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Assessment of economic sustainability of the strip clear-cutting system in the Peruvian Amazon

Xanic J. Rondon [a,b,*], David L. Gorchov [a], Steve R. Elliott [c]

[a] Department of Botany, Miami University, Oxford, OH 45056, United States
[b] Percy FitzPatrick Institute, University of Cape Town, South Africa
[c] Department of Economics, Miami University, Oxford, OH 45056, United States

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ABSTRACT

Strip clear-cutting (or the Palcazú Forest Management System) is a natural forest management system where narrow strips are clear-cut with harvest cycles of every 40 years. We assessed the economic sustainability of this system by calculating net present values (NPVs) at the time of a second harvest in two strips clear-cut in 1989, in the Peruvian Amazon. NPVs were calculated under three growth models or scenarios: (1) realistic (all light environments), (2) optimistic (higher light as could be achieved under intensive forest management), and (3) growth potential (fastest growing individuals). For each scenario, we calculated the production and value of timber products (sawnwood, roundwood, and charcoal), and their cost of harvesting, processing and transport. For comparison purposes, these calculations were also done for a deferment-cut treatment, applied in 1989 to half of one of the two strips.

The three growth models predicted a production of 1.88 to 22.43 m^3/ha of sawnwood, 81 to 92 pieces/ha of roundwood, and 11 to 19 ton/ha of charcoal from clear-cut strips. The total value of these products ranged from \$3112 to \$10,511/ha, assuming that sawnwood was purchased at certified prices. The total cost of harvesting, processing, and transport of timber products ranged from \$3020 to \$6167/ha. Net earnings ranged from −\$75/ha to +\$4344/ha. The net present value (NPV) of the clear-cut strips with certified sawnwood ranged between −\$54/ha and +\$1271/ha at a 5% discount rate, and between −\$73/ha and +\$78/ha at a 15% discount rate, the most realistic rate for Peru. These values were much lower than +\$131 to +\$540, the range of NPV at 15% discount rate for the deferment-cut treatment with certified sawnwood. The strip clear-cutting system is not economically sustainable due to slow tree growth, low income from timber products, and high costs for this system. Cutting cycles longer than 40 years may be required to increase timber yields and make this system profitable.

1. Introduction

Strip-clear cutting has extensively been used in the temperate zone for forest management (Thornton, 1957; Smith, 1986; Heitzman et al., 1999; Allison et al., 2003). Tosi (1982), and Hartshorn (1989a, b; 1995) introduced this system to manage tropical rainforests for timber extraction. In the strip clear-cutting system of Tosi (1982) and Hartshorn (1989a, b; 1995), also known as the Palcazú Forest Management System, heterogeneous tropical forests are managed for native gap-dependent timber species by simulating gap dynamics through clear-cutting long, narrow strips, with cutting cycles of 30 to 40 years. Upland forest is cleared into 30–40 m wide strips; the length of the strip varies and depends upon topography (Hartshorn, 1989a). All timber, regardless of species, is harvested and used locally (sawnwood, preserved roundwood, and charcoal) or sold to attain maximum value from the strips (Hartshorn, 1989a; Gorchov et al., 1993). Animal traction is used to reduce soil compaction (Hartshorn, 1989a; Gorchov et al., 1993). Natural regeneration of seeds and stump sprouts is permitted (Gorchov et al., 1993). Silvicultural treatments may also be applied in the regenerating strips to promote growth of desired species (Dolanc et al., 2003).

Initially, this system was proposed to be a sustainable alternative for timber extraction compared to uncontrolled logging and selective logging (Tosi, 1982). The rationale for the assumed sustainability was that most valuable tropical timber species are gap-dependent canopy tree species (Swaine and Whitmore, 1988), which have rapid height growth and diameter increments (Lieberman et al., 1985). Tosi (1982) and Hartshorn (1989a) also predicted that non-commercial pioneer species would not regenerate well in this system because the strips were too narrow to allow sufficient sunlight.

Despite the potential benefits, current research on the strip clear-cutting system has questioned its ecological and economic sustainability. Although clear-cut strips had high tree species richness at the

* Corresponding author. Percy FitzPatrick Institute, University of Cape Town, Private Bag X3, Rondebosch 7701 Cape Town, South Africa. Tel.: +27 21 685 2896; fax: +27 21 650 3295.
E-mail address: rondonxj@gmail.com (X.J. Rondon).

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early stages of regeneration (Hartshorn, 1989a), composition was dominated by pioneer species (Gorchov et al., 1993). After 15 years of regeneration, pioneer species still dominated the composition of the strips, and commercial species comprised only 8 to 15% of the strips' basal area (Rondon et al., 2009a). Furthermore, commercial stems in this system had low diameter growth rates, averaging <0.3 cm/yr even after the application of silvicultural thinning (Dolanc et al., 2003). When the growth of all commercial trees ≥6.5 cm dbh from the strips was projected, realistic and optimistic growth models predicted that only 3–8 m^3/ha of merchantable timber would be produced at the time of a second harvest, whereas the most optimistic growth model, or growth potential model, predicted a production of 32–38 m^3/ha (Rondon et al., 2009b). Nevertheless, it is still unknown whether this production would be sufficient to make this system economically sustainable in a second harvest, since high costs for harvesting and implementing this system have been reported (Cornejo and Gorchov, 1993; Gram, 1997; Southgate, 1998).

We assessed the economic sustainability of the strip clear-cutting system using two strips (30 × 150 m) clear-cut in 1989 in the Peruvian Amazon. We were interested in determining whether this system would produce viable economic returns in a future second harvest; that is, 40 years after the initial harvest. To assess the economic viability of this system, a cost and benefit analysis, using net present values (NPVs), was carried out for each of the strips based on three different growth models or scenarios: (1) realistic, using diameter increments under all light environments; (2) optimistic, using increments under high light environments as could be achieved under intensive forest management; and (3) potential tree growth, using increments of the fastest growing individuals to simulate growth potential. For each scenario, we calculated the production and value of sawnwood, roundwood and charcoal from the clear-cut strips at the time of second harvest. Costs of harvesting, processing, and transporting timber products were also calculated. For comparison purposes, growth projections and cost–benefit analysis were also performed for a deferment-cut treatment, applied in 1989 to half of one of the two strips.

