

## Impacts of conventional and reduced logging on growth and stand composition four years after harvest in a neotropical forest in Misiones, Argentina

Impactos da exploração convencional reduzida sobre o crescimento e composição florística numa floresta neotropical em Misiones, Argentina

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### Resumo

O objetivo deste trabalho foi analisar a evolução de uma floresta após quatro anos da aplicação de dois sistemas de exploração: convencional (CH) e de impacto reduzido (RIL). A floresta está localizada na Reserva Guarani em Misiones, Argentina. Em 1998 foram instaladas aleatoriamente 18 unidades amostrais para identificar as espécies e mensurar o diâmetro à altura do peito (DAP) e área basal das plantas. A exploração seletiva foi realizada em Julho de 1999 e as medições foram feitas todos os anos até 2003, durante o mês de julho. Antes da exploração não havia diferença significativa na área basal e na densidade das árvores entre tratamentos (265 a 315 indivíduos por hectare,  $p = 0,34$ , e área basal de 23 a 26 m<sup>2</sup>/ha,  $p = 0,39$ ). Na CH e RIL, ao comparar os resultados dos anos 1998 e 2003, não se encontrou diferença significativa na densidade ( $t = -1,212$ ;  $df = 5$ ;  $p > 0,27$  e  $t = -2,36$ ;  $df = 3$ ;  $p > 0,09$ ) nem na área basal ( $t = 1,48$ ;  $df = 5$ ;  $p > 0,19$  e  $t = 0,10$ ;  $DF = 3$ ;  $p > 0,92$ ). Nas áreas de controle (CP) houve diferença significativa na densidade ( $t = -2,8$ ;  $df = 4$ ;  $p < 0,05$ ), mas não na área basal ( $t = 0,55$ ;  $df = 4$ ;  $p > 0,6$ ). Aos quatro anos da exploração pelo tratamento CH, a área basal não atingiu os seus valores iniciais. Com relação à densidade de plantas, houve melhor recuperação onde a abertura de grandes clareiras permitiu o reestabelecimento de inúmeras espécies pioneiras. Por sua vez o RIL recuperou os valores iniciais de ambas as variáveis, atingindo classes de 70 cm de DAP. Além dos tratamentos apresentarem um constante aumento de diâmetro das árvores individuais, encontraram-se também diferenças significativas no crescimento de espécies comerciais após quatro anos da exploração no RIL e CP. Ficou evidente que a exploração planejada permite uma melhor e mais rápida recuperação da floresta.

**Palavras-chave:** Colheita de baixo Impacto, Crescimento, Floresta subtropical, Manejo florestal

### Abstract

This study analyzed the evolution of a forest from harvesting to four years after timber harvesting, using two systems of timber extraction: conventional harvesting (CH) and reduced impact logging (RIL) in the Guarani Reserve, Misiones, Argentina. In 1998, 18 plots were installed randomly where species were identified, diameter at breast height (dbh), and basal area measured. Harvesting occurred in July 1999 and forest measurements were repeated annually in July until 2003. Previous to the harvest there were not significant differences in basal area and density of trees between treatments (265 to 315 individuals per hectare,  $p = 0.4$ , and a basal area from 23 to 26 m<sup>2</sup> ha<sup>-1</sup>,  $p=0.42$ ). In CH and RIL, when comparing the 1998 and 2003 results, there were not significant differences in density ( $t = -1.212$ ,  $DF = 5$ ,  $p > 0.27$  and  $t = -2.36$ ,  $DF = 3$ ,  $p > 0.09$ ) nor in basal area ( $t = 1.48$ ,  $DF = 5$ ,  $p > 0.19$  and  $t = 0.10$ ,  $DF = 3$ ,  $p > 0.92$ ). In the control plots (CP) there were significant differences in density, ( $t = -2.8$ ,  $DF = 4$ ,  $p < 0.05$ ) but not in basal area ( $t = 0.55$ ,  $DF = 4$ ,  $p > 0.6$ ). Four years after harvesting, the CH plots did not regrow to the levels of the initial basal area. The density of individual trees in the stands regained their initial levels faster, since the large clear-felling openings allowed the recruitment of numerous individuals of pioneer species. On the other hand, with RIL the initial values of both variables recovered after 4 years, through the classes up to 70 cm of dbh. Both RIL and the control that was not harvested had a constant diameter increase of individual trees, but there were significant differences in the growth of individuals of commercial species four years after harvesting. Overall, the planned harvest of RIL led to faster recovery of the forest, including better composition of timber species, less damage to residual trees, and faster growth of desirable species.

**Keywords:** Reduced impact logging, Growth rates, Subtropical forests

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## INTRODUCTION

Reduced Impact Logging (RIL) has been promoted as a means to enhance protection of tropical forests and improve sustainable forest management through more careful planning and logging practices, in response to domestic and international concerns over the ecological and economic sustainability of natural tropical forests. RIL systems are intended to reduce damage during the initial forest entry, reduce ecosystem damage by planning forest operations to limit soil disturbance by heavy equipment, and reduce damage to the residual stand.

RIL concepts and methods have developed over the last decade. The FAO model code of forest harvesting (DYKSTRA and HEINRICH, 1996) provides the basis for RIL system design. RIL techniques and guidelines are not fixed prescriptions but are developed in concert with management objectives, ecosystem characteristics, and market conditions. RIL systems adapt best harvesting techniques based on the following fundamental activities: pre-harvest inventory and mapping of trees; pre-harvest planning of roads and skid trails; pre-harvest vine cutting; directional felling; low stumps; efficient utilization of felled trunks; optimum width of roads and skid trails; winching of logs to planned skid trails; optimal size of landings; minimal ground disturbance; and slash management.

