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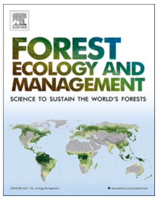

Increase in liana prevalence after logging and thinning in an eastern Amazonian forest

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ABSTRACT

Sustainability of forestry relies on the recovery of forest structure and timber stocks after logging. Canopy gaps created by logging often lead to liana proliferation, which can reduce forest productivity and reduce global CO_2 sequestration. Using inventory data from Brazil's Tapajós National Forest, we examined changes in liana prevalence (proportion of trees with lianas) following selective logging and thinning. Prevalence increase was proportional to the reduction of tree basal area (BA), measured from 12 ha of logged and 9 ha of subsequently thinned inventory plots. Following a 24 % BA reduction, liana prevalence doubled within seven years after logging and thereafter remained elevated throughout the 20-year study period. Twelve years after logging, 3/4 of the plots were thinned of non-commercial species by girdling. Annual increase in liana prevalence was similar (c. 2 percentage points per year, %pts/yr) in the immediate years after both logging and thinning. However, after thinning, for each additional m^2/ha of basal area reduction, the increment in annual increase of liana prevalence was four times larger than after logging (0.28 vs. 0.06 %pts/yr). Thinning occurred before forest structure had recovered to mid- and top-canopy closure, and leaving the liana vegetation intact led to a more intense increase in liana prevalence than had occurred after the initial logging. Our results suggest that thinning by girdling may not effectively liberate future crop trees, unless combined with ecologically sound suppression of excessive liana growth. Adequate forest recovery time appears necessary to prevent recurring liana increases after successive logging cycles and thinning.

1. Introduction

For forest management to be sustainable in the long term, logging practices and other interventions should support forest recovery. Recent studies in managed forests in Brazil have documented slow commercial timber volume recovery, indicating that removal rates of 20–30 m^3/ha at 25-to-35-year intervals are so high that they may cause major changes in forest structure and species composition (Sist et al., 2021; Piponiot et al., 2018; Castro et al., 2021). Timber harvesting (Photo 1) can kill up to 35 % of tree saplings and poles of 1–10 cm diameter, which considerably slows down recovery of the timber stock and forest structure (Pinard and Putz, 1996). Lianas increase the collateral damage during tree felling by pulling down neighbouring trees or parts thereof (Parren and Bongers, 2001). Reduced impact logging aims to limit the damage to the remaining forest, but its efficiency has varied considerably among sites (Hermudananto et al., 2024).

Structural changes in managed tropical forests, together with higher temperatures, higher CO_2 levels and lower precipitation, appear to favour liana proliferation globally (Ngute et al., 2024). Liana proliferation, in turn, can slow down tree growth in logged forests (Feldpausch et al., 2016; Estrada-Villegas et al., 2022) and reduce the seed production of mature trees (Nabe-Nielsen et al., 2009). Lianas compete with

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Photo 1. A Skidder is mowing down saplings and poles to do a skid trail for dragging logs to the landing. Fazenda Rio Capim. Paragominas, Pará. 11.12.2021 by Johan Slätis.

trees for light, nutrients, and water, reducing the growth of trees and shifting forest composition towards species that store less carbon (Van Der Heijden et al., 2019). Consequently, liana proliferation reduces global carbon uptake (Putz et al., 2023). Therefore, understanding liana-tree interactions in tropical forests and their sensitivity to climate and anthropogenic impacts is necessary for worldwide forest restoration and climate change mitigation (Marshall et al., 2020). Hegarty and Caballé (1991) conclude in The Biology of Vines that

"… [the] invasion of forest by vines, at the community scale, is determined almost completely by the size and frequency of canopy gaps and the type and persistence of disturbances."

Forest gaps caused by unplanned selective logging cover vast areas in the Amazon (Matricardi et al., 2020). Selective logging creates canopy gaps (Photo 2), which stimulate growth of trees in the understory (Schnitzer et al., 2004; Pinagé et al., 2019). Horizontal gap filling is slow. Hunter et al. (2015) report from the Tapajós, Brazil, that only 6 % of the gap area was filled by remaining trees in 4 years, and post-logging tree mortality was elevated in the gaps. In eastern Amazonia, the fraction of gaps in a managed forest declined to a pre-logging level of 4–6 % in 4–5 years, but this was due to saplings and pole-sized trees, while structural changes and high light intensities in the mid to upper canopy can prevail (Photo 3), despite decades of recovery(Fauset et al., 2017; Rocha et al., 2024; Likoski et al., 2021). An increase in direct sunlight makes the microclimate in gaps drier, which favours lianas over trees (Marimon et al., 2020).