2. Materials and methods

2.1. Study site

This study took place at the Centro de Investigaciones Jenaro Herrera (CIJH S 4° 53.952′ W 73° 39.041′), located on the Ucayali River, 200 km south of Iquitos, Loreto, Peru (Fig. 1). The mean annual temperature is 26.5 °C and mean annual precipitation is 2521 mm (Spichiger et al., 1989). There is a relatively dry period from June to August, but rainfall is highly variable each month of the year (Ascorra et al., 1993; Rondon et al., 2009b). Soils are sandy-loam and the vegetation is considered lowland tropical rainforest on high terrace (Spichiger et al., 1989). The families with highest tree densities on high terrace at the CIJH are Sapotaceae, Leguminosae, Lecythidaceae, Chrysobalanaceae, Lauraceae, and Myristicaceae (Spichiger et al., 1996).

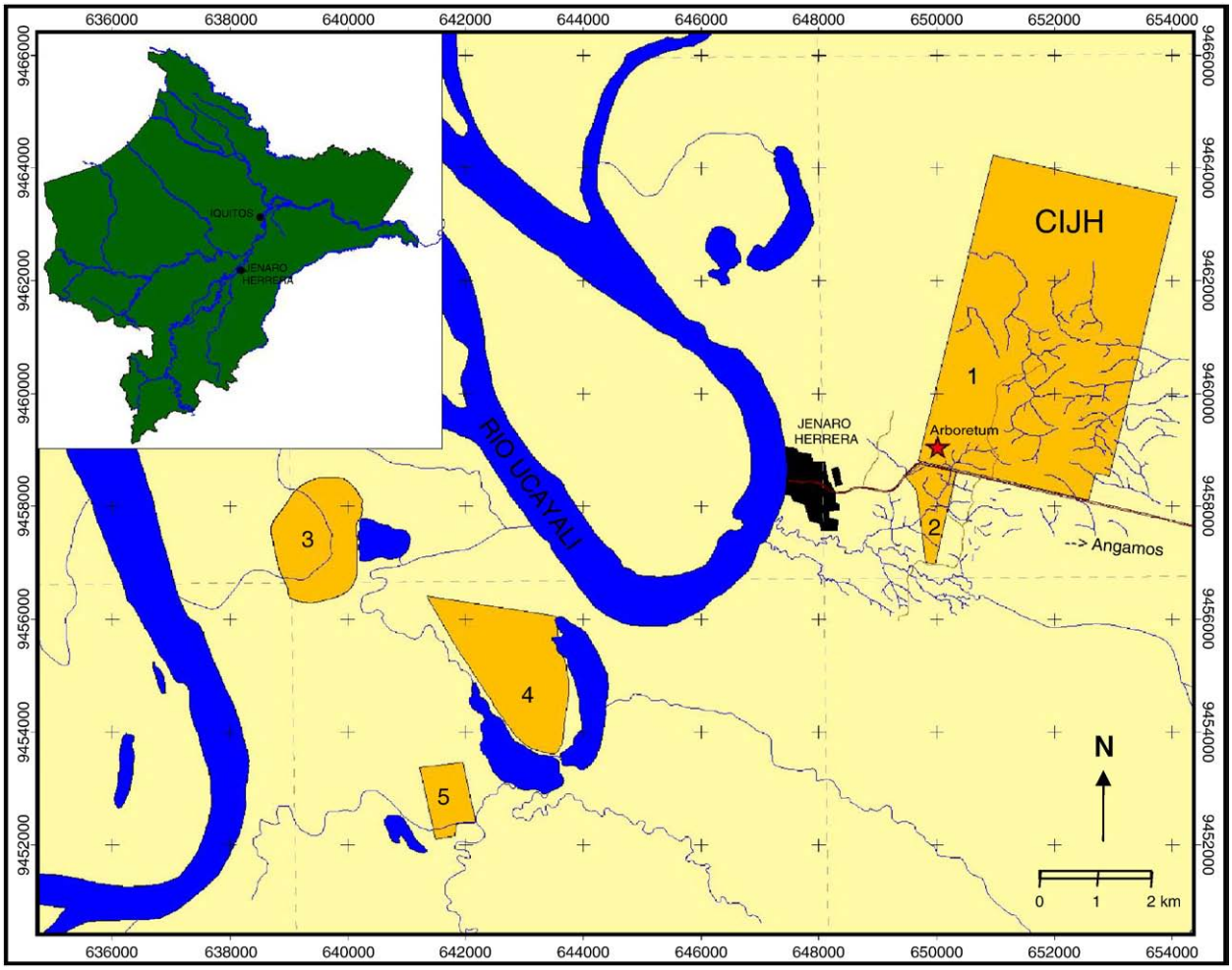

Fig. 1. The Centro de Investigaciones Jenaro Herrera (CIJH) is located on the Ucayali River, about 200 km South of Iquitos, and about 2.8 km away from the Villa Jenaro Herrera in Loreto, Peru. Strips 1 and 2 were approximately 1.6 km and 1.4 km north of the road, and north of the Arboretum (marked by the star). (Map from IIAP and Euridice Honorio pers. comm.).

2.2. History of clear-cut strips in CIJH

Two 30×150 m strips, 150 m apart, were clear-cut in 1989 in primary high terrace tropical rain forest at the CIJH (Cornejo and Gorchov, 1993). Strip 1 was cleared in April–May 1989 and strip 2 in October–November 1989. Most trees >5 cm in diameter at breast height (dbh) were felled in each strip using directional felling (Gorchov et al., 1993). An experimental deferment-cut treatment was applied to the south half of strip 2. In this treatment all trees ≥30 cm dbh were felled, but trees <30 cm dbh of species commercially valuable for sawnwood were left uncut ($n=56$) (Cornejo and Gorchov, 1993). All timber was either used locally or carried off site. All stump sprouts and survivors (saplings <5 cm dbh that survived the clearing in 1989) were identified and tagged throughout each strip, with each strip divided into 20 15× 15 m plots. An experimental silvicultural thinning treatment took place in March 1996 (Dolanc et al., 2003): pioneer trees (all *Cecropia* trees and trees <10 m tall of the genus *Alchornea* and the family Melastomataceae) were girdled, using machetes, in 12 plots within each strip. Stump sprouts and survivors throughout each strip were censused once per year during 1990–1994, in 1996 and 2000, and in 2004 and 2005 (Rondon et al., 2009a), as were recruits (seedlings >2 m tall) on 8 of the 20 plots in each strip.

