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Pre-logging liana cutting reduces liana regeneration in logging gaps in a forest of the eastern Brazilian Amazon

Running title: Liana regeneration in a logged forest

Key Words: Brazil, gap, liana, natural forest management, regeneration

Jeffrey J. Gerwing[a,b,†] and Christopher Uhl[a,c,‡]

[a] Interdepartmental Program in Ecology, Pennsylvania State University, University Park, PA 16802.
[b] Instituto do Homem e Meio Ambiente da Amazônia (IMAZON) Caixa Postal 1015, Belém, Pará, 66.017-000, Brazil.
[c] Department of Biology, Pennsylvania State University, University Park, PA 16802

[†]Address for correspondence: 208 Mueller Lab, University Park, PA 16802, USA; phone: (814) 863-5895; email: jjg156@psu.edu.

‡ Address for correspondence: 208 Mueller Lab, University Park, PA 16802, USA; phone: (814) 863-5895; email: cfu1@psu.edu.

ABSTRACT

The cutting of all lianas prior to logging is a "reduced-impact" logging technique that is predicted to reduce liana proliferation in logging gaps. This study compares liana abundance and species composition in gaps created during conventional and reduced-impact logging in a forest of the eastern Brazilian Amazon. Logging treatments were conducted in side-by- side plots. Shortly following logging, 50 m^2 plots were located in the approximate centers of four single treefall and four multiple treefall-gaps in each logging area. Six years following logging, there were ca. 40% fewer climbing lianas in reduced-impact gaps than in conventional logging gaps. In both logging areas multiple-tree gaps had higher liana densities and a higher proportion of lianas recruiting from seed than single tree gaps where sprouts from cut or fallen lianas were more common. The mean number of liana species encountered per plot varied little among treatments, however, increased species evenness in the reduced-impact logging gaps resulted in them having significantly higher diversity (Fisher's α). The results of this study suggest that pre-logging liana cutting can significantly reduce post-logging liana proliferation in gaps with no discernible negative impact on the species diversity of regenerating lianas.

Keywords: Brazilian Amazon, liana, tropical forest management, gap, regeneration

INTRODUCTION

The management of tropical forests for timber production is often complicated by the presence of lianas. For example, in a forest in the eastern Brazilian Amazon lianas were found to connect each tree of harvestable size to an average of 3 – 9 other large trees (Vidal et al. 1997). Thus, for each tree felled during logging several neighboring trees, that would not have otherwise been impacted by the treefall, are pulled down or broken off. In addition, lianas may proliferate in logged forests (e.g., Dawkins 1961, Niel 1984, Appanah and Putz 1984) and abundant lianas in gaps retard tree growth (Putz 1984a). In some cases, dense lianas may impede tree growth to the extent that gap succession remains stalled in a low-stature state (Schnitzer et al. 2000). Pre-logging liana cutting has been found to mitigate some of these negative effects. For example, liana cutting has been found to reduce felling damage to the residual stand by ca. 50% (Fox 1968, Appanah and Putz 1984). Yet we know little about its impacts on post-logging liana proliferation. With this study we sought to assess the impacts of pre-logging liana cutting on gap-phase regeneration of lianas in a logged forest of the eastern Brazilian Amazon.

Because of their abundance in treefall gaps and other disturbed areas such as abandoned pastures (Uhl et al., 1988), and their rapid growth rates in high light conditions (Baars and Kelly 1996), lianas are generally thought to be light demanding. Because light availability increases with increasing gap size, one might expect a positive relationship between gap size and liana density (e.g., Babweteera et al., 2000). In a logged forest, the larger gaps, formed by the removal of several trees from the same area, might be those predicted to have the most vigorous liana proliferation.

