Regeneration in felling gaps after logging in Acre State, Western Amazon

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Abstract

Regeneration of tree species in felling gaps were studied during the first two years following harvesting in a tropical forest in Acre state, Brazil. Felling gaps averaged 340 m^2 in size, while canopy openings averaged 17%. Seedling mortality in adjacent undisturbed forest was 4.6% yr^{-1}, and 59.6% yr^{-1} and 100% yr^{-1} in the crown and trunk zones respectively, two years after logging. Recruitment of new seedlings in the undisturbed forest understorey averaged 462 plants $ha^{-1} yr^{-1}$, two years after gap creation. In the crown zones of the gaps, recruitment of seedlings averaged 1350 $ha^{-1} yr^{-1}$, and in the trunk zones 1392 $ha^{-1} yr^{-1}$. The entire seedling community in trunk zones after logging was composed of new recruits. There was a tendency for seedling growth rates to increase from the natural forest (0,21cm yr^{-1}) to the crown zone (0.40cm yr^{-1}). Before gap creation, species richness and diversity and seedling density were quite similar. After gap creation a sharp decrease could be verified in the gap zones, however the differences between gap and undisturbed forest decreased rapidly in the second year after gap creation. The regeneration of commercial species was not affected by gap creation apart from the increase in growth rates.

Key words: *Natural regeneration, forest management, forest exploitation*

Regeneração em clareiras de derruba após exploração no Estado do Acre, Amazônia Oriental

Resumo

A regeneração de espécies arbóreas em clareiras de derruba foi estudada nos primeiros dois anos após a exploração em uma floresta tropical no Estado do Acre, Brasil. As clareiras apresentaram área média de 340 m2, enquanto que, em média, as aberturas no dossel foram de 17%. A mortalidade de plântulas dois anos após a exploração nas áreas adjacentes não perturbadas foi 4,6% ano-1 e 59,6% ano-1 e 100% ano-1 respectivamente nas áreas da copa e do tronco. O recrutamento de novas plântulas no sub-bosque da floresta não perturbada foi em média, 462 plantas ha-1 ano-1, dois anos após a formação da clareira. Nas áreas de copas das clareiras, o recrutamento foi em média de 1.350 plântulas ha-1 ano-1 e nas áreas de troncos, 1.392 plântulas ha-1 ano-1. Todas as comunidades de plântulas nas áreas de troncos foram de novas recrutas.Observou-se uma tendência do crescimento aumentar da floresta natural (0,21 cm ano-1) para a área de copas (0,40 cm ano-1). Antes da formação da clareira a riqueza de espécies, a diversidade e a densidade de plântulas eram bem similares. Após a formação das clareiras, pode ser verificado um forte decréscimo nas áreas de clareiras. Porém as diferenças entre as clareiras e a floresta não perturbada decresceram rapidamente a partir do segundo ano após a formação da clareira. A regeneração de espécies comerciais não foi afetada pela formação das clareiras, a não ser pelo aumento nas taxas de crescimento.

Palavras-chaves: *Regeneração natural, manejo florestal, exploração florestal.*

Introduction

A forest lacking anthropogenic disturbance can be viewed as a spatial mosaic of these structural phases which change over time as a result of dynamic processes (Watt 1947, Richards 1952, Torquebiau 1986, Whitmore 1978, 1989) that are influenced by a variety of biotic and abiotic conditions (Martinez-Ramos *et al.* 1989). Characteristics of gaps have been recognised as an important factor determining the outcome of forest regeneration because of their influence on plant growth and establishment. The driving variables are size, age, micro-habitat conditions of the gap and the composition and size of the seeds and seedlings present (Uhl *et al.* 1988, Brown and Whitmore

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1992, Whitmore and Brown 1996). The gap phase is the most important part of the growth cycle for the determination of future natural regeneration (Brokaw 1985, 1989, Whitmore 1989). Creation of a gap in the canopy acts on patterns already established in the understorey of the forest (Brokaw 1989) and is the starting point for secondary succession.

Forest management for timber production via selective logging creates, in many aspects, disturbances similar to natural tree falls which produce canopy openings that stimulate the growth of advance regeneration (Uhl *et al.* 1988).