Authors like Pereira Jr *et al.* (2002), Holmes *et al.* (2002) and Boltz *et al.* (2003) usually indicate that RIL is an effective means to harvest forests with more care and often at reduced costs, because better planning will improve efficiency, reduce waste, and protect residual trees. However, the number of long-term studies on the forest stand and ecological effects of RIL is small.

Sustainable Forest Management (SFM) has become the dominant paradigm for forestry throughout the world, including in the tropics. RIL has been proposed as one means that is necessary, albeit perhaps not sufficient, to achieve SFM. RIL techniques have been recently implemented successfully in some areas of Asia (PINARD and PUTZ, 1996; PÉLISSIER *et al.*, 1998; SIST *et al.*, 2002) and Latin America (VIDAL *et al.*, 2002). Some studies found reduced levels of damages, from 30 to 50% compared to conventional harvesting (PINARD and PUTZ, 1996; SIST *et al.*, 2002, MAC DONAGH *et al.*, 2003).

Research has been carried out in several tropical areas of the world studying the evolution

of harvested forest stands for up to 13 years, including Asia (PINARD and PUTZ, 1996, SIST *et al.*, 2002, SIST and NGUYEN-THÉ, 2002) and Latin America (GRAAF *et al.*, 1999; PARROTTA *et al.*, 2002; SILVA *et al.*, 1995; DELGADO *et al.*, 1997; KAMMESHEIDT *et al.*, 1995; WAGNER, 1997). These studies have found that RIL tends to be less intrusive and does produce better residual stand conditions. Most studies, however, suggest that more time will be required to reach definitive conclusions on the final effects of harvesting native forest.

Some results show that timber harvesting can be used as a silvicultural treatment, since it should be a stimulus for the growth of the remaining individuals. This effect was observed mainly in the short term in economically interesting species, when applying planned techniques (PÉLISSIER *et al.*, 1998; SILVA *et al.*, 1995; GRAAF *et al.*, 1999; SIST and NGUYEN-THÉ, 2002). This positive effect in the diameter growth could be correlated with the initial size of the tree (PÉLISSIER *et al.*, 1998; SILVA *et al.*, 1995) or with variables as the crown opening and vines density (VIDAL *et al.*, 2002).

Sist and Nguyen-Thé (2002), in a selective harvesting of several intensities in East Kalimantan, found that residual trees in harvested plots had more diameter growth than trees in plots with no harvesting. In the harvested plots, those with higher extraction percentage had higher diameter growth than those with lesser interventions. They also observed that growth increased significantly more in four years after harvest than for first two years.

On the other hand Silva *et al.* (1995) in Tapajós, Brazil, observed a decrease of the annual periodic increment from the first to the second period in approximately 50% for all the species, due to the closing of the canopy. This study confirms that the degree of canopy opening is an important factor to consider in management decisions. Furthermore, Graaf *et al.* (1999) found a growth decrease of commercial species after the application of silvicultural treatments in Suriname. Gauto (1997), conducted a research in the same area, and found that two years after a selective harvest, there was a gross increment of 2.4% and a net increment of 0.16%. Gross increment is the increase in volume including the volume of standing but dead trees. Net growth after a harvesting excludes mortality, so is only the growth in live trees (DAVIS and JOHNSON, 1987). Thus net growth is a better measure of

stand health, and the difference between the two metrics may indicate the level of damage caused by harvesting in the residual stand.

In another study, Pélissier *et al.* (1998) in India found an increase in the number of individuals of 0.47% per year in plots with no harvesting and 0.79% per year in areas with selective harvest. Gauto *et al.* (1996) found a gross growth in basal area of 2.5 %, a net growth of 0.57%. Pélissier *et al.* (1998) found a 1.02% increase basal area in a forest without interventions, and 1.61% in a harvested forest.

Research results on the impacts of timber harvest on floristic composition vary considerably. In some cases, forest harvesting did not affect flora (GAUTO, 1997; PANFIL and GULLISON, 1998; PÉLISSIER *et al.*, 1998). In others the structural parameters and some species and families could be seriously affected (KAMMESHEIDT *et al.*, 1995). Guariguata and Ostertag (2001) found that species with high light requirements were more prevalent after interventions, as one would expect. Finally, Panfil and Gullison (1998) found that the loss of species is random, independent of the analyzed surface.

The native forests in Misiones have been exploited for timber continuously over the last century. However, very few studies have examined the natural evolution of a harvested forest for more than two years, mainly due research costs (GAUTO, 1997; MAC DONAGH *et al.*, 2001). Long term studies on the evolution of the harvested forest, including the growth analysis, are required for planning operations and for the sustainable forest management.

Traditional timber harvesting techniques commonly employed in Misiones are based on the selective harvesting of species of commercial interest, without operations planning nor care to avoid damage to the remainder forest. As a consequence of this system, Gauto (1997) found a high mortality of small diameter trees due to damage. Similarly, Mac Donagh *et al.* (2003) compared conventional logging and RIL, and reported a direct relationship between harvesting intensity and level of damages for conventional logging, while in the case of RIL no relationship was found.

The research summarized here provides better ecological information on the longer term effects of RIL on residual forest stand composition and growth, based on a four year study of native subtropical forests in the Province of Misiones in northeast Argentina. The objective of this study was to analyze the evolution of the

tree density, basal area, and floristic composition of a forest four years after harvest with conventional commercial logging versus reduced impact logging.