In addition to gap size, liana abundance is likely to be influenced by both the number lianas present shortly following gap formation. Climbing lianas have been found to recruit from a variety of sources. Prior to climbing, many, but not all, species are present as free-standing stems in the forest understory where they commonly make up ca. 25% of the upright woody plants < 2 m tall (Putz 1983, Putz 1984a, Gerwing and Farias 2000). In addition to advanced regeneration lianas recruit into gaps via seed, sprouts from severed stumps or roots, and sprouts from sections of fallen stems that have produced adventitious roots (i.e., layering) (Hegarty 1989). It is the latter of these that is the likely source of many of the liana tangles found in gaps in logged forests. Because many species of lianas have anatomical adaptations that allow them to suffer stem bending and twisting without breaking, they are often able to survive serious disturbance (Fisher and Ewers 1991). For example, one study found only 10% mortality among liana stems whose host trees had fallen (Putz 1984a). Many of these fallen stems are capable of rooting and producing shoots that account for a large proportion of the climbing lianas found in logging gaps (Appanah and Putz 1984).

Pre-logging liana cutting is part of a suite of reduced-impact logging (RIL) techniques designed to minimize logging damage to the residual forest stand. In addition to liana cutting, some of the components of RIL are forest inventorying and mapping, directional felling, and careful log extraction (Barreto et al., 1998). There are several reasons to predict that RIL would result in less liana proliferation than conventional logging. First, liana cutting largely eliminates layering fallen liana stems as a source of regenerating stems. Second, cutting of mature lianas is likely to greatly reduce the quantity of liana seed arriving in newly formed gaps. Finally, average gap sizes are significantly lower following RIL (Johns et al., 1996). Here, we test the prediction of reduced liana proliferation following RIL by comparing liana

abundance and species composition in single- and multiple tree gaps created during conventional and reduced-impact logging in a forest of the eastern Brazilian Amazon. We also compare liana density in gaps to that of adjacent undisturbed forest predicting that lianas will be significantly more common in gaps. Finally, we test for a positive relationship between liana abundance and gap size in each of the logging areas.

STUDY SITE

This study was established in a 210 ha patch of old-growth forest 30 km southeast of the town of Paragominas, Pará, Brazil (3°S. 50°W.). The forests of the region are evergreen and receive 1700 mm of rainfall annually occurring mainly from December through May; during the remainder of the year mean monthly rainfall is about 40 mm. Forest stands at the study site are a mosaic of patches that differ in stature, biomass, and liana abundance (Gerwing and Farias 2000). High stature forest patches contain trees 25-40 m tall and infrequent lianas. Medium stature forest canopy height ranges from 15 – 25 m and the density of climbing lianas is ca. 2500 ha^{-1}. In low stature patches canopy height is $\leq$ 15 m and liana density is ca. 5500 ha^{-1}. Prior to logging, a 130 ha tract of intact forest at the study site consisted of 18% high stature, 46% medium stature, 28% low stature forest and 8% natural treefall gaps resulting in a mean total aboveground live biomass of 314 t ha^{-1} (Gerwing and Farias 2000). The soils of the region are clay-rich, oxisols and ultisols.

METHODS

Logging treatments

The logging treatments included unplanned logging, the industry standard for the region, and RIL in adjacent plots of 80 and 105 ha, respectively. All climbing lianas were cut in the RIL area during March 1991 and the entire study site was logged during October and November 1993. Conventional logging resulted in 20 - 40% reductions in forest canopy cover and density of trees > 10 cm diameter (Johns et al., 1996). In addition, for every tree extracted, nearly 500 m^2 of the forest floor was disturbed and 51 trees > 10 cm in diameter were damaged. Compared to conventional logging, the use of RIL resulted in 10% less forest canopy cover loss, a nearly 50% reduction in mean gap size, and a 40% reduction in damage to trees in the residual stand (Johns et al., 1996).

Liana sampling

To quantify liana regeneration in logging gaps, we installed 5 x 10 m plots in the centers of logging gaps in the RIL and conventional logging areas eight months following logging. In each logging area four single tree gaps, and four multiple tree gaps (i.e., gaps formed when 3 or more trees were felled in the same area) were randomly selected from the total population of logging gaps for a total of 16 study gaps. In each plot, all lianas ≥ 5 cm tall that were rooted in the plot were measured, identified, classified according to their mode of recruitment (i.e., newly-recruited seedling, layered sprout, root/stump sprout, or advanced regeneration), and marked with numbered aluminum tags. The diameter of each climbing stem was measured at 1.3 m above the ground or below the first branch whichever came first. Because we were interested in quantifying the abundance of potentially independent liana

stems in the plots, each liana with its own root system was counted. Thus individual genets were sometimes sampled more than once. Lianas were identified to species by Nelson Rosa of the Museu Emilio Goeldi, Belém, Pará, Brazil, a field botanist with 20 years experience working in the region. The total area of each gap was estimated by measuring the distance from the approximate center of the gap to its edge along eight compass bearings, joining the end points of these radii on a map, and summing the areas of the triangular pieces.