The increased light availability after logging promotes liana propagation mainly from clonal stems that fall to the ground with the felled timber (Schnitzer et al., 2004, 2021; Putz, 1984; Alvira et al., 2004). This increases above- and below-ground competition between lianas and trees, which can reduce tree growth, seedling survival, and species richness (Schnitzer et al., 2005; Schnitzer and Carson, 2010; Martínez-Izquierdo et al., 2016).

Few long-term studies have quantified the increase in lianas after logging. Gerwing (2006) observed a doubling of five liana species after conventional logging and liana cutting. In Guyana, 16 of 76 liana species demonstrated pioneer-like ecological behaviour by proliferating until six years after logging, after which liana prevalence (proportion of trees that have lianas) returned to pre-logging levels (Zagt et al., 2003).

In unlogged forests, liana abundance is increasing globally, one of the likely reasons being climate change; however, local variation is considerable (Rueda-Trujillo et al., 2024). In undisturbed Amazonian and Central American forests, the stem density of lianas DBH $>$ 10 cm, increased annually in proportion to the initial site value by 4.0 % over periods of 5 years or more (Phillips et al., 2002).

Silvicultural treatments, such as liana suppression and thinning, release future crop trees and improve their growth (Peña-Claros et al., 2008). Canopy openness has a significant influence on liana proliferation and sapling growth in logging gaps (Schnitzer et al., 2004).

Here, we investigate liana prevalence dynamics after basal area reduction after logging and thinning, and address the following questions:

Photo 2. Canopy gaps after logging in a managed forest. Fazenda Rio Capim. Paragominas, Pará. 11.12.2021 by Johan Slätis.

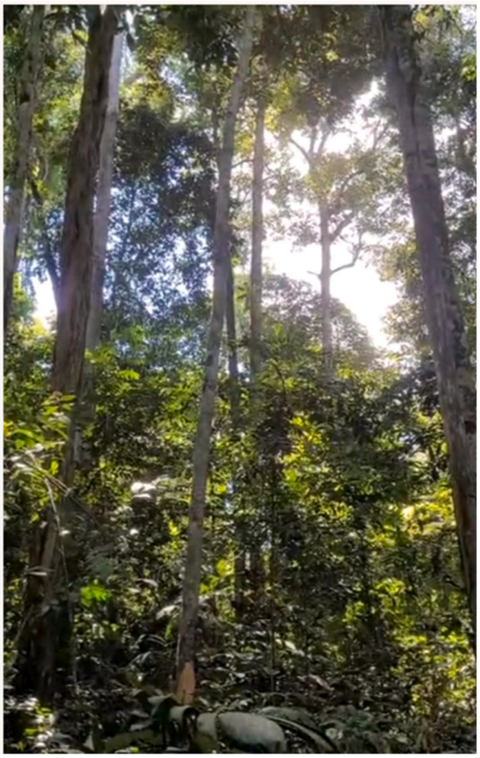

Photo 3. Forest recovery and mid-canopy gaps 22 years after logging, Km 114, Tapajos National Forest, Pará. 17.7.2024 by Johan Slätis.

- How does the annual change in liana prevalence (proportion of trees with lianas) depend on the basal area reduction after logging and subsequent thinning?
- Does the rate of change in liana prevalence differ between the first and second rounds of basal area reduction?
- How does liana prevalence change over 20 years after logging?
- How does liana prevalence change in an unlogged area?

2. Materials and methods

2.1. Study site and forest inventories

The National Forest of Tapajós is in the western part of Pará state in the Brazilian Amazon. Forest development following selective logging, including the presence of lianas, has been inventoried there since 1981. The area is characterised by dense tropical forest, with a rainy season from December to May, and the driest months are July and August (Reategui-Betancourt et al., 2024). Within an area designated for selective logging in 1982, 48 permanent plots were established in 1981 and inventoried several times thereafter. Within a nearby area that remained unlogged, 12 control plots were established and measured since 1983. The plots were placed randomly and each was 50 m x 50 m in size (Fig. 1). The original objective was to investigate the dynamics of forest growth following various logging and thinning intensities. For site characteristics, see Reategui-Betancourt et al. (2024), and for the original experimental setup and research objectives, see de Avila et al. (2017).