## MATERIALS AND METHODS

This research was conducted in Misiones, Argentina, at 25° 56' S latitude and 54° 15' W longitude, inside the Guarani subtropical forest reserve of the National University of Misiones (UNaM). The landscape is hilly with some steep slopes. The highest elevation is 574 m above sea level. The soils are derived of the weathered basalt with different degrees of evolution, leading to varying cartography of soil depth and slope. The soil was a Typic Distrocrepts: argilic-loam in surface and argilic in depth, brown dark red, shallow to deep depth (PAHR *et al.*, 1997). The climate is subtropical without a dry season, the average annual precipitation is 2130 mm, ranging between 1400 and 3500 mm with occasional brief periods of drought. The maximum and minimum temperatures respectively are 38° C and -8° C.

The study area is covered with subtropical semideciduous forests, comprised of different species strata. There were 89 tree species and 30 botanical families, mainly Leguminosae, Lauraceae, Euphorbiaceae, Rutaceae. The dominant trees averaged 23.9 m<sup>2</sup> ha<sup>-1</sup>, with an average density of 282 trees ha<sup>-1</sup>.

This experiment was carried out on 100 hectares, of which 60 ha were harvested according to two treatments, reduced impact logging and conventional harvesting, as described below.

**Reduced impact logging (RIL)** techniques were applied selecting the trees to be felled and the trees to be cut were chosen according to Government regulations for diameter at breast height and species, this mean minimum diameter criteria depending on the group of species established in the regulation. For example the minimum dbh varied between 0.35 cm dbh up to 0.55 cm dbh in a list of 10 commercial species that have been merchantable at the moment of the harvesting operation (MINISTERIO DE ECOLOGIA Y RECURSOS NATURALES RENOVABLES, 1987).

Regarding to the presence of tree seedlings and seedlings, two measures were taken. The first was that in any RIL plot, at least one tree of each commercial species that was recorded in the previous inventory was left. Second, in the case of trees with adjacent clusters of tree seedlings or saplings, the skid trail was design to

avoid these areas, even if the skid distance was longer than in the commercial harvesting.

For the felling operation, unfortunately it was impossible to find any trained crew of chainsaw operators in the region that specialized native forests. However, the felling direction was guided by technical personnel of the project to avoid the areas with clusters of seedlings or saplings of commercial species, and to avoid major damages to the remaining trees.

For the selection of the skid trails, and locating the landings area, the procedure was to first draw on field maps all the possible skid trails. In those field maps the information of all trees more than 10 cm dbh were located in x and y coordinates, then the project team decided the location together with the skidder operator, taking in account the micro site slope variations, the protection of trees for future crops mentioned above, and the restriction to use only one skid trail to concentrate all the traffic to the landing area, so there would be only one way to go in and out of the plot. Thus, in the selected areas, the distance to driven over by the machine in the plots and, skid trails were established and the timber yard located. Finally, during all the operations, project technical staff supervised the contract workers, to guarantee that the RIL guidelines were followed.

**Conventional harvesting (CH):** the logging contractor selected the trees to be felled and defined skid trails and landing inside each plot without guidelines. The project technician only was an observer of the operations.

Each harvesting plot was 200 m by 200 m. Each harvest plot included a central sample plot where measurements were taken in an area of 100 by 100 meters, with a total of four control plots (CP) with no harvesting, six CH and eight RIL. All trees with a dbh equal to or larger than 10 cm in the sample plots were identified, and their dbh recorded.

The study began in 1998 with the installation of the plots. All trees greater than 10 cm of diameter at breast height (dbh 1.30m) were identified and measured with tape in each plot. In July 1999, the harvest occurred employing the same crew for both treatments, with the considerations mentioned above. During the harvest the trees were cut using a chainsaw Stihl 070. Trees were bucked into logs of variable length size that were hooked together with steel cable, and then skidded to landings by a rubber tired skidder of 10 ton of total weight and 140 CV power engine; the tire size was 18.4\*34 agricultural type, diagonal bias design.

The 18 plots were measured systematically each year in July from 1998 to 2003. After the plots were installed, a tornado affected them unequally, adding an unplanned disturbance factor to the analysis. Several RIL plots were affected most, and they were removed from the analysis, leaving 6 plots with CH, 4 plots with RIL and 4 plots of CP.

The 1998 and 2003 data were compared using the values of basal area, tree density, diameter distribution species abundance and floristic composition, discriminated against by treatment using "t" Student test, Chi-square and ANOVA, respectively.

Differences in stand density over time were measured in each individual tree diameter for each treatment. The differences in diameter were analyzed using repeated measures variance analysis (Wilks test) (NEMEC, 1996). The analysis of the diameter growth of individual trees was carried out considering the annual periodic increment of all the individuals at the beginning at the end of the considered period. These periods were considered as 2 years for each: 1998 to 2000 and 2000 to 2002 in order to detect changes in early responses and longer term responses.

Volume growth is difficult to measure in tropical forests due to poor tree form, multiple branches, difficulties in identifying merchantable tops of the trees, and difficulties in cruising conditions. Thus it was used basal area increases to measure net changes in timber species conditions, more precisely gross and net increase for basal area of the stands were calculated by adapting the method described by Davis and Johnson (1987) for volume growth:

$$\begin{aligned} \text{Gross Increase (GI)} &= BA_2 + M + H - BA_1 \\ \text{Net Increase (NI)} &= BA_2 + H - BA_1 \end{aligned}$$

Where:

BA<sub>n</sub> = basal area in period n

M = basal area of mortality during the period

H = basal area of harvested timber

## RESULTS AND DISCUSSION

### Changes in density and basal area

Previous to the application of the treatments, all the plots had a stem density from 265 to 315 individuals per hectare and a basal area that varied from 23 to 26 m<sup>2</sup>ha<sup>-1</sup>, without significant differences among treatments in any of the variables (F = 0.98 and p=0.4 and F = 0.91 and p=0.42).