Plots were resurveyed six years after logging. In some cases minor excavation was required to determine the mode of recruitment for stems that had established between surveys. At this time, we also sampled a plot under undisturbed forest canopy that was paired with each of the gap plots. Forest plots were located 10 m from the edge of the gap in a randomly chosen compass bearing from the approximate gap center with the restriction that potential plot locations that fell within 10 m of a neighboring gap were rejected and selection process was repeated.

Several months after the second gap plot survey, we assessed liana cover in 35 additional randomly selected gaps in each of the logging treatment areas. Both single and multiple tree gaps were included in this sample. The purpose of this expanded sample was to assess the degree of liana infestation of gaps at the stand level and to quantify the relationship between gap size and liana cover in each of the logged areas. To assess liana cover, we first divided each gap into four roughly equal sections by bisecting it with two perpendicular lines that passed through the approximate center of the gap. Within each of the resulting quarters, we randomly selected a compass bearing to establish a sampling transect from the center of the gap to its edge. Along each of these transects, we tallied liana cover at 1-m intervals using a dichotomous rating considering a point to be liana covered if more half of the leaf area at the

Horn indices, we first summed the data from each of the four replicate plots for each combination of logging treatment and gap type into a master list for that treatment combination. We then calculated the indices for the six possible pair-wise comparisons among the four master lists.

RESULTS

Liana stem density and mode of recruitment

Six years following logging, the density of climbing lianas differed significantly between logging treatments (Table 1). Single and multiple tree RIL gaps had 52 and 32%, respectively, fewer stems than their conventionally logged counterparts (Fig. 1). Gap type also had a significant effect on the density of climbing lianas (Table 1). In both logging treatments multiple tree gaps had more climbing stems than single tree gaps (Fig. 1). Free-standing lianas $\geq$ 10 cm tall had lower stem densities in RIL gaps (45% lower for multiple tree gaps and 27% for single tree gaps) but given the relatively small sample size, these differences were not statistically significant ($P = 0.061$; Table 1). The density of free-standing lianas was nearly equal between gap types within each of the logging treatments (Fig. 1).

There were also differences among logging treatments and gap types in the source of the regenerating lianas (Fig. 1). Liana establishment from seed was common in multiple tree gaps were seedlings accounted for 56% of the total stems in the conventional logging area and 31% in the RIL area. This contrasts with the low representation of seedlings in single tree gaps; only 11% of the total stems in the RIL area and 21% of those in the conventional logging area were seedlings. Vegetative propagation, including root/stump sprouting and the layering of fallen stems, was most important in single tree gaps in conventional logging where it

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accounted for 78% of climbing stems. In all treatment combinations, stems originating as sprouts from layered stems were conspicuously absent among the free-standing stems (Fig. 1). A possible explanation for this was that these sprouts seemed to either attain climbing status over the course of the study or die; few remained free-standing (J. Gerwing, personal observation). Stems present as advance regeneration prior to gap formation were present in all combinations of gap type and logging treatment but never accounted for more than 30% of the total climbing stems.

In both logging areas there were significantly higher densities of climbing lianas in gaps than in adjacent patches of undisturbed forest (Table 2). In the conventional logging area there were 3 – 4 times as many climbing lianas in gaps plots as in adjacent forest plots. Liana basal area in the gaps, however, was approximately half that of undisturbed forest. In the RIL area, where all lianas had been cut prior to logging, mean liana density in gaps was 7 – 8 times that found in adjacent forest plots. Liana basal area was also significantly higher in multiple tree gaps than in undisturbed forest but there was no difference between forest and single tree gaps.