This study was carried out in a small farmers forest management project in an area of the Amazon Basin that had been recently settled. The silvicultural system originally designed for small scale sustainable timber production in small farms prescribes the conversion of the logs to planks within the gap created by tree-felling and skidding of the planks by animal traction (Oliveira *et al.* 1998). The proposal is based on the ecological principle that low-impact disturbance at short intervals, combined with silvicultural treatments, will create a gap mosaic of different ages and permit the maintenance of a forest with a similar structure and biodiversity to that of the original natural forest.

The study sought to determine whether this low impact system would have a negative impact on tree regeneration. Relevant changes produced by logging in growth, recruitment and mortality of regenerating seedlings and in species richness and diversity of the seedling community were investigated. Comparisons were established between areas disturbed by silvicultural operations with adjacent undisturbed areas (Hawthorne 1993). Our hypothesis is that the felling gaps can provide conditions for the establishment of the regeneration of canopy species, which have to compete with pioneer species in these gaps, allowing for sustainable timber production.

Methods

Site description

The PC (Colonisation Project) Pedro Peixoto was created in 1977 in Acre state, West Amazon. Originally, the PC covered 408 000 ha (afterwards reduced to 378 395 ha) for the settlement for 3000 families (Cavalcanti 1994). Currently, forest management research is being carried out along two trails off road BR-364 (from Rio Branco to Porto Velho), 80 km and 90 km from Rio Branco. It involves 11 farms 80 ha each; half the extension of each farm is devoted to forest management.

The nearest meteorological station to the area is at CPAF-ACRE (9°58'22" S, 67°48'40" W). The climate is classified as Awi (Köppen) with an annual precipitation of 1890 mm and an average temperature of 25°C. There is a dry season from June to September and a rainy season from October to April. Normally, between June and July, and occasionally in August (exceptionally until October under the El Niño influence) there is a water deficit (data from EMBRAPA 1996a, b). The managed forest has an average of 180 $m^3 ha^{-1}$ (trees >10 cm) and a volume of commercial species around 40 $m^3 ha^{-1}$ (Oliveira *et al.* 1998).

Gap creation and plot establishment

Felling gaps were created in 1997 during the dry season. The study involved the measurement of seedling growth, recruitment, mortality, density and species richness and diversity in gaps and adjacent undisturbed forest. All seedlings of woody species above 1 m height were tagged, identified and measured for diameter at 0.30 m height, prior to gap creation. Plots in gaps were classified according to their position in either the crown or the trunk zone (Orians 1982, Popma *et al.* 1988).

Trees were felled across plots using directional felling. To cover the future gap area, eight 5 m x 5 m plots were established, four in the trunk zone and four in the crown zone. The experiment consisted of seven replicate gaps and five additional transects of eight contiguous 5 x 5 m quadrats distributed at random in the undisturbed forest around the felled trees. Ten gaps were chosen at random in the managed areas; a hemispherical photograph was taken at the centre of each (Whitmore *et al.* 1993) and its area measured in the field following Brokaw's (1982) definition.

Data manipulation and analysis

Mortality rates.- Seedling mortality rates were calculated with the following formula (Sheil *et al.* 1995):

$$m = 1 - (N_1/N_0)^{1/t}$$

Where: N_0 and N_1 are population densities at the beginning and end of the measurement interval, t

Recruitment rates.- We considered the recruitment of all seedlings in the quadrats with a minimum measurement height of 1 m. Recruitment rate was standardised by dividing the total number of recruits in one census by the number of adults in the previous census, and dividing by the census interval (Condit *et al.* 1996).

Growth rates were calculated by the formula:

$$(dbh_2 - dbh_1) / time$$

Where: dbh_1 - Diameter of the tree in a previous census
dbh_2 - Diameter of the tree in a subsequent census
$time$ – Interval in years between the census

The effect of gap position (trunk zone or gap zone) was compared with the control plots by analysis of variance (one way anova). The differences in growth, mortality and recruitment between crown and trunk zones were analysed using paired T-tests. If there was evidence that the residuals were not normally distributed the data were transformed using a square root transformation.