Tree identification was done in the field using Gentry (1993) and Spichiger et al. (1989; 1990). Voucher specimens were deposited at the CIJH, AMAZ, and MU herbaria.

Most of the trees (>90%) were identified to the species level in 2004 and 2005 censuses, and voucher specimens of difficult taxa were brought for identification to Missouri Botanical Garden (MOBOT).

2.3. Growth projections

To estimate the potential production of sawnwood, roundwood, and charcoal in each strip at the time of a second harvest, we modeled the growth of individual commercial trees in the strips, and estimated the volume of "other" species for this time period.

All trees ≥6.5 cm dbh in the two strips were classified as commercial, pioneer, or "other" species (Rondon et al., 2009a; Appendix A). Commercial species belonged to genera valued for sawnwood at international and local markets for the Peruvian Amazon, and did not include genera valued for roundwood or for non-timber forest products (Rondon et al., 2009a). "Other" species were taxa not classified as either commercial or pioneer species (Appendix A). Since both strips were about 15 years-old when the last censuses took place, the growth of individual commercial trees from the strips was projected for the next 26 years (2030/2031), about 40 years after the initial clearing, which is the proposed cutting cycle for this system (Hartshorn, 1989a).

The growth projection for commercial trees (≥6.5 cm dbh) regenerating in the clear-cut strips was published in Rondon et al. (2009b); here we briefly describe the methods. All growth projections made use of mortality rates and two-year (2004–2006) diameter increments of all size classes of six focal timber species (*Eschweilera bracteosa*, *Guarea cinnamomea*, *Micropholis guyanensis*, *Pouteria gianensis*, *Qualea paraensis* and *Cedrelinga catenaeformis*). Other commercial taxa were assigned to growth models based on functional group and successional status. All growth projections were performed using the bootstrapping model of Lieberman and Lieberman (1985). The growth of commercial species in each strip was projected using three growth models: (1) in the realistic model, we simulated the full range of growing conditions using all diameter increments with high mortality rates; (2) in the optimistic model, we simulated growth in an intensive forest management system using the diameter increments of trees exposed only to high light and low mortality rates and (3) in the growth potential model, we simulated fast growing conditions using diameter increments of the fastest growing individuals (e.g. due to genotype or micro-environment; top 25% in each size class) with low mortality rates. Further details can be found in Rondon et al. (2009b).

The volume of "other" species was estimated for 2030/2031 in order to calculate the additional charcoal production for each strip. In the clear-cut strips, this group of "other" species is very diverse (Rondon et al. 2009a). Due to the limited information on fuctional groups for western Amazonia trees (Spichiger et al., 1989; 1990; Vásquez, 1997; Laurance et al., 2004a; 2004b), the volume of these species was estimated indirectly. We assumed that the volume ratio of "other" species to commercial species would be the same in 2030/2031 as in 2004/2005 (Rondon, 2008). Thus, for each growth projection, the volume ratio of "other" to commercial species in 2004/2005 was multiplied by the volume of commercial species in 2030/2031 (Rondon, 2008).

2.4. Cost–benefit analysis

The net present value (NPV) was used to determine the profitability of a potential second harvest in the strips, about 40 years after the initial cutting (1989). The NPV, or discount cash analysis, is defined as the current value of future income (Tietenberg, 2000). The NPV of a one-time net benefit received n years from now is: $\mathrm{NPV}=(B_n)/(1+r)^n-I$, where B_n = cash flow in year n, r = discount rate, and I = initial investment (Tietenberg, 2000). NPVs per ha were calculated for the three growth projections in each strip. B_n was the cash flow or total potential earnings (value of timber products minus harvesting costs) for the year 2030 in strip 1 and 2031 for strip 2, 23 to 24 years from the present (2007). I was the cost of silvicultural thinning applied in 1996. Three discount rates (5%, 10% and 15%) were used to calculate NPVs; NPVs with a discount rate of 5% provided a base for comparisons with NPVs calculated with discount rates of 10% and 15%, which are more realistic for South American countries (Howard et al., 1996) including Peru (Pinedo-Vasquez et al., 1992; Flores and Ashton, 2000). A maximum discount rate of 15% is suggested for Peru given the lending environment (Flores and Ashton, 2000).

All calculations were done using US$ (1US$ = 3 Peruvian Nuevo Soles in 2007). Most of the values and costs were correct as of 2007; in some cases, however, older prices were used (e.g. Boletín de Promoción de Negocios Forestales, 2005), but these were adjusted for inflation using the GDP deflator from UNData (2008) for Peru (Rondon, 2008). Prices obtained in US$ (e.g. timber certification) were adjusted for US inflation using the inflation calculator from the Bureau Labor of Statistics (2007, 2008). Conversion factors used for this study are in Appendix A.

2.4.1. Timber products and their value

The basis of the strip clear-cutting system is complete utilization of all wood harvested from the strips (Tosi, 1982; Hartshorn, 1989a, 1995). To simulate this scenario, we estimated the 2030/2031 production of sawnwood, roundwood, *cinchina* (defined below) and charcoal for each strip, based on the projected size distributions and volume of trees in the strips (Rondon et al., 2009b). The deferment-cut portion was analyzed in the same way.

Sawnwood volume (m^3) was calculated for each commercial tree that would reach commercial size of 30 cm dbh (Cornejo and Gorchov, 1993) in the strips at the time of a potential second cutting. Taxa were assigned to functional/successional groups, and for each group we used allometric equations to estimate commercial height (Rondon, 2008; Rondon et al., 2009b). Sawnwood volume of each tree was calculated from diameter and commercial height using a modified equation of the International ¼" Log Rule (Peters et al., 1997), typically used in forestry studies for Peru (Cornejo and Gorchov, 1993); and the form factor of 0.7 for tropical trees in Peru (Barrena and Llerena, 1988). We used export prices to calculate sawnwood value because these were much higher than domestic prices (International Tropical Timber Organization Market Information Service, 2007). Thus, we assumed that sawnwood production in the strips would be of export quality. We found export prices in Iquitos (free-on board) for *Virola* and *Simarouba* sawnwood at

the International Tropical Timber Organization Market Information Service (2007), but not for other taxa. The average of these prices, \$241/m^3, was used for calculations. We used a price of \$330/m^3 for certified sawnwood, calculated using a ratio of non-certified to certified sawnwood prices found in Nebel et al. (2005) (Appendix A).

