown form 1–3, crown position 1–2; 5, stem quality 1–2, crown form 1–3, crown position 1–2, vine loads 1–2.

References

Alder, D., Synnott, T.J., 1992. Permanent sample plot techniques for mixed tropical forest. Oxford Forestry Institute, Oxford, UK. Tropical Forestry Papers No. 25, 124 pp.

Alvira, D., Putz, F.E., Fredericksen, T.S., 2004. Liana loads and post-logging liana densities after liana cutting in a lowland forest in Bolivia. For. Ecol. Manage. 190, 73–86.

Davis, L.S., Johnson, K.N., 1987. Forest Management, third ed. McGraw-Hill, New York, 790 pp.

Dawkins, H.C., Philip, M.S., 1998. Tropical Moist Silviculture and Management: A History of Success and Failure. CAB International, Oxford, UK, 359 pp.

Fredericksen, T.S., Pariona, W., 2002. Effects of skidder disturbance on commercial tree regeneration in logging gaps in a Bolivian tropical humid forest. For. Ecol. Manage. 171, 223–230.

Fredericksen, T.S., Peralta, R., 2001. Opciones silviculturales de los bosques tropicales de Bolivia. In: Mostacedo, B., Fredericksen, T.S. (Eds.), Regeneración Natural y Silvicultura de los Bosques Tropicales en Bolivia. Proyecto BOLFOR, Santa Cruz, Bolivia, pp. 157–172.

Fredericksen, T.S., Licona, J.C., 2000. Encroachment of non-commercial tree species after selection logging in a Bolivian tropical forest. J. Sust. For. 11, 113–123.

Fredericksen, T.S., 1998. Limitations of low-intensity selective logging for sustainable tropical forestry. Commun. For. Rev. 77, 262–266.

Gullison, R.E., Panfil, S.N., Strouse, J.J., Hubbell, S.P., 1996. Ecology and management of mahogany (*Swietenia macrophylla*) in the Chimanes Forest, Beni, Bolivia. Bot. J. Linn. Soc. 122, 9–34.

Kammesheidt, L., 1998. Stand structure and spatial pattern of commercial species in logged and unlogged Venezuelan forest. For. Ecol. Manage. 109, 163–174.

Mostacedo, B., Fredericksen, T.S., 1999. Status of forest tree regeneration and Bolivia: assessment and recommendations. For. Ecol. Manage. 124, 263–273.

Nicholson, D.I., Henry, N.B., Rudder, J., 1988. Stand changes in north Queensland rainforests. Proc. Ecol. Soc. Aust. 15, 61–80.

Peña, M., Fredericksen, T.S., Pariona, W., Putz, F.E., Blate, G., Licona, J.C., Leaño, C., Alarcon, A., Choque, U., Justiniano, J., 2003. Silviculture for sustainable forest management. In: Presentation at the Annual Meeting of the Association for Tropical Biology, July 2003, Aberdeen, Scotland..