Figure 1A and 1B present the results of the basal area and number of trees for three periods,

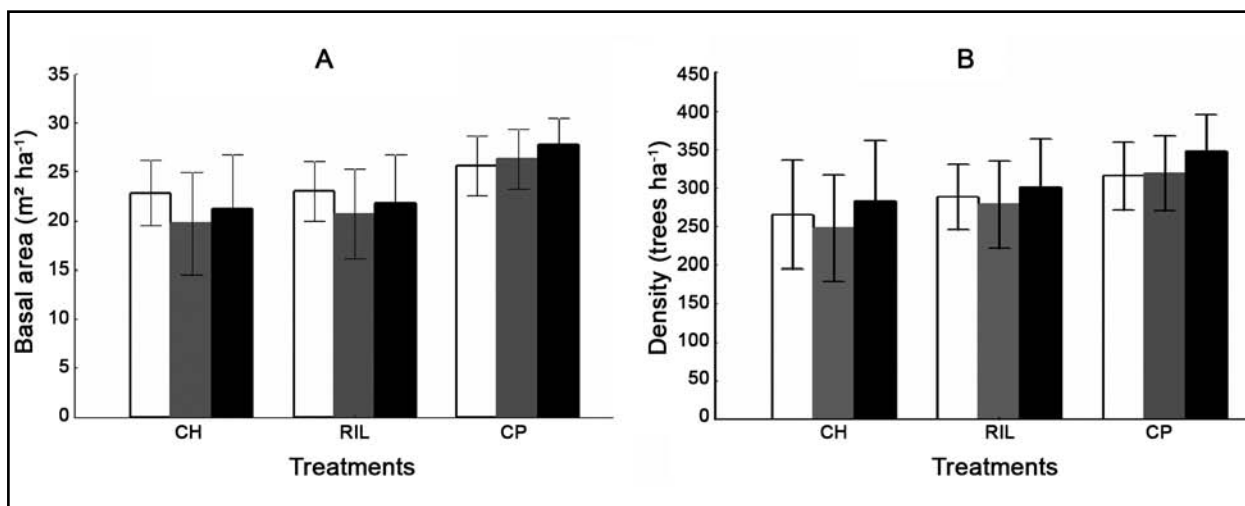
before harvesting (1998), two years after the harvest in July of 1999 (2001), and four years after (2003). In the CH treatment, an average of 4.33 trees ha<sup>-1</sup> was harvested with a basal area of 1.9 m<sup>2</sup> ha<sup>-1</sup>. One year after harvesting, 94% of the initial density (248 ± 70 trees ha<sup>-1</sup>) and 85% of the initial basal area (19.74 ± 5.18 m<sup>2</sup> ha<sup>-1</sup>) remained. Four years after, 283 (± 78) trees ha<sup>-1</sup> (108%) and 21.23 (± 5.48) m<sup>2</sup> basal area (92%) existed. When comparing the results of 1998 and 2003, no significant differences were found for the number of individuals ( $t = -1.212$ ,  $df = 5$ ,  $p > 0.27$ ), or for the basal area ( $t = 1.48$ ,  $df = 5$ ,  $p > 0.19$ ).

In RIL, an average of 2.88 trees ha<sup>-1</sup> and 1.36 m<sup>2</sup> ha<sup>-1</sup> were harvested. One year after, 99% of the initial density (294 ± 38 trees ha<sup>-1</sup>) and 94% of the initial basal area (22.53 ± 3.43 m<sup>2</sup> ha<sup>-1</sup>) remained. Four years after harvesting, 315 ± 36 individuals ha<sup>-1</sup> (106%) with basal area of 23.90

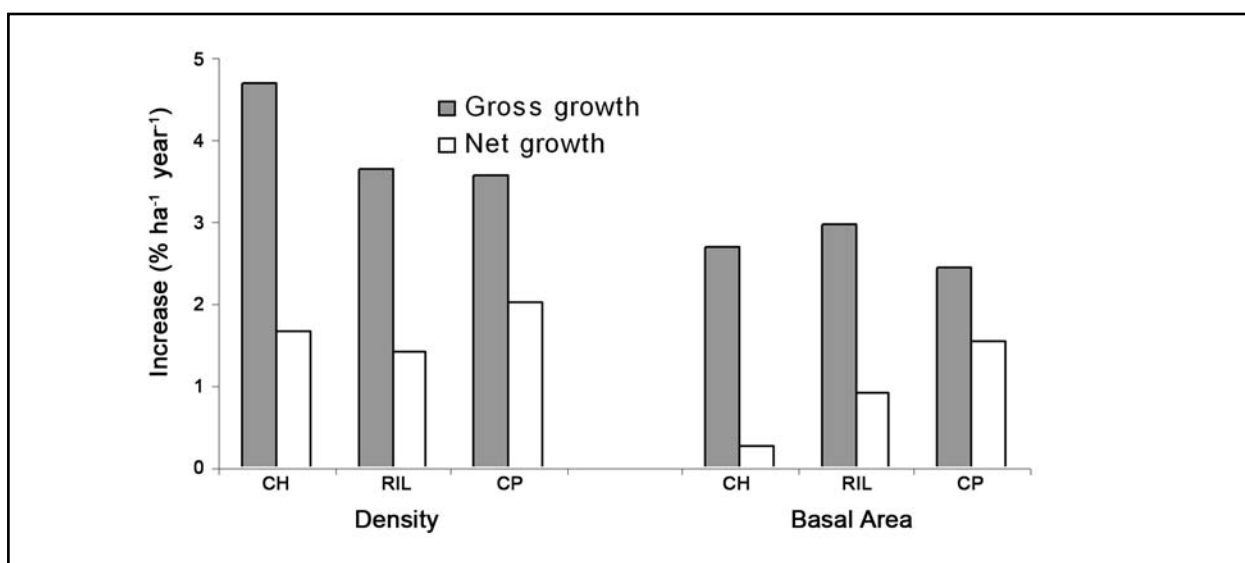
± 3.56 m<sup>2</sup> ha<sup>-1</sup> (100%) existed. No significant differences were found for the number of trees, ( $t = -2.36$ ,  $df = 3$ ,  $p = 0.09$ ), or for the basal area ( $t = 0.10$ ,  $df = 3$ ,  $p > 0.92$ ).