Liana species diversity

In total, 75 species of lianas were recorded in the 16 gap plots. Six additional morphospecies, identified only to family or genus, and one unidentified liana were also recorded. Eight species were represented in all of the treatment combinations. In contrast, 19 species were represented by single individuals in the total sample. The ten most common species accounted for ca. 50 to 70% of the total liana stems in each of the combinations of gap type and logging treatment (Table 3). Four species Bauhinia guianensis, Adenocalyma prancei, Memora schomburgkii, and Croton ascendens were among the ten most common in each of

the treatment combinations. The first three of these species, in addition to recruiting from seed, were common as free-standing advance regeneration in the understory of undisturbed patches of forest. However, C. ascendens, and four other species that were common in multiple tree gaps (namely, Gounia pyrifolia, Tournefortia laevigata, Davilla kunthii, and Passiflora glandulosa), recruited exclusively from seed. Three other species (Salacia megistophylla, Combretum laxum, and Arrabidea trailii) were encountered only as shoots from layered fallen stems and were among the most common in the single treefall gaps in the conventional logging area.

Liana species diversity in gaps was higher following RIL than following conventional logging (Table 4). Although the mean number of species encountered per plot varied little among treatments (range 18 – 21), increased evenness in species representation in the RIL gaps resulted in them having significantly higher values for Fisher's α ($F = 4.90$, $DF = 1,16$, $P = 0.042$). There was also a trend of lower species diversity in multiple tree gaps than in single tree (Table 5) but this difference was not significant ($F = 2.59$, $DF = 1,16$, $P = 0.127$).

Interestingly, the values of the Morisita – Horn index of species similarity, which ranges from 0 (when there are no species in common) to 1 (when all species shared in equal relative proportions) were highest for treatment combinations that had gap type in common and not for those in the same logging treatment (Table 5). The two highest values were for the pairs that included the multiple tree gaps (0.91) and the single tree gaps (0.65) in both areas. The values for all other pairs of treatment combinations ranged from 0.47 to 0.57.

Liana cover and gap size

The mean area of the 35 gaps sampled in each logging treatment was significantly greater ($t = 4.06$, $df = 51$, $P < 0.0001$) in the conventional logging operation (319 $m^2 \pm 179$) than in the RIL area (180 $m^2 \pm 93$). The conventional logging gaps also had a mean canopy cover by lianas that was almost twice that of RIL gaps (53% ± 25 vs. 28% ± 18; $t = 4.81$, $df = 62$, $P \leq 0.0001$). There were 20 (57% of the total gaps) with > 50% liana cover in the conventional logging and three (9% of the total gaps) in the RIL.

There was a significant quadratic relationship between gap size and liana cover in the RIL area and a nearly significant relationship ($P = 0.053$), in the conventional logging area (Fig. 2). In both areas liana cover increased with increasing gap size to maximum values in gaps that were 200 – 300 m^2. In larger gaps (i.e., > 400 m^2) the slopes of the relationships became flat.

DISCUSSION

Differences in liana community structure between logging treatments

As hypothesized, pre-logging liana cutting combined with other techniques that reduced logging damage significantly reduced liana proliferation in logging gaps in the study forest. This effect was largely the result of a sharp reduction of layering fallen lianas as a source of regenerating stems. A previous study in Malaysia found that 53% of the climbing lianas in six-year-old logging gaps originated as sprouts of fallen lianas (Appanah and Putz 1984). In the current study such stems accounted for 55% of the climbing stems in single tree gaps in the conventional area compared to only 9% in the RIL area. Of this 9%, nearly all of the stems were Dolicarpus gracilis, one of the ten most common species encountered in single

tree gaps the in RIL area (Table 3). In the study forest, D. gracilis is a common, thin-stemmed liana (maximum diameter ca. 2 cm, but commonly much thinner) that was frequently left uncut by liana cutting crews (J. Gerwing, personal observation).

In multiple tree gaps the difference between the two treatments was largely the result of reduced liana seedling establishment following RIL. Total seedling density (including climbing and free-standing stems) in multiple tree gaps following conventional logging was 1 m^{-2} compared to 0.3 m^{-2} in the RIL area. The importance of liana establishment from seed has not been previously quantified for gaps in topical forest where studies have typically not distinguished among different regeneration modes of establishing lianas.