Trees of *P. guianensis* that would be >25 cm dbh in the three growth projections were used to estimate production of fence posts, known as *cinchinas* (Cornejo and Gorchov, 1993). A *cinchina* is made by splitting the heartwood of *P. guianensis* stems; their length is between 2.2 and 2.5 m (Cornejo and Gorchov, 1993). The number of *cinchinas* produced from 1 m^3 of roundwood was 67 (Cornejo and Gorchov, 1993). The price for a *cinchina* in Jenaro Herrera was \$0.50/unit.

Trees of commercial species that would reach a dbh of 8 to <11 and 11 to <15 cm in the three growth projections were used to calculate *soleras* and *vigas* production, respectively; these are roundwood categories for housing construction. To calculate the number of *soleras* or *vigas* that could be obtained from a tree, the roundwood volume of that tree was divided by the volume of a *solera* (0.044 m^3/unit) or *viga* (0.089 m^3/unit) (Cornejo and Gorchov, 1993). The price for a *solera* or *viga* in Jenaro Herrera was \$6.67/unit. For the deferment-cut portion, roundwood production was not calculated because these smaller commercial trees would be left uncut to grow for the next harvest.

Commercial trees that would reach a dbh of ≥15 but <30 cm, excluding *P. guianensis*, and trees of "other" species of all dbh sizes were used to calculate charcoal production in each strip. Average tropical hardwoods produce 170 kg of charcoal from 1 m^3 of roundwood (Openshaw, 1983). This conversion factor was used to estimate the amount of charcoal (kg) that could be produced from the roundwood volume in each strip. The price of a 15 kg sack of charcoal was \$2.67 in Iquitos (\$0.18/kg or \$180/metric-ton of charcoal). For the deferment-cut portion, charcoal was only produced from "other" species; smaller commercial trees were not used for charcoal production, so that they would grow for the next harvest.

2.4.2. Costs

The amount of labor involved in harvesting, processing, and transport of timber products was quantified in "jornales". One jornal is equivalent to one day of labor. The cost of a jornal for a non-permanent job at Jenaro Herrera was about \$3.40 (E. Honorio pers. comm.). Formulae used in the calculation for harvesting, certification, processing, and transport of timber products are described in Appendix A and Rondon (2008), and are summarized below.

2.4.2.1. Harvesting. Harvesting a strip consists of site preparation, tree felling and bucking (cutting trees into logs) and log removal, which totals 195.54 jornales/ha (Cornejo and Gorchov, 1993). Fuel consumption while felling a strip was 55.5 gal/ha of gasoline and 23.31 gal/ha of oil (Cornejo and Gorchov, 1993). The cost for 1 gal of gasoline in Jenaro Herrera was \$4.00 (E. Honorio, pers. comm.). We estimated the price for 1 gal of oil in Jenaro Herrera at \$12.00 (Rondon, 2008). The cost of maintaining equipment (replacing parts such as saw chains and blades) was calculated using the maintenance cost to gasoline cost ratio of \$0.56/0.76, in Barreto et al. (1998) (Rondon, 2008).

2.4.2.2. Processing. The estimated cost for processing sawnwood at a mill in Jenaro Herrera was set at \$55.28/m^3. A mill fee was obtained from mills in Iquitos (Boletín de Promoción de Negocios Forestales, 2005) since at the time of this study there was no mill in Jenaro Herrera. This value was further adjusted using gasoline prices for Jenaro Herrera (Appendix A). The number of jornales required to cut roundwood into *soleras* and *vigas* was estimated at 0.08 jornales/unit and for *cinchinas* at 0.03 jornales/unit (Cornejo and Gorchov, 1993). The average number of jornales to produce 945 kg of charcoal was set at 20 jornales or 0.02 jornales/kg (Coomes and Burt, 2001).

2.4.2.3. Transportation. The costs of transporting logs for sawnwood, *soleras*, *vigas*, *cinchinas* and charcoal from the strips to the road and then to the port of Jenaro Herrera were obtained from Cornejo and Gorchov (1993) (Fig. 1). The costs for transporting timber products from the strips to the road (approximately 1.6 km from strip 1 and 1.4 km from strip 2) using oxen were obtained from Cornejo and Gorchov (1993): sawnwood logs 4.05 jornales/m^3, *soleras* and *vigas* 5.37 jornales/m^3, *cinchinas* 3.07 jornales/m^3 and charcoal 0.003 jornales/kg. The cost of transporting all timber products on a seasonal dirt road to the port of Jenaro Herrera (2.8 km) was estimated at \$1.34/m^3 (Boletín de Promoción de Negocios Forestales, 2005; Appendix A). Transportation costs by river from Jenaro Herrera to Iquitos (a distance of 200 km, linked only by river, Fig. 1) were calculated only for sawnwood and charcoal , due to higher retail prices for these products in Iquitos. The cost of transporting sawnwood was \$6.20/m^3 (Boletín de Promoción de Negocios Forestales, 2005; Appendix A) and for charcoal was \$0.022/kg (Appendix A).

2.4.2.4. Other costs. The costs of certification assessments in tropical countries ranged from \$0.22/ha/yr to \$0.41/ha/yr or \$1.38/ha/yr (Baharuddin, 1995; Sandoval, 2000; Appendix A). We set the cost for certification using the average of these values, \$0.67/ha/yr, and it was multiplied by about 40 years. In strip 1, certification cost was multiplied by 41 years, and in strip 2 by 42 years because the first harvest of strip 2 was at the end of 1989. An extra cost of 10 jornales or 22.2 jornales/ha (Appendix A), was added to cover a silvicultural thinning treatment that was applied to each strip in 1996 (Gorchov pers. comm.).

3. Results

3.1. Timber products

Realistic, optimistic, and growth potential models projected a sawnwood production of 1.88 to 18.94 m^3/ha in strip 1, and 3.92 to 22.43 m^3/ha in the clear-cut portion of strip 2 (Table 1). This production was much lower than the deferment-cut portion of strip 2, 29.60 to 81.65 m^3/ha (Table 1). Out of the three growth models, the growth potential model projected the highest production of sawnwood in strip 1, the clear-cut, and the deferment-cut portion of strip 2, whereas the realistic growth model projected the lowest production.