In the control plots (CP), the variables increased from 315 to 347 individuals ha<sup>-1</sup> from 1998 to 2003, and from 25.64 to 27.77 m<sup>2</sup> ha<sup>-1</sup> in basal area. CP plots had significant differences in the number of trees ( $t = -3.44$ ,  $df = 3$ ,  $p < 0.05$ ), but not in basal area ( $t = -2.75$ ,  $df = 3$ ,  $p > 0.07$ ).

In Figure 2 the gross and net increase in basal area and stand density is presented (expressed in percentages by hectare and per year), for number of individuals and basal area, and the treatments. The gross increase in the number of individual trees was larger in CH than RIL and CP, while for the net increase in density, the control was the largest. The gross increase in basal area was largest for RIL and the net increase was largest for CP.



**Figure 1.** Forest basal area and density before harvesting (white column), two years after (grey column) and four years later (black column): (A) basal area (m<sup>2</sup> ha<sup>-1</sup>), (B) tree density (trees ha<sup>-1</sup>). CH: Commercial Harvesting (n=6); RIL: Reduced Impact Logging (n=5); CP: Control (n=4).



**Figure 2.** Gross and net increase for basal area and number of trees, expressed in percent by hectare and by year. CH: Commercial Harvesting, RIL: Reduced Impact Logging and CP: Control Plots

The increase in the number of individual trees four years after harvesting in RIL was significant, probably due to the less damages to the remaining forest. This change in number of trees was similar to that found in the control plots.

Gross annual increase in basal area before harvest until four years after harvest was fairly similar for all plots. The net annual increase was smallest for conventional harvest, intermediate for RIL, and largest for CP. On the other hand, the gross annual increase in density was largest for CH and similar for RIL and CP, but the net annual increase in density was largest for CP and smallest for RIL.

The CH plots with more intensive harvesting had a slower recovery of the species density and basal area than the RIL stands with less intensive harvesting, while the control plots had a constant growth of basal area and number of trees. These results were similar to those found by Parrotta *et al.* (2002) in the Amazon.

The amount of gross and net increase in the number of individual trees was larger than those obtained by Gauto (1997) at the same location and Pélissier *et al.* (1998) in India. The gross increase of the basal area in the treatments and the control was similar to that found by Gauto *et al.* (1996). Net increase in the plots with planned harvesting and control plots was larger than that reported by Gauto *et al.* (1996) and similar to those of Pélissier *et al.* (1998).

### Diameter distribution

Diameter distribution of basal area and number of trees are shown in Figure 3, comparing the data previous to harvesting and 4 years after. In the harvesting treatments, a logical reduction took place in the upper classes due to the harvesting. In CH, four years after, up to the 40 cm class, the quantities of basal area and tree density exceeded their levels before harvesting. In the RIL treatments, an increase in number of trees and basal area occurred up to the 70 cm class. On the other hand, the control plots had an increase of these variables in almost all of the diameter classes. However, there were not significant differences for diameter distribution in either treatment or in the control pre- and post-harvesting (Chi-Square,  $p > 0.05$ ).

The plots with harvesting treatments had a decrease in the number of trees and basal area. Four years after harvesting, the commercial treatment still has less basal area than before harvest, because the increase occurred mainly in