Species richness and diversity.- Species richness of the seedling community was defined as the total number of species in the plot (Kent and Coker 1992) and diversity was calculated using Fisher's α. This index was chosen because it is relatively insensitive to differences in sample size and is suitable for extrapolation (i.e. the index can be used to predict the number of species in larger samples than those used to derive it) (Condit *et al.* 1996, 1998). Differences between growth rates were tested statistically with the analysis of variance. Statistical differences in relative density, mortality rates and recruitment rate were tested by the χ^2 test.

Results

As shown in Table 1, the felling gaps varied in size from 190 to 640 m^2 (340 m^2 average); canopy opening varied from 11 to 23% (17% average).

Seedling mortality

Seedling mortality in the forest understorey averaged 4.6% yr^{-1} over two years and was significantly lower than in both gap zones. In the crown zones of gaps created by felling trees, seedling mortality after logging was 596 % and 100% in the trunk zones. From the first to the second year after logging there were no differences in seedling mortality rates between forest understorey and gaps (Table 2).

Table 1. Gap area and canopy opening for ten gaps in the managed forest of PC Peixoto

Gap	Area (m^2)	Canopy opening (%)
1	345.5	20.6
2	335.5	22.2
3	641	22.6
4	546.3	20.6
5	173.5	16.3
6	240.5	10.7
7	190.5	10.8
8	315.5	12.2
9	329.0	22.4
10	280.2	15.7
Average	339.7	17.4

Table 2. Mortality of seedlings in the felling gaps (trunk and crown zones) and in the undisturbed forest understorey one year after logging, from the first to the second year after logging and during the first two years after logging

	N	Annual mortality rate (%) 1997-1998*	Standard error	t-value	p-value
Understorey	5	5.41	2.28		
Crown zone	7	59.61	13.04	19.27	0.001
Trunk zone	7	100.00	0.00		
		Annual mortality rate (%) 1998-1999*	**Standard error**	**t-value**	**p-value**
Understorey	5	2.86	7.53		
Crown zone	7	11.59	4.36	0.01	0.942
Understorey	5	2.86	7.53		
Trunk zone	7	3.34	9.31	3.65	0.085
Trunk zone	7	3.34	9.31		
Crown zone	7	11.59	4.36	1.81	0.121
		Annual mortality rate (%)* 19971999*	**Standard error**	**t-value**	**p-value**
Understorey	5	4.62	1.48		
Crown zone	7	44.31	1.72	26.54	< 0.001
Trunk zone	7	100.00	0.00		

* means tested by one-way anova
** means tested by paired t-test

Recruitment

The mean recruitment rate in the forest understorey was 462 recruits ha^{-1} yr^{-1}. In the crown zones of the felling gaps the mean recruitment was 1392 recruits ha^{-1} yr^{-1} compared to 1350 plants ha^{-1} yr^{-1} in the trunk zones. The differences in recruitment between the crown zones and the forest understorey were significant (anova one way $p < 0.05$) but differences between the trunk zones and forest understorey were not (Table 3). The seedling community in the trunk zones after logging was entirely composed of recruits.

Table 3. Recruitment of seedlings >1 m height in plots in managed forest over two years, in undisturbed forest understorey and the trunk and crown zones of the felling gaps (number of plants ha^{-1}) two years after logging

	N	Recruits yr^{-1} (plants ha^{-1})*	Standard error	t-value	p-value
Understorey	5	462	118		
Trunk zone	7	1392	238	9.45	0.012
Understorey	5	462	118		
Crown zone	7	1350	211	10.67	0.008
Trunk zone	7	1392	238		
Crown zone	7	1350	211	0.11	0.919

* means tested by anova one way
** means tested by paired t-test

Seedling growth

Between the first and second year after logging, seedling growth rates were greater in the crown zone (0.40 cm yr^{-1}) than in the forest understorey (0.21 cm yr^{-1}) (one way anova, $p < 0.05$), but did not differ significantly between the trunk zone (0.29 cm yr^{-1}) and forest understorey. Seedling growth rates were also significantly higher in the crown zone than in the trunk zone (paired t-test, $p < 0.05$) (Table 4).