Logging intensities in 1982 were nearly twice those currently allowed by the reduced-impact logging protocols. We use the term *logging* to refer to the planned, selective timber harvesting that was applied. Conventional liana cutting, i.e. cutting the lianas to the degree necessary for work security and to reduce damage from felling (Silva, 1996), was likely carried out (although not documented) prior to logging. In 1994, non-commercial tree species were thinned in 36 of the 48 logged plots through poison-girdling to favour the growth of the remaining commercial species. Droughts were recorded in Amazonia in 1983 and 1997–1998 (Alves et al., 2013).

The logged forest plots were measured in eight inventories: 1981, 1983, 1987, 1989, 1995, 2003, 2008, and 2012. Data from 144,000 trees of 330 named species were collected. Observations of liana presence were recorded in 21,000 trees. We used data from the first inventory (1981) and four post-logging inventories to form three study periods (1983–1989, 1989–1995, 1995–2003). In 1997, an understory fire affected 19 of the plots, and these were excluded from the third period (1995–2003) analysis. We concluded this liana prevalence study at the 2003 inventory, as other drivers, such as a prolonged drought, affected the forest after 2003.

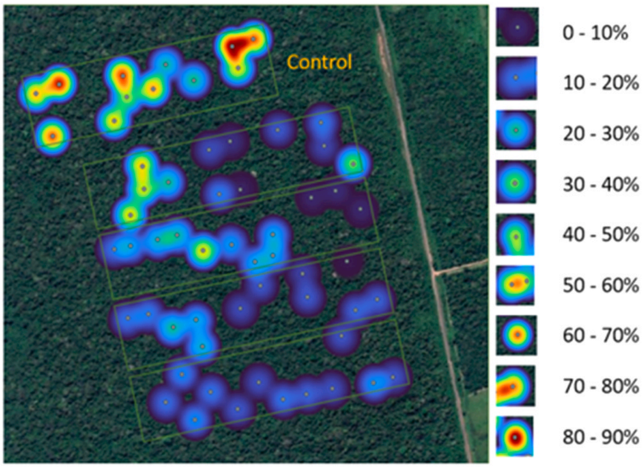

Fig. 1. The Km114 experimental area in Tapajós National Forest and plot-level pre-logging liana prevalence (% of trees with lianas) in 1981 and in unlogged control plots in 1983. The layout of the experiment consisted of five 36-ha blocks, with 48 experimental plots and 12 control plots, each measuring 0.25 ha, distributed over a total area of 180 ha. The area is close to Highway BR-163, which was completed in 1976. The eastern side of the road has been gradually deforested over the last 20 years, exposing the experimental area to fire and anthropogenic disturbances.

2.2. Liana prevalence and tree basal area

Liana data were based on visual observations and were available for trees with a diameter at breast height (DBH) $\geq$ 10 cm. We included all living trees above this DBH in the study. A binary variable indicating the liana status (presence vs. absence of lianas) was defined for each tree. For each plot, we express its liana prevalence as the percentage of trees with lianas. The rates of change in liana prevalence are expressed as percentage points per year (%pts/yr). Natural tree mortality was deemed to be similar between the observation periods.

The total basal area (BA) for each plot was calculated as the sum of the basal areas of the individual trees. BA is expressed in units of m^2 /ha. The BA reduction after logging in 1982 was calculated as the difference in BA between 1983 and 1981, thus including logging damage (20 %). On average, 12 trees per hectare, with an average tree basal area of 0.41 m^2 (DBH 69 cm), representing 35 species, were logged.

A thinning of non-commercial species was undertaken in 1994 to alleviate competition and promote the growth of commercial tree species. Trees with a DBH > 10 cm were thinned by girdling and application of 2,4-D® herbicide. Of the BA reduction, 60 % was represented by trees of DBH 20 −50 cm, and 20 % each by trees of DBH 10—20 cm and 50—80 cm. On average, 106 trees per hectare with an average tree basal area of 0.049 m^2 (DBH 25 cm) were thinned. Lianas were likely not affected by the thinning (not documented). The reduction in basal area at thinning was quantified from the mortality of girdled trees documented in 1995 and 2003. Due to the original experimental setup (de Ávila, 2016), BA reduction due to thinning varied considerably across the plots. We use the term *thinning plots* to refer to those plots that were logged in 1982 and subsequently thinned in 1994, and the term *logged-only plots* to refer to plots that were logged in 1982 but not thinned afterwards. Liana prevalence at the end of the second post-logging period (1989 −1995) was calculated based on all trees in the plot, including the trees killed by thinning and their liana status.