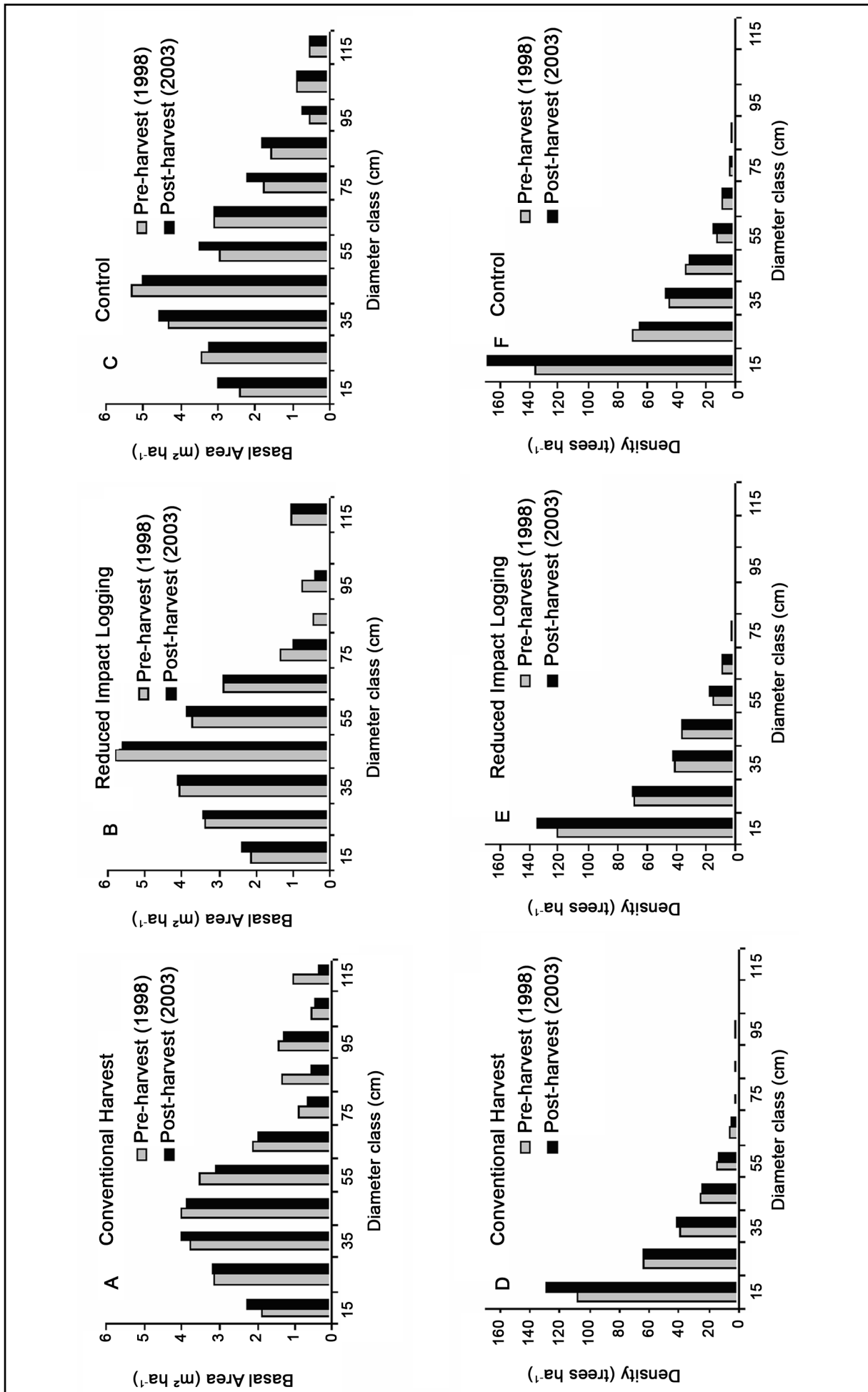
the classes of smaller size (up to 40 dbh cm). The density of individual trees recovered faster because the opening of big clearings allowing the recruitment of numerous pioneer species. On the other hand, in RIL, the initial values of both variables recovered for their initial levels through the classes of 70 cm of dbh.

Gauto *et al.* (1996), in a natural unharvested forest of the Guarani reserve, reported a decrease of the number of trees in the class from 10 to 20 cm dbh, due to the natural mortality and the movement toward the larger classes. Pinard and Putz (1996), in a natural unharvested dipterocarpaceas forest, found a reduction of number of the trees per hectare in all diameter classes, including the lower class of 10 cm of dbh. On the other hand, Parrotta *et al.* (2002) found an increase in the number of trees in all diameters in all natural stands. This agrees with the results of this research, where the control plots had a constant increase in the number of trees measured in all diameter classes.

### Diameter growth

When considering the individuals species, the commercial harvest had increases in diameter in both periods, and was significantly different in both periods for RIL and CP (Table 1). For the commercial species, CH also had a larger diameter increase in both periods, and that increment was statistically significant in the period immediately after harvesting (Table 2). A pair-wise comparison for each treatment indicated that all three treatments had significant differences (Wilks test  $p < 0.05$ ). The diameter increase for all species was always larger in the second period. For the commercial species the diameter growth was always larger in the second period, too, but in any treatment such difference were not statistically significant (Wilks test  $p > 0.05$ ) (Table 3).

For the diameter increase of all individuals, two results occurred. First, all classes had larger average diameter increase in the second period for CP (Figure 4 C). Second, there was a larger average diameter increase in the classes of smaller size, until the 40 cm of dbh size in CH (Figure 4 A) and until the 70 cm of dbh in RIL (Figure 4 B), for the period 2000-2002. In CH there was a positive correlation between the diameter increase of the period 1998 to 2000 and the size of the individuals ( $r^2 = 0.77$ ,  $p < 0.05$ ). In RIL and CP this relationship was not significant (Figures 4 B and 4 C).



**Figure 3.** Basal area and tree diameter distribution, before and 4 years after harvesting.

**Table 1.** Average diameter increase for all species (cm year<sup>-1</sup>) for the periods: 1998 to 2000 and from 2000 to 2002.

	Period 1998-2000	Period 2000-2002	N
	Mean ± SD	Mean ± SD	
Commercial Harvesting	0.40 ± 0.42 a	0.45 ± 0.42 a	963
Control Plots	0.36 ± 0.36 ab	0.41 ± 0.37 ab	730
Reduced Impact Logging	0.34 ± 0.35 b	0.39 ± 0.37 b	767

Different letters mean significant differences between treatments in the same period.