The establishment of seedlings in the conventional logging area was facilitated by the high levels of soil disturbance found in the multiple tree gaps particularly in the conventional logging area (Johns et al., 1996). The lower level of seedling establishment in the RIL area may explained as resulting from a sharp reduction in the density of mature climbing lianas capable of producing seed. Perhaps more surprising than the reduced seedling density was the finding that establishing seedlings were relatively common in RIL gaps. We were unable determine the origins of these seeds, however, there are several possible sources. One likely source was the soil seed bank where liana seeds are often present, albeit at low densities (Dalling and Denslow 1998). In addition, even though an attempt was made to cut all climbing lianas, approximately 180 stems ha^{-1}, 7% of the total climbing lianas, were missed by the cutting crews that could have served as seed sources (Gerwing and Vidal, in press).

Changes in liana cover with increasing gap size

The results of this study provide some support for the hypothesis that liana cover increases with increasing gap size but the observed relationship was not one of simple linear increase. Among small to medium-sized gaps in both logging areas, there was a positive relationship between liana and gap size. However, the highest values of liana cover (i.e., > 70%) were not found in the largest gaps (i.e., those >400 m^2) that had consistently between 40 to 60% liana cover.

One explanation for the plateau of liana cover among the largest gaps may be related to the relatively high abundance of trees of pioneer species (e.g., Cecropia sp., Vismia sp., Trema micrantha) in these gaps (J. Gerwing, personal observation). Where pioneer trees are abundant liana growth may be suppressed by rapidly-developed tree canopy cover and because these species are ill-suited as liana hosts owing to their large leaves, flexible stems, rapid growth, and, in the case or Cecropia, monopodial growth form (Putz 1984b). A study in Suriname found that the contribution of liana leaves to total leaf biomass dropped from a forest-wide average of ca. 7% to only 3% in patches dominated by Cecropia sp. (Beekman 1981). Two studies of gap regeneration in logged forests in Uganda also provide indirect support for the possible effects of pioneer trees on limiting liana proliferation.

Another explanation for the lack of further increase in liana cover among the largest gaps may lie in the differences in the sources of regenerating lianas among different sizes of gaps and the relatively short time that had passed since gaps formation. Of the 16 gaps that were closely studied, the multiple tree gaps had the highest proportions of lianas establishing from seed and these stems were, on average, smaller diameter than the sprouts from stumps

and fallen liana stems that were more common in the smaller gaps. Indeed although mean liana stem density was significantly higher in the multiple tree gaps than in smaller single tree gaps, there was little or no difference in mean liana basal between gap types (Table 2). Because of the log-log relationship between liana stem basal area and total leaf area (Gerwing and Farias 2000), a given total basal area in a few thick-stemmed lianas will support more leaf area than an equal amount basal spread among many thin stems. Thus, small to medium-sized gaps with relatively few large diameter lianas originating as coppice sprouts could have had larger portions of their canopy surfaces dominated by lianas than larger gaps were many of the lianas were thin-stemmed having originated as seedlings. Ultimately, if most of the newly recruited lianas survive and grow to larger diameters, the forests regenerating from large gaps, because of their higher liana stem densities, are likely to have higher overall liana abundance, in terms of biomass and leaf area, than smaller gaps.

Implications for the management of Amazonian forests

The results of this study suggest that with respect to of liana regeneration, six-year-old logging gaps at the study site could be grouped into three broad classes. The first class included large gaps (> 400 m^2) where newly recruited seedlings and sprouts from roots and stumps were the major source of regenerating lianas. Liana cover ranged from 40 - 60% and liana proliferation was likely limited by competition from pioneer trees. This situation contrasts with a study of logging gaps in a forest in Uganda where liana cover increased steadily with gap size to a consistent 100% in the largest gaps (Babweteera et al. 2000). Part of the explanation for the higher levels of liana proliferation in large gaps in the Ugandan study compared to the forest we studied might be that the guild of aggressive, fast-growing, large-

leafed pioneer tree species, that is commonly found in neotropical forests, was largely absent from the Ugandan forest (Chapman et al. 1999). The second class of logging gaps were mostly medium-sized (200 - 400 m^2) and are distinguished by having liana cover 60% or more where sprouts from lianas that fell in the canopies of felled trees was the principal source of regenerating lianas. The third class of logging gaps consisted of small to medium-sized gaps (100 - 400 m^2) where sprouts, advanced regeneration, and seedlings each contributed to the pool of regenerating lianas. In these gaps liana cover ranged from < 10 to 50% and within this class, there was an apparent positive relationship between liana cover and gap size.