The 12 control plots, first measured in 1983, remained unlogged and unthinned and are referred to as *unlogged plots*. The initial liana prevalence in these plots was high (48 %), possibly due to natural or anthropogenic disturbances prior to 1983. In contrast, the initial liana prevalence in the logged plots in 1981 was 13 %. Due to the fire in 1997, the number of unlogged plots declined from 12 to 6, thinned plots from 31 to 24, and logged plots from 17 to 11. In five plots with few trees exposed to thinning, no mortalities were registered, and these were therefore included in the logged-only group. Fig. 2 presents the BA development in the logged, thinned and unlogged plots.

2.3. Data analysis

We describe the temporal development of liana prevalence after logging in 1982, during three study periods (1983–1989, 1989–1995, and 1995–2003), and after thinning in 1994 during the third period (1995–2003). We used a longitudinal regression model (Diggle et al., 2002) to estimate the rates of change in liana prevalence, with random intercepts accounting for between-plot heterogeneity in liana prevalence at the start of the study period. A separate model was used for each study period. For each period and treatment (logging or thinning), we report the average liana prevalence at the onset of the period, the estimated rate of change in prevalence, and their 95 % confidence intervals. The rates are interpreted as the average annual change in liana

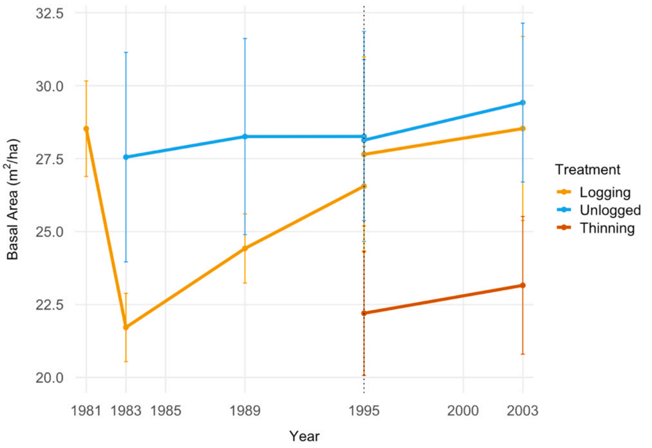

Fig. 2. Average plot basal area (BA) and its range (minimum, maximum) by treatment and inventory year. The three study periods were 1983–1989, 1989–1995, and 1995–2003. The BA reduction of living trees (DBH ≥ 10 cm) at logging was 6.8 m^2/ha, and after thinning, 5.2 m^2/ha. The number of plots declined from 60 to 41 after 1995 due to the fire in 1997. The variation between the plots was considerable, as expressed by the ranges (vertical intervals).

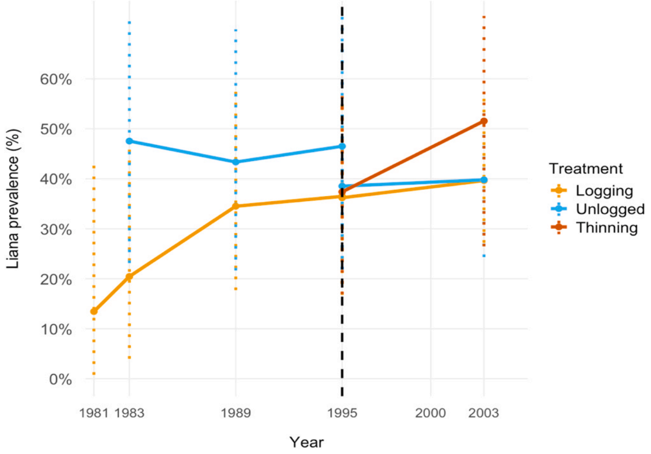

Fig. 3. Average plot liana prevalence and its range (minimum, maximum) per treatment and study period in the Tapajós inventory area from 1981 to 2003. The study periods are 1983–1989, 1989–1995, and 1995–2003. The liana prevalence increased rapidly in the periods after logging, from 20 % to 35 % (2.5 %pts/yr), and after thinning, from 37 % to 52 % (1.9 %pts/yr). The number of logged plots declined from 48 to 11 in the third study period (1995–2003) due to the exclusion of 24 plots exposed to thinning and 13 plots to fire. The six unlogged plots that were not exposed to fire had a lower liana prevalence than those that burned.