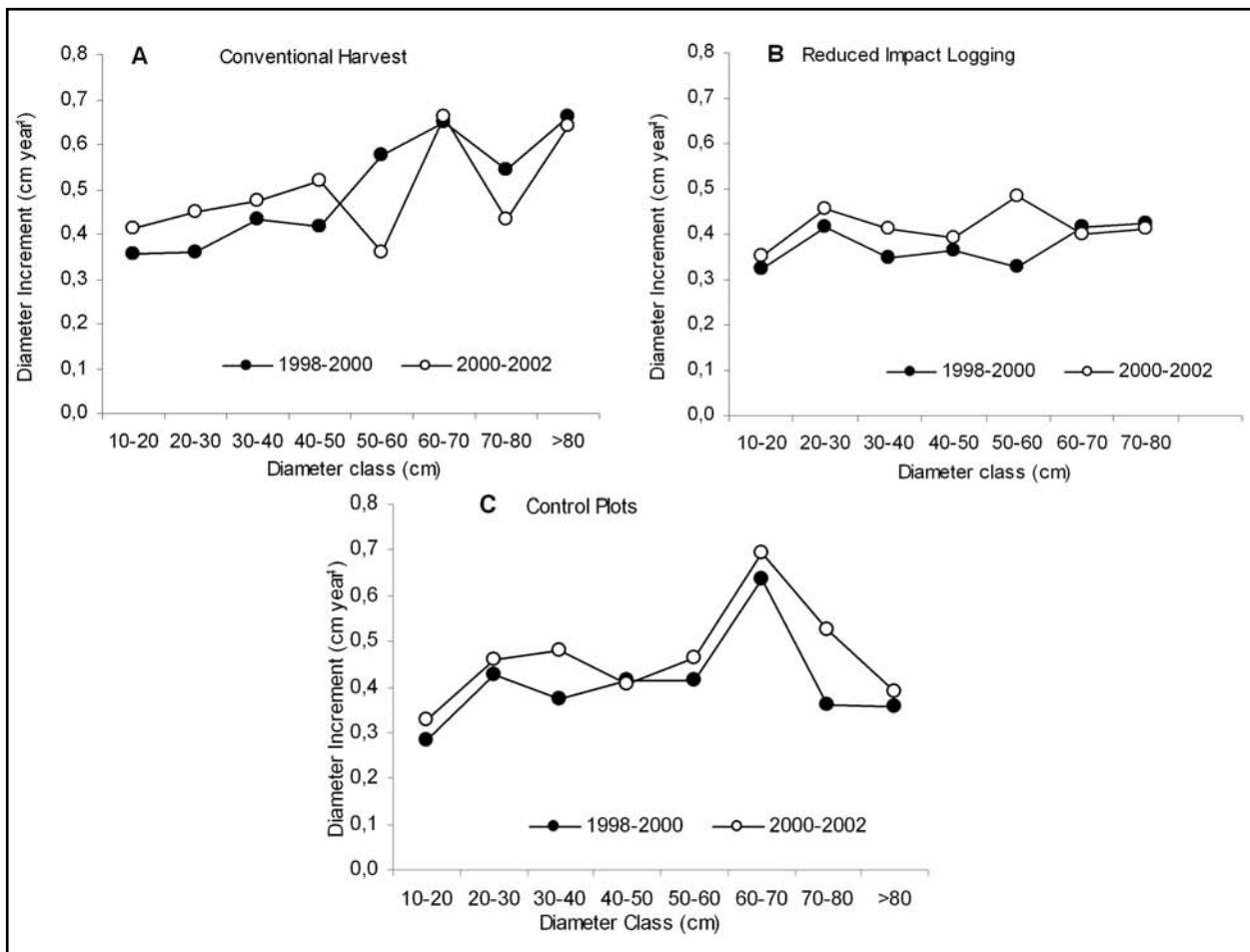
**Table 2.** Commercial species diameter increment (cm year<sup>-1</sup>) for the periods: 1998 to 2000 and 2000 to 2002.

	Period 1998-2000	Period 2000-2002	N
	Mean ± DS	Mean ± DS	
Commercial Harvesting	0.48 ± 0.46 a	0.50 ± 0.46 a	513
Reduce Impact Logging	0.41 ± 0.37 b	0.47 ± 0.42 a	393
Control	0.39 ± 0.39 b	0.47 ± 0.40 a	484

Different letters mean significant differences between treatments in the same period.

**Table 3.** Wilcoxon test for diameter increase for all species and for commercial species (cm year<sup>-1</sup>).

		CH	RIL	Control
All species	1998-2000 (Mean ± DS)	0.40 ± 0.42	0.34 ± 0.35	0.36 ± 0.36
	2000-2002 (Mean ± DS)	0.45 ± 0.42	0.39 ± 0.37	0.41 ± 0.37
	Wilks p-level	0.00	0.00	0.00
	N	963	767	730
Commercial species	1998-2000 (Mean ± DS)	0.48 ± 0.46	0.41 ± 0.37	0.39 ± 0.39
	2000-2002 (Mean ± DS)	0.50 ± 0.46	0.47 ± 0.44	0.47 ± 0.40
	Wilks p-level	0.41	0.16	0.35
	N	513	393	484



**Figure 4.** Average diameter increase (cm year<sup>-1</sup>) by diameter class for the periods: 1998 to 2000 and 2000 to 2002: 4A: Commercial Harvesting; 4B: Reduced Impact Logging; 4C: Control Plots.