One of the primary differences between the two logging treatments with respect to liana regeneration was the difference in the relative proportion of the three classes of gaps. For example, among the 35 gaps sampled in the conventional logging area, 11 (31%) were of the first class (i.e., large gaps dominated by pioneer trees) whereas there were only 2 (6%) such gaps in the sample from the reduced-impacts logging area. In addition, 11 (31%) of the gaps sampled in the conventional logging area and only 2 (6%) of the those in the reduced impact area belonged to the second class (i.e, medium-sized and dominated by lianas). From a silvicultural perspective, this is an important difference because high levels of liana cover are likely to impede the regeneration and growth of timber species in logging gaps (Fox 1976, Buschbacher 1990, Fedricksen & Mostacedo 2000). Furthermore, it is likely that many liana-dominated gaps will remain in a low stature condition for several decades (Schnitzer et al., 2000), making them unproductive for the foreseeable future.

When considering how the results of this study might be extrapolated to other regions, it is important to note that liana stem density and aboveground liana biomass at the study site are relatively high (Gerwing and Farias 2000) compared to other sites that have been studied in

the Amazon basin (e.g., Klinge and Rodriguez 1974, Laurence et al. 2001). Given the importance of pre-logging liana abundance in determining post-logging liana proliferation, in forests where liana density is lower, the proportion of liana-dominated gaps that develop following logging is likely to be less than what we have reported here. Nevertheless, give the patchy nature of liana occurrence within many tropical forests (Hegarty and Caballé 1991), some liana-dominated gaps are likely to result even in regions where mean liana densities are relatively low.

The current study provides evidence that pre-logging liana cutting can reduce post logging liana proliferation but liana cutting did not prevent liana-dominated gaps from developing in the logged forest. In the RIL area 6% of the gaps were found to have >60% liana cover largely resulting from the proliferation of coppices of cut lianas. Coppicing rates are likely to be influenced by several factors including the amount of time between liana cutting and logging. In the current study the amount of successful coppicing may have been kept in check because lianas were cut a full 2 years prior to logging. Thus, many cut lianas coppiced initially but the sprouts died without ever reaching the canopy presumably for lack of light (J. Gerwing, personal observation). In response to high liana coppicing rates, several studies have employed selective herbicide application to the stumps of cut lianas and found that coppicing was greatly reduced (Appanah and Putz 1984, Fredericksen 2000). Understanding the impacts of cutting lianas in different seasons and with differing amounts of lead time before logging on post-logging liana regeneration and on need for herbicide use are subjects that merit further study.

The silvicultural benefits of liana cutting carry with them potential costs to the conservation value of the managed forest. Although the results of the current study suggest

that the diversity of liana species that regenerated in logging gaps was not negatively affected by liana cutting, eight years following liana cutting and logging there were 14% fewer species of lianas represented by climbing individuals > 1 cm diameter in the study forest (J. Gerwing and E. Vidal, in press). Furthermore, liana basal area at the stand level remained at < 20% of the pre-logging value. Such sharp reductions in liana abundance could negatively impact animal species that use them for food and inter-crown walkways (Gentry 1991, Peres 1993). In the study forest an attempt was made to cut all climbing lianas prior to logging. Future studies could focus on liana cutting protocols that seek to balance the silvicultural goals of minimizing logging damage and post-logging liana proliferation with the conservation goal of preserving the beneficial roles that lianas are likely to play in the forest ecosystem.

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Table 1. Results of ANOVA for the density of free-standing and climbing lianas in six-year-old logging gaps created during conventional and reduced-impact logging near Paragominas, Pará, Brazil. Treatment compares the two types of logging. Gap type compares single and multiple tree gaps.

Source of variation	Df	MS	F	P
Free-standing stems				
Treatment	1	0.154	4.28	0.061
Gap type	1	0.000	0.00	0.990
Treatment * Type	1	0.015	0.42	0.530
Error	12	0.036		
Climbing stems				
Treatment	1	0.815	12.81	0.004
Gap type	1	0.363	5.71	0.034
Treatment * Type	1	0.014	0.22	0.650
Error	12	0.064		

Table 2. Comparison of the abundance of climbing lianas in gaps and plots in adjacent patches of forest that was not directly impacted by logging six years following conventional and reduced-impact logging near Paragominas, Pará, Brazil.