Table 4. Annual diameter increment in trunk and crown zones of the gaps and in forest understorey two years after gap creation

	N	Mean diameter increment* (cm yr^{-1})	Standard error	t-value	p-value
Understorey	5	0.21	0.01		
Trunk zone	7	0.29	0.05	1.18	0.300
Understorey	5	0.21	0.01		
Crown zone	7	0.40	0.03	17.17	0.002
Trunk zone	7	0.29	0.05		
Crown zone	7	0.40	0.03	1.84	0.116

* means tested by one-way anova

Species richness and diversity and seedling density

Before gap creation, the species richness and diversity and seedling density in the plots were quite similar. After gap creation, a sharp decrease in these variables was observed in the gap zones. However, differences between gap and undisturbed forest tended to decrease quickly from the first to the second year after gap creation. After harvesting, seedling density in gaps fell drastically especially in the trunk zone where logs were moved around, crashing and killing all seedlings in this zone (Figure 1). The percentage of pioneer species in the seedling community before harvesting was between 1 and 2 % of all individuals. One year after harvesting pioneer species had increased to 30% in the crown zone and 45% in the trunk zone. In the second year, there was a tendency for the two gap zones to have a similar proportion of pioneer species. As expected, there was a strong variation in the local densities of seedlings generated by logging, resulting from the mortality of a large number of seedlings (Figure 1).

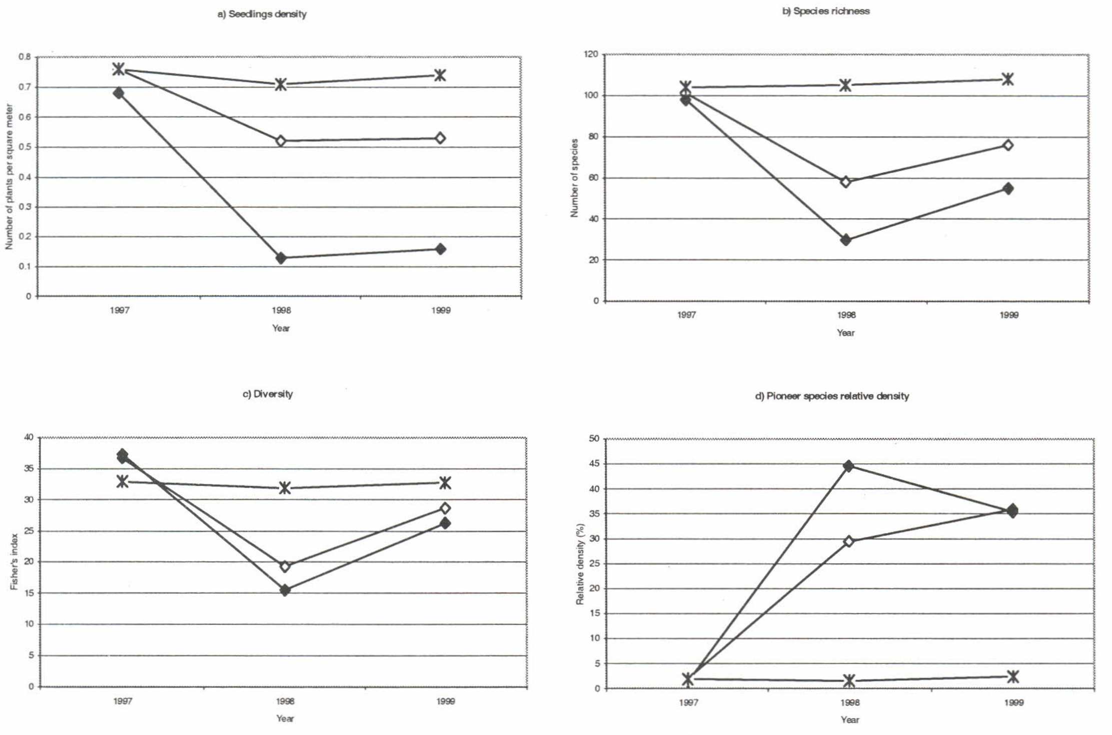

Figure 1: Seedling density (a), species richness (b), Fisher's α diversity index (c) and pioneer species relative density (d) in the undisturbed forest understorey (stars), crown zone (open diamonds) and trunk zone (closed diamonds)

Commercial species regeneration

The relative density of seedlings of commercial species varied from 3.5% in the natural forest understorey and trunk zone to 5.7 % of total seedling population, showing no significant differences among them two years after logging. Recruitment of seedlings of commercial species did not differ neither between undisturbed forest understorey nor in the gap zones two years after logging. Growth rates were significantly higher in the crown zones (0.9 cm yr^{-1}); trunk zone and undisturbed forest understorey did not differ significantly (Table 5).