In the CH, considering all species, the diameter increase in the two periods considered was larger than the other treatments. This was probably due to a larger canopy opening, which favored remaining trees growth. These results differ from the results found by Silva *et al.* (1995) in Brazil, and Graaf *et al.* (1999) in Suriname, where diameter growth decreased after silvicultural interventions. Those authors suggested that competition for light caused by the closing of the canopy decreased growth. However, conventional forestry wisdom certainly supports our findings of increased diameter growth on residual trees after harvesting or thinning.

In the case of commercial species, the RIL had significantly larger increases in diameter. This may be because the careful RIL planning operations avoided damages to future crop trees, while in the CH more trees were damaged (MAC DONAGH *et al.*, 2003). This reason may explain why statistically significant increases in diameter were not found in the CH in the two periods analyzed.

With CH, the significant correlation between the diameter increase and the size of the tree was similar to that found in other studies, such as Pélissier *et al.* (1998) and Sist and Nguyen-Thé (2002). In RIL and CP plots this tendency was not observed, indicating that the small trees grew at the same rate as the trees of larger diameter. Perhaps this indicates that RIL (and CP) have smaller impacts on the residual stand than CH.

### Floristic composition

The values of species richness in each treatment are presented in the Table 4 before and four years after harvesting. There were no significant differences in the number of species by treatment before and after the harvesting, nor among treatments in 2003 (ANOVA,  $F=0.36$   $p=0.70$   $df = 11$ ).

**Table 4.** Number of species before and three years after harvesting.

Treatment	Species number			
	1998	2003	New	Disappeared
CH	83	86	6	3
RIL	81	80	4	5
CP	79	82	4	1

The data of the 10 dominant species are presented in Table 5, for the three treatments. In all three treatments the dominant species before and after the harvesting was *Nectandra megapotamica*. The ranking of the most prevalent species among the two treatments and the control did differ somewhat in the evaluation at initial state. However, CH had a change in the ordinal ranking of the number of species after harvesting, probably due to the intensive harvesting of *Luhea divaricata*, *Parapiptadenia rigida* and *Apuleia leiocarpa*. In RIL, only occurred an important change of *Parapiptadenia rigida*. In CP, there were no relative changes in the number of species after harvest.

The new species inventoried after harvesting need high levels of light, such as *Solanum* sp., *Trema* sp, *Inga* sp. (GUARIGUATA and OSTERTAG, 2001; SILVA *et al.*, 1995; PARROTTA *et al.*, 2002). Consequently, they generally appear in areas with large clearings (Delgado *et al.*, 1997). The species that disappeared from the stands included individuals such as *Ilex paraguariensis* and *Allophylus edulis*. These results agree with those found by Gauto (1997), Wagner (1997), Delgado *et al.* (1997), Panfil and Gullison (1998) and Pélissier *et al.* (1998). These findings are better for commercial species than those obtained by Kammesheidt *et al.* (1995), who found the virtual disappearance of the most valuable forest species in an exploited Venezuelan forest.

**Table 5.** Dominance values ( $m^2 ha^{-1}$ ) before and four years after harvesting for the three treatments.

Commercial Harvesting			Reduce Impact Logging			Control		
Species	Before	After	Species	Before	After	Species	Before	After
LN	2.34	2.16	LN	3.62	3.48	LN	3.14	3.06
GB	1.66	1.68	RI	2.10	2.13	RI	2.87	2.88
SC	1.25	0.74	MP	1.29	1.22	AC	1.90	2.21
AC	1.07	0.38	AL	1.29	1.32	MP	1.63	1.54
GR	1.05	0.77	M	1.26	1.19	GB	1.17	1.28
AL	1.02	1.05	G	1.05	0.96	GR	0.95	0.96
RI	0.86	0.80	AC	1.03	0.55	IS	0.92	0.94
O	0.82	0.83	IS	0.95	0.85	LY	0.90	0.86
G	0.77	0.59	GB	0.94	0.99	LG	0.90	1.04
LG	0.77	0.26	LY	0.70	0.75	AL	0.89	0.90
Others	11.21	10.46		9.81	9.05		10.35	10.62
Total	22.82	19.74		24.04	22.50		25.64	26.30

AC: *Parapiptadenia rigida*, AL: *Holocallix balansae*, G: *Balforouedron riedelianum*, GB: *Patagonula americana*, GR: *Apuleia leiocarpa*, IS: *Machaerium stipitatum*, LG: *Ocotea puberula*, LN: *Nectandra megapotamica*, LY: *Ocotea diospirifolia*, M: *Ruprechtia laxiflora*, MP: *Diatenopterix sorbifolia*, O: *Phytolaca dioica*, RI: *Lonchocarpus leucantus*, SC: *Luehea divaricata*

## CONCLUSIONS

Reduced Impact Logging in this study in native forests of Misiones, Argentina provided better results than conventional harvesting in terms of promoting retention and regeneration of valuable timber species, caused less damage to the residual stand, and promoted faster growth in the residual stand. Four years after harvesting the diameter increase of the commercial species in the Reduced Impact Logging treatment was similar to the undisturbed control plots. The planned harvest allowed a better and faster recovery of the forest.

Reduced Impact Logging harvests served as a constructive silvicultural treatment, not only stimulating the diameter increase of commercial species of small diameters, but also residual trees that will provide part of the future crop. It also provides income to forest owners to help encourage forest retentions and management. The findings of the positive impacts of RIL on future forest composition and structure in Misiones indicate that it can contribute successfully to sustainable forest management in neotropical forests.

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