	Density (stems m^{-2})	P - value[a]	Basal area (cm^2 m^{-2})	P – value
Conventional logging				
Single tree gaps	0.98 (0.25)	0.006*	0.78 (0.21)	0.025
Adjacent forest	0.35 (0.11)		1.68 (0.77)	
Multiple tree gaps	1.22 (0.23)	0.001*	0.78 (0.17)	0.045
Adjacent forest	0.31 (0.27)		1.73 (0.91)	
Reduced-impact logging				
Single tree gaps	0.47 (0.24)	0.010*	0.26 (0.20)	0.268
Adjacent forest	0.07 (0.05)		0.18 (0.13)	
Multiple tree gaps	0.83 (0.28)	0.006*	0.52 (0.20)	0.009*
Adjacent forest	0.10 (0.05)		0.12 (0.06)	

[a] From paired, one-tailed t-tests comparing gap and forest plot means, N = 4.

* Indicates significant effect ($P < 0.05$) after sequential Bonferronnii correction.

Table 3. The number of stems ≥ 10 cm tall of the ten most common species of lianas encountered in four, 50 m^2 plots in six-year-old gaps in forest subjected to conventional and reduced-impact logging (RIL) near Paragominas, Pará, Brazil. Each species was classified according to its observed modes of regeneration (S = seed, C = coppice/root sprout, L = layer (i.e., sprout from rooted section of fallen stem), and A = advanced regeneration).

Species	Observed regeneration modes	Conventional logging		RIL	
		Single tree	Multiple tree	Single tree	Multiple tree
Bauhinia rutilans Spr. Ex Bth	A,S	19		10	
Bauhinia guianensis Auble	A,S	27	52	12	41
Adenocalyma pranceii A. Gentry	A,S	19	25	9	22
Bauhinia siqueiraeii Ducke	A,S		8	8	
Bauhinia cupreonitans Ducke	A,S				7
Memora schomburgkii (DC.) Miers	S,A,C	8	33	5	25
Croton ascendens R. Secco & N. Rosa	S	8	9	4	7
Gounia pyrifolia Reiss	S		10	5	7
Tournefortia laevigata Lam.	S		11		7
Davilla kunthii ST. Hil.	S		16		11
Passiflora glandulosa Cav.	S		13		
Memora bracteosa (DC) Bur ex K. Schum	C			12	
Acacia multipinnata Ducke	L,C,S	11	12		
Dalbergia subcymosa Ducke	L,C	14		5	7
Doliocarpus gracilis Kubitzki	L			17	10
Salacia megistophylla Standl	L	13			
Combretum laxum Jacq	L	12			
Arrabidaea trailiiSprague	L	9			
Total ten most common species		140	189	87	144
Total of all species		252	273	170	222

Table 4. Mean (SD) liana species diversity characteristics of 50 m^2 plots (N = 4) in the centers of six-year-old gaps formed during conventional and reduced impacts logging near Paragominas, Pará, Brazil. Small gaps were formed by the felling of a single tree and large gaps included three or more trees.

	Liana stems sampled	Liana species recorded[a]	Fisher's α
Conventional logging			
Small gaps	66 (10)	21 (3)	10.7 (1.8)
Large gaps	80 (14)	19 (2)	8.7 (1.8)
Reduced-impact logging			
Small gaps	44 (16)	18 (5)	12.3 (2.9)
Large gaps	60 (9)	21 (3)	11.3 (1.7)

[a] Includes 6 morphospecies that were identified to genus or family.

Table 5. Morisita – Horn indices of quantitative liana species similarity among six-year-old gaps in forest subjected to conventional and reduced-impact (RIL) logging near Paragominas, Pará, Brazil. Small gaps were formed by the felling of a single tree and large gaps included three or more trees.

	RIL multiple tree	Conventional logging single tree	Conventional logging multiple tree
RIL single tree	0.56	0.65	0.47
RIL multiple tree		0.57	0.91
Conventional logging single tree			0.57