The three growth models projected a roundwood production (*soleras* and *vigas*) of 11 to 81 pieces/ha in strip 1, and 3 to 92 pieces/ha in the clear-cut portion of strip 2. For the clear-cut strips, the realistic growth model projected a higher production of *soleras* and in some cases a higher production of *vigas* than the optimistic model (Table 1). The growth potential model in the clear-cut strips projected the lowest production of roundwood (Table 1).

In both strip 1 and the clear-cut portion of strip 2, no *P. guianensis* trees were projected to reach ≥25 cm dbh, the size threshold for *cinchina* production. For the deferment-cut portion of strip 2, the three growth models projected a *cinchina* production of 28 to 657 pieces/ha.

Charcoal production was also lower in the clear-cut strips, 11–19 ton/ha in strip 1 and 11 to 17 ton/ha in the clear-cut portion of strip 2, than in the deferment-cut, 15–26 ton/ha (Table 1). The growth potential model projected the highest production of charcoal in the clear-cut strips and the deferment-cut portion of strip 2, whereas the realistic model projected the lowest production.

3.2. Value and cost of harvesting the strips

The value of the clear-cut strips using the three growth models was lower than the value for the deferment-cut portion. The value of strip 1 and the clear-cut portion of strip 2 ranged from \$3112 to \$10,511/ha when using certified prices for sawnwood, and \$2945 to \$8515/ha when not using certified prices (Table 2). The value of the deferment-cut portion ranged from \$12,486 to \$31,591/ha when

Table 1
Estimated sawnwood volume, number of soleras, vigas, and cinchinas, and charcoal production from commercial and "other" species in strip 1, clear-cut and the deferment-cut portions of strip 2 in 2030/2031, using realistic, optimistic, and potential growth models.

Products	Strip 1			Clear-cut in strip 2			Deferment-cut in strip 2		
	Real. 2030	Opt. 2030	Potent. 2030	Real. 2031	Opt. 2031	Potent 2031	Real. 2031	Opt. 2031	Potent 2031
Sawnwood m^3/ha	1.88	2.35	18.94	3.92	4.94	22.43	29.60	36.04	81.65
Roundwood									
Soleras (no. pieces/ha)	32.63	3.98	0.00	20.07	7.13	0.00	–	–	–
Vigas (no. pieces/ha)	47.93	76.29	10.56	72.31	63.45	3.05	–	–	–
Total (no. pieces/ha)	80.56	80.27	10.56	92.38	70.58	3.05	–	–	–
Cinchinas (no. pieces/ha)	0.00	0.00	0.00	0.00	0.00	0.00	541.36	657.27	28.14
Charcoal									
Comm. spp.(ton/ha)	1.68	2.57	4.94	3.23	4.77	3.46	–	–	–
"Other" spp. (ton/ha)	9.36	13.00	14.53	7.82	10.09	13.99	14.86	18.80	26.17
Total (ton/ha)	11.04	15.57	19.47	11.05	14.86	17.45	14.86	18.80	26.17

Table 2
Value of timber products (US$/ha) in strip 1, the clear-cut, and deferment-cut portions of strip 2 in 2030/2031, using realistic, optimistic, and potential growth models.

Products	Strip 1			Clear-cut in strip 2			Deferment-cut in strip 2		
	Real. 2030	Opt. 2030	Potent. 2030	Real. 2031	Opt. 2031	Potent. 2031	Real. 2031	Opt. 2031	Potent. 2031
Sawnwood									
If certified	620	776	6250	1294	1630	7402	9768	11,893	26,945
If non-certified	453	566	4565	945	1191	5406	7134	8686	19,678
Roundwood									
Soleras	218	27	0	134	48	0	–	–	–
Vigas	320	509	70	482	423	20	–	–	–
Total	538	536	70	616	471	20	–	–	–
Cinchinas	0	0	0	0	0	0	88	112	14
Charcoal	1954	2756	3446	1956	2630	3089	2630	3328	4632
Total value									
W. certified sawnwood	3112	4068	9766	3866	4731	10,511	12,486	15,333	31,591
W. non-certified sawnwood	2945	3858	8081	3517	4292	8515	9852	12,126	24,324

using certified sawnwood and $9852 to $24,324/ha when not using certified prices (Table 2). The value of the strips was the highest with the growth potential model and the lowest with the realistic growth model.

In the clear-cut strips, sawnwood was the most economically valuable timber product only in the growth potential model, whereas in the deferment-cut sawnwood was the most valuable product in all three growth models. In the realistic and optimistic growth models of strip 1 and the clear-cut portion of strip 2, sawnwood production comprised only 19 to 34% of the total value of products when using certified prices for sawnwood, and 15 to 28% when not using certified prices (Table 2). In the growth potential model, however, sawnwood production comprised 64 to 70% of the total value when using certified prices and 56 to 63% when using non-certified prices. In the deferment-cut, sawnwood comprised 71 to 85% of the total value of products (Table 2).

Charcoal was the product generating the largest value in both the realistic and optimistic growth models of the clear-cut strips, but not in the growth potential model. Charcoal production in strip 1 and the clear-cut portion of strip 2, under the realistic and optimistic growth model, comprised 51 to 68% of the total value of products when using certified prices for sawnwood, and 56 to 71% when not using certified prices (Table 2). In the growth potential model, however, charcoal production comprised 29 to 35% when using certified prices, and 36 to 42% when using non-certified prices (Table 2).

Roundwood for housing construction was the least valuable product in all three growth models of the clear-cut strips. Roundwood

Table 3
Harvesting, certification, processing, and transport total costs, and total earnings (US$/ha) for strip 1, the clear-cut, and deferment-cut portions of strip 2 in 2030/2031, using realistic, optimistic, and potential growth models.

Costs	Strip 1			Clear-cut in strip 2			Deferment-cut in strip 2		
	Real. 2030	Opt. 2030	Potent. 2030	Real. 2031	Opt. 2031	Potent. 2031	Real. 2031	Opt. 2031	Potent. 2031
Harvesting	1501	1501	1501	1501	1501	1501	1501	1501	1501
Certification	27	27	27	28	28	28	28	28	28
Processing and transport									
Sawnwood	232	294	2366	477	609	2809	3545	4306	9717
Soleras	37	4	0	23	8	0	–	–	–
Vigas	97	154	21	146	128	6	–	–	–
Cinchinas	0	0	0	0	0	0	142	172	7
Charcoal	1153	1626	2033	1154	1552	1823	1552	1965	2733
Total costs									
If certified	3047	3606	5948	3329	3826	6167	6768	7972	13,986
If non-certified	3020	3579	5921	3301	3798	6139	6740	7944	13958
Earnings									
W. certified sawnwood	65	462	3818	537	905	4344	5901	7578	17,605
W. non-certified sawnwood	−75	279	2160	216	494	2376	3295	4399	10,366

comprised only 10 to 18% of the total value of strip 1 and the clear-cut portion of strip 2 in the realistic and optimistic growth model (Table 2). The growth potential model projected much lower roundwood production because commercial trees surpassed the threshold size for production of *vigas* and *soleras*.