Table 5. Density, recruitment, and growth and mortality of commercial species in the felling gaps and undisturbed forest understorey two years after gap creation

Density	N	Number of plants ha^{-1}	Standard error
Understorey	5	209	47
Trunk zone	7	114	49
Crown zone	7	135	30
Recruitment		Number of plants ha^{-1}	Standard error
Understorey	5	44	9
Trunk zone	7	136	36
Crown zone	7	114	30
Growth rate		Mean diameter increment (cm yr^{-1})	Standard error
Understorey	5	0.35	0.11
Trunk zone	5	0.35	0.14
Crown zone	7	0.85	0.22
Mortality		Annual mortality rate (%)	Standard error
Understorey	5	2.36	2.36
Trunk zone	7	100.00	0.00
Crown zone	7	61.10	8.91

Discussion

The gaps produced by the logging in PC Peixoto can be classified as small size gaps (openings around 10-15% and 200-300 m^2 in area) and less frequently medium size gaps (openings greater than 20% but not greater than 25% and maximum measured area of 640 m^2). Gap size depend on the felled tree dimensions and the structure of the surrounding forest. Small gaps are opened by the crown, while larger ones usually form the classical "chablis" (Oldeman 1978) shaped gap (formed by the area of the former crown of the felled tree and the crown zone after felling). Thus, the felling of a tree sometimes produce disturbed areas in places other than the site where the crown fell. These areas may or may not have increased canopy opening. Therefore, they may or may not be considered as part of the gap (Brokaw 1982, Popma *et al.* 1988). For felled trees, these areas are usually around the trunk, because felling does not result in uprooting. As a result, this zone was sometimes disturbed, but did not receive a different amount of irradiance from the natural forest. In this study, the trunk zone was used to convert the logs to planks that were later removed from the gap area, causing some soil compaction and leaving a large amount of wood residue covering the soil.

The composition, richness and diversity of species in the seedling community before logging were similar, with values of Fisher's α between 32 and 37. The crown's branches possibly acted as a barrier to seed germination and establishment of seedlings, thereby limiting recruitment. A similar effect was reported by Putz (1983) who showed that seedlings of pioneer species were concentrated in the root zone (*sensu*, Orians 1982) of gaps in a semi-evergreen forest in Panama, because the root zones are clear of roots and free from litter and overhead shade. These factors assist the germination and establishment of pioneer species. In crown zones, 40% of the original seedlings survived logging, increasing competition in these areas. These seedlings negatively affected growth rates because most of them were damaged or remained suppressed under the branches and did not grow during the study period. Seedling mortality in the crown zones decreased significantly from the first to the second year after logging, becoming non-significantly different from that in the undisturbed forest understorey. It is possible that higher survival were related to the prior establishment of seedlings and saplings which were protected by the branches of felled trees.

In the trunk zone, the felling of the tree, conversion of logs into planks and skidding of planks killed almost all the original seedlings. In addition, the residues of logging (e.g. sawdust) probably interfered with seed germination and reduced the rate of recruitment. Seedling low mean growth rate in this zone is possibly associated with the low exposure to irradiance (in some cases, no exposure at all). A high proportion of pioneer species colonised these areas in the first year, probably because of lack of competition from other plants and the availability of seeds in the seed bank.

Conclusions

High seedling mortality in gap zones, especially in the trunk zone, was expected because of the logging operations. However, recruitment was high in the gap zones two years after logging, promoting a rapid recovery in the species richness and diversity. Diversity will continue to increase in the gap zones, and soon will become higher than the forest understorey confirming the expectation of a higher species diversity in the gaps.

Although higher than in forest understorey locations, relatively low seedling growth rate in gap zones might be associated with low canopy opening (trunk zone) and shade from felled branches (sunlight obstruction) in the crown zone. The regeneration of commercial species was not affected by canopy opening apart from the increase in growth rates. The logging operations produced a relatively low impact in the seedling community regeneration.

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