The costs for harvesting, processing and transport timber products were lower for the clear-cut strips than the deferment-cut in the three growth models (Table 3). Using the three growth models and certified and non-certified costs, total costs in strip 1 and the clear-cut portion of strip 2 ranged from $3020 to $6167/ha, whereas in the deferment-cut portion of strip 2, total costs ranged from $6740 to $13,986/ha (Table 3). The cost of harvesting a strip was $1501/ha. The costs for processing and transporting sawnwood, roundwood, and charcoal increased with the amount of timber products produced (Table 3). There was not much difference between certified and non-certified costs (Table 3). Further breakdown of the costs for harvesting, processing, and transport of timber products in strip 1, the clear-cut portion and the deferment-cut portion of strip 2 are provided in Appendix A.

3.3. Earnings and NPVs

In each of the three growth models, the clear-cut strips had lower earnings than the deferment-cut (Table 3). Total earnings in 2030/2031 for strip 1 and the clear-cut portion of strip 2 ranged from $65 to $4344/ha with certified sawnwood and −$75 to $2376/ha with sawnwood not certified. Total earnings in 2031 for the deferment-cut portion of strip 2 would be much higher; ranging from $5901 to $17,605/ha with certified sawnwood and $3295 to 10,366/ha with sawnwood not certified (Table 3).

Net present values were calculated only for positive earnings (Fig. 2). At a low discount rate of 5%, the NPV for strip 1 and the clear-cut portion of strip 2 ranged from about −$54 to +$1271/ha with certified sawnwood and from −$9 to +$661/ha with sawnwood not certified (Fig. 2). The NPVs for the deferment-cut portion were higher, ranging from +$1754 to +$5383/ha with certified sawnwood and from +$946 and +$3139/ha with sawnwood not certified (Fig. 2). At the 15% discount rate, the most realistic discount rate for the Peruvian economy, the NPVs for strip 1 and the clear-cut portion of strip 2

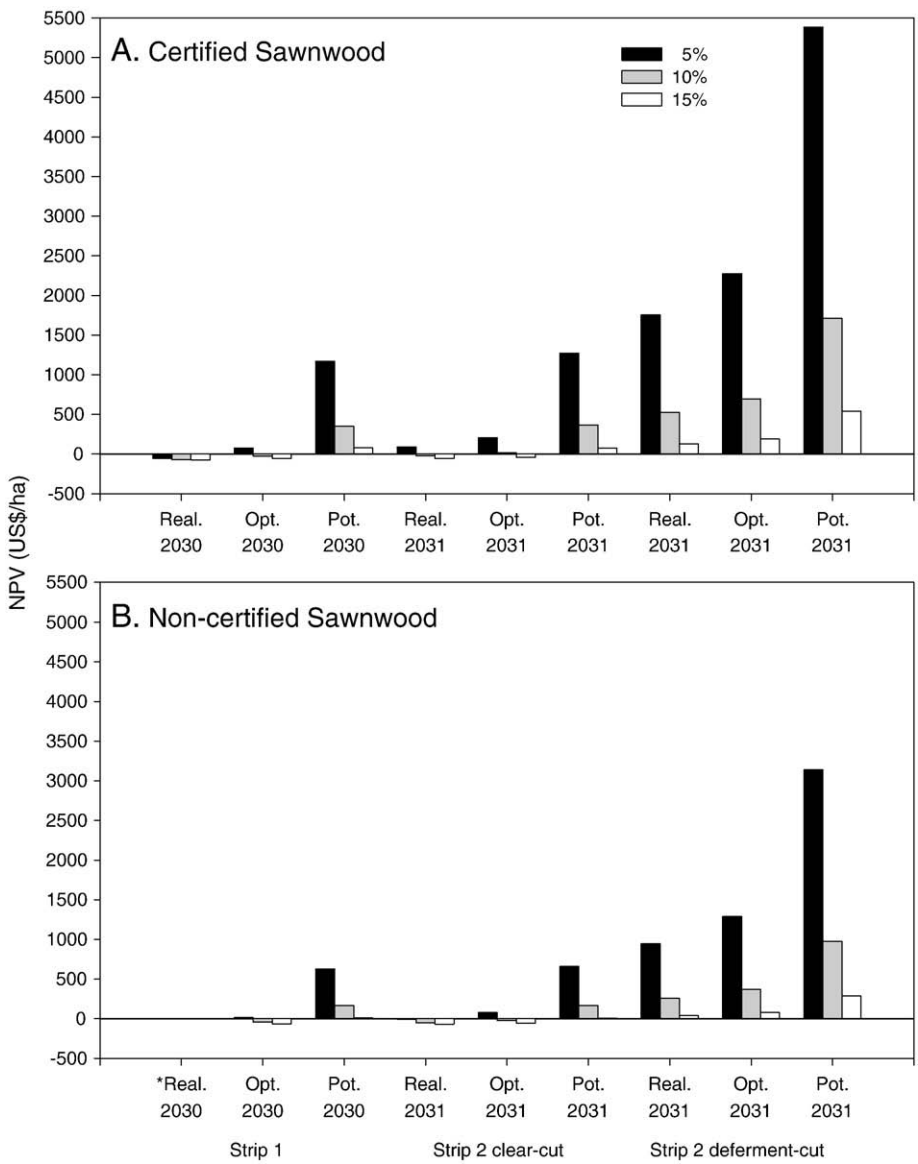

Fig. 2. Net present values (NPV) for strip 1, clear-cut and deferment-cut portions of strip 2 calculated with (A) certified and (B) non-certified sawnwood, using pessimistic, optimistic, and potential growth model, and 5%, 10% and 15% discount rates. *NPV was not calculated due to negative earnings.

ranged from −$73 to +$78/ha with certified sawnwood and −$64 to +$11/ha with sawnwood not certified (Fig. 2). In contrast, the NPV for the deferment-cut portion of strip 2 ranged from +$131 to +$540/ha with certified sawnwood and from +$40 to +$287/ha with sawnwood not certified (Fig. 2).

4. Discussion

4.1. Sustainability of the strip clear-cutting system

Contrary to the predictions of Tosi (1982) and Hartshorn (1989a), the clear-cut strips in this study would not be economically sustainable in a potential second harvest due to the regeneration of few timber species, slow tree growth rates, low income from timber products, and high costs for this system.

The regeneration of few timber species in the clear-cut strips (Rondon et al., 2009a) along with their slow growth rates affected sawnwood production. In the strip clear-cutting system, it was assumed that high abundance of timber species and high tree growth rates in subsequent cutting cycles would lead to higher production and profits than the first harvest (Tosi, 1982; Hartshorn, 1989a); however, this may not occur. Fifteen years after the first harvest of the clear-cut strips, the relative abundance of commercial species was still far from reaching pre-harvesting levels (Rondon et al., 2009a). Due to slow growth rates, a small number of trees projected to reach commercial size (30 cm dbh) after 40 years (Rondon et al., 2009b). Our projection of 1.88 to 2.35 m^3/ha of sawnwood under the realistic and optimist growth corresponds to only 2% of the 105 m^3/ha, estimated for the initial clear-cuts in 1989 (Cornejo and Gorchov, 1993). The growth potential model projected 22.43 m^3/ha, a much higher sawnwood production, but only a 21% recovery of the first 1989 harvest.

Although sawnwood was the most valuable product in this study, it only generated a high income in the growth potential model, and this amount was still much lower than the first harvest. The estimated value of sawnwood production in 1989 was $13,335/ha, using a domestic, non-certified value of $127/$m^3$ (Cornejo and Gorchov, 1993). The value of sawnwood in a second harvest ranged from $3112 to $4731/ha with realistic and optimistic models, and from $9766 to $10,511/ha with the growth potential model when using certified prices.

This projected income, however, would have been much lower if domestic prices had been used instead of export prices. Domestic prices for sawnwood of common timber genera (not Mahogany or Cedar) have not changed much in Peru since 1989. In Iquitos, domestic sawnwood value was $127/$m^3$ in 1989 (Cornejo and Gorchov, 1993) whereas in 2007 it ranged from $120 to $122/$m^3$ for *Virola* spp., and $135 to $138/$m^3$ for *Simarouba* spp. (International Tropical Timber Organization Market Information Service, 2007). It appears that the high timber supply for domestic consumption has maintained prices fairly constant throughout these years. If the strip clear-cutting system were to be implemented to supply the Peruvian domestic market, it would fail not only because of low production, but also low prices.

Charcoal production increased the income generated from the clear-cut strips, and in some cases was much higher than sawnwood (Table 2). Charcoal production depends on several factors such as the density of the parent wood, moisture content, and kiln type (Openshaw, 1983). In this study, we calculated charcoal production from average hardwoods (all non-pioneer trees) using an earth kiln, the typical production method for the Peruvian Amazon (Cornejo and Gorchov, 1993; Coomes and Burt, 2001). Using the volume of hardwoods that would neither be utilized for the production of sawnwood, roundwood, nor *cinchina*, we projected a charcoal production from the clear-strips of 11–19 tons/ha, which is higher than 10 tons/ha produced in 9 year-old secondary forest by peasant households near Iquitos (Coomes and Burt, 2001). There is a high demand for charcoal in Iquitos; in the peak period of demand about 156 tons of charcoal per month enters the Iquitos markets (Coomes and Burt, 2001). Although charcoal production generates a high price, this is a time-consuming activity with high costs (Coomes and Burt, 2001).

Roundwood production was projected to generate the least income of the three timber products. These projections were very optimistic since some wood is lost in the process of making a *solera* or *viga* (Gorchov pers. comm.). We could have increased roundwood production in a second harvest if we had projected the growth of smaller stems (<6.5 cm dbh) or more tree taxa. In this study, we assumed that all projected commercial trees within the threshold of 8 to <15 cm dbh would be of roundwood value regardless of taxa, but this is not strictly true (Pinedo-Vasquez et al., 1990; Cornejo and Gorchov, 1993). Some commercial taxa (e.g. *Virola* and *Guarea* spp.) are valued only as sawnwood and not for roundwood, while others (e.g. *Guatteria*, *Xylopia*, and *Brosimum* spp.,) can be used for both; and also some 'non-commercial' taxa (e.g. *Neea* and *Unonopsis*) in this study (Appendix A) are valued only for roundwood (Peters et al., 1989; Pinedo-Vasquez et al., 1990). Nevertheless, due to their low price in the domestic market, additional roundwood production would have had little effect on the overall value of the strips in a second harvest. In this study, we modeled the sale of roundwood in the town closest to the strips, rather than in Iquitos, because of lower transports costs and higher retail prices. To increase the value of roundwood, Tosi (1982) and Hartshorn (1989a; 1995) proposed the construction of a wood treatment plant to make preserved telephone poles and posts, but this would require an investment of $295,000 (Tosi, 1982).

Strip clear-cutting is a very expensive forest management system. Harvesting of two strips in 1989 indicated that labor and fuel costs were higher than gross value in one strip and only slightly lower than gross value in a second strip (Cornejo and Gorchov, 1993). We estimated the cost of harvesting and extracting timber from a strip to be $1500/ha (Table 3) whereas Tosi's (1982) estimate was $985/ha; after adjusting for inflation rates Tosi's (1982) estimate would be much greater than $2000/ha in 2007 (Rondon, 2008). To calculate labor expenses, we used a wage of $3.40 per jornal or day, the amount paid for non-permanent workers in Jenaro Herrera (E. Honorio, pers. comm.). If this system were to be implemented at a broad scale as originally proposed (Tosi, 1982; Hartshorn, 1989a; 1995), it would require permanent workers as well as outside professional assistance for training local people, making this system even more expensive (Simeone, 1990). Other costs that were not taken into consideration were exportation permits and local taxes for timber.

The profits of the strip clear-cutting system have been largely overestimated. The potential yearly returns for this system in the Palcazú Valley were estimated to be of $736/ha (Stocks and Hartshorn, 1993) to $786/ha (Hartshorn, 1989b). Gram (1997) argued that these amounts implied large outputs of timber products from the processing center established in the Palcazú, consisting of a sawmill, a carpenter's workshop, wood preservation plant, and a portable kiln for making charcoal. Gram's (1997) estimates for yearly returns for a 320 ha-production of forest in the Palcazú without wood processing were much lower, $12 to $17/ha, and within the rage of our estimates for certified sawnwood (−$73 to $78/ha) with a 15% discount rate. Our estimates are in some cases higher because we assumed fast growth rates in one of our models and the processing of timber products in our NPV calculations.

Strip clear-cutting is not an attractive option for forest management since the opportunity cost for using this system is lower than for selective logging, deferment-cutting, and mahogany plantations. The realistic growth model projected the lowest negative NPV while the optimistic model projected higher NPVs. However, all the NPVs in these two models were negative and much lower than other systems. The estimated NPV of selectively logging 30 m^3/ha every 20 years in the Peruvian Amazon was $490/ha with a 5% discount rate, and considered sustainable (Peters et al., 1989). Our NPVs were also lower than the $507/ha and $615/ha projected for selective logging

(about 30 to 40 m^3/ha) with planned logging operations projected in a 30-year and 20-year cutting cycles in Eastern Amazonia, with a 6% discount rate (Barreto et al., 1998). The growth potential model predicted higher NPVs for the clear-cut strips than for these selective logging systems. However, these high NPVs would only occur if commercial trees in the strips were to grow at increments similar to those observed in the top 25% of each size class; which is very unlikely (Rondon et al., 2009b). Even if trees were to grow with such high rates, the NPVs of the growth potential model were less profitable than the NPVs of the deferment-cut, less profitable than the NPV (>$471/ha in 35–40 years with a 10% discount rate) of some mahogany plantations (Browder et al., 1996), and similar to the high end estimate for harvesting palm (*Geonoma deversa*) leaves for roof thatching (Flores and Ashton, 2000).

The lowest and highest NPVs calculated by the realistic and growth potential model can be considered as the limits of the range of possible NPVs that could be obtained from this system. We consider these NPV estimates to be fairly accurate. Although in some cases values and costs were estimated indirectly, conversion factors were obtained from reliable sources (Appendix A) and they were further adjusted for inflation. NPV values can be affected by future fluctuations in costs and prices. Fuel prices are likely to increase in the future, affecting harvesting, processing of sawnwood, and transport costs, thereby, lowering overall NPVs for the strips in a second harvest. Also, over time the taxa of commercial value (e.g. sawnwood and roundwood for construction) in the Amazon will change, and this may affect the NPV of the strips. The price of timber, however, is likely to remain low, as long as supply remains plentiful (Southgate, 1998). In a high demand timber scenario, timber price increases barely exceed 1% per annum over the next 60 years (Sohngen et al., 1998; Pearce et al., 2003).

Low NPVs for the strip clear-cutting system in a second harvest indicated that this system is not economically sustainable. In this study, we evaluated the economic viability of timber extraction using the strip clear-cutting system as originally proposed by Tosi (1982) and Hartshorn (1989a). The estimated NPVs do not reflect the total value of the strips because the value of other activities such as harvesting non-timber forest products (e.g. palm leaves) and ecosystem services were not considered and are beyond the scope of this study. Findings from this study, however, should be interpreted with caution due to low sample size, a major constraint in forestry research.

4.2. Deferment-cut

The deferment-cut treatment would be more profitable in a second harvest than the clear-cut strips (Fig. 2). The three growth models projected a greater number of commercial trees reaching ≥30 cm dbh in deferment-cut than in the clear-cut strips (Rondon et al., 2009b), generating a higher income and increasing substantially the overall value of the deferment-cut in a second harvest. These models also projected a higher charcoal production in the deferment-cut than in the clear-cut strips. Also, only in the deferment-cut treatment, *P. guianensis* trees were projected to reach >25 cm dbh for *cinchina* (fence posts) production (Table 1). The NPV for the deferment-cut ranged between $128 and $539/ha with certified sawnwood prices and at a 15% discount rate, much greater than the clear-cut strips and some of the selective logging systems.

4.3. Conclusions

Although growth models predicted low timber yields in a second harvest for the clear-cut strips, this system could be greatly improved to increase its yields and overall income. Enrichment planting of valuable and fast-growing timber species can be implemented to increase economic value of the strips as has been done in other studies when desirable species are absent or in low densities (Peña-Claros et al., 2002; Schulze, 2008). Enrichment planting of *Cedrelinga* trees, as done on a limited scale in strip 1, would increase sawnwood volume since some individuals would reach commercial size in 40 years based on growth projections (Rondon et al., 2009b). Intensive silvicultural treatments (e.g. cutting of lianas and pioneer species) and periodic thinning have been shown to increase growth rates of commercial trees (Peña-Claros et al., 2008) and could also be implemented in the strip clear-cutting system. Finding markets for fast-growing trees would add value to the strips: *Cecropia* could be sold for the manufacture of paper pulp (as in Faber-Landgendoen, 1992) and *Alchornea* could be sold in the local markets because it is valuable as roundwood for construction (Pinedo-Vasquez et al., 1992).

Alternatively, cutting cycles longer than 40 years may be necessary in this system to achieve higher timber yields and presumably increase profits from the strips. Selective timber logging in Amazonia extracts much lower volumes than does strip clear-cutting (166–185 m^3/ha total roundwood felled at this study site (Cornejo and Gorchov, 1993)) and requires cutting cycles longer than 30–40 years to achieve sustained timber yields. For instance, in the Tapajós forest of Brazil commercial volume did not recover following the logging of 75 m^3/ha in a proposed 33-year cutting cycle (Silva, 1989); only extractions of 10 m^3/ha over a 30-year cutting cycle were found sustainable for this region (van Gardingen et al., 2006). Several studies in Amazonia indicate that tree growth rates are too low to achieve sustained timber yields in their proposed cutting cycles (Silva et al., 1995; Dauber et al., 2005; Keller et al., 2007; Sist and Ferreira, 2007; Peña-Claros et al., 2008; this study). On the other hand, longer harvesting cycles implies longer waits for financial returns, and this may decrease the NPVs of a second harvest. Unless intensive silvicultural treatments are applied to increase growth rates and markets start accepting new species, timber harvesting in Amazonia will not be sustainable.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.forpol.2010.02.004.

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