Table 1
The rates of change in liana prevalence in the logged, logged and thinned, and unlogged plots. The estimates of the average initial prevalence and the subsequent annual rates of change in liana prevalence are presented for the three study periods.

	Prevalence at period start (% of trees with lianas)		**Rate of change** (% pts/year)	
Study periods	Estimate	CI (95 %)	Estimate	CI (95 %)
Logging 1982				
1983–1989	20.46	[17.62, 23.30]	2.34	[1.96, 2.71]
1989–1995	34.51	[31.60, 37.42]	0.33	[0.09, 0.57]
1995–2003	36.21	[29.63, 42.78]	0.43	[−0.01, 0.87]
Thinning 1994				
1995–2003	37.38	[32.77, 42.00]	1.77	[1.29, 2.25]
Unlogged				
1983–1989	47.55	[39.40, 55.70]	−0.70	[−1.25, 0.14]
1989–1995	43.35	[35.69, 51,02]	0.52	[0.08, 0.96]
1995–2003	38.53	[29.26, 47.80]	0.16	[−0.33, 0.65]

Liana prevalence in recruits (trees that reached the DBH limit of 10 cm and were registered for the first time) developed similarly to the larger trees.

prevalence, expressed as percentage points (%pts) per year.

We used linear regression to estimate the dependence of the rate of change in liana prevalence on BA reduction after logging during the first study period and after thinning during the third study period. The plot-specific rate of liana increase, calculated as the difference in liana prevalence over the period in question divided by the period duration in years, was used as the dependent variable. The plot-specific BA reduction was used as the independent variable. We adjusted the post-logging model with pre-logging BA, pre-logging liana prevalence, as well as the plot's average DBH at the period start as a proxy for forest structure. The post-thinning model was adjusted with pre-thinning BA, pre-thinning liana prevalence, plot's average DBH and logging basal area reduction in 1982. Variables that showed strong collinearity with BA reduction were eventually discarded, as confirmed by the variance inflation factor (VIF > 5.0). We report the estimates and 95 % confidence intervals of the increment on the rate of liana increase for each 1 m^2/ha BA reduction after logging (1983–1989) and thinning (1995–2003), as well as the effects of the adjusting variables. Statistical significance was determined based on the 95 % confidence interval (CI) not including zero.

3. Results

3.1. Dynamics of liana prevalence after logging and thinning

In the logged plots, the average liana prevalence increased from 21 % to 40 % over 20 years, and in the thinned plots, from 38 % to 52 % over eight years. The average liana prevalence increased primarily in the immediate study periods following logging or thinning (Fig. 3). During the second and third periods, 7—20 years after logging, liana prevalence remained stable in the logged plots at a new, higher level. In the unlogged plots, liana prevalence oscillated but remained at a relatively stable level.

Based on the longitudinal regression model, the increase in liana prevalence, after logging an average of 6.8 m^2/ha, was 2.34 %pts/yr (95 % CI [1.96, 2.71]) over the first period (1983–1989), corresponding to an increase of 14 %pts in six years (Table 1). During the second and third post-logging periods (1989—1995 and 1995—2003), the increase rates were considerably slower at only 0.33 % pts/yr and 0.43 % pts/yr, respectively.

Most logged plots were subjected to thinning with an average reduction in BA of 5.2 m^2/ha (19 % of pre-thinning BA), which was smaller than the BA reduction of 6.8 m^2/ha at logging (24 % of pre-logging BA). The increase in liana prevalence was rapid during the post-thinning period (1995–2003), 1.77 %pts/yr (95 % CI [1.29, −2.25]). The prevalence increase in the logged-only plots during the same period was 0.43 %pts/yr (95 % CI [-0.01, 0.87]), which is 1.34 % pts (95 % CI [0.04, 2.64]) smaller than in the thinned plots.

3.2. Dependence of liana increase rates on basal area reduction

We next focused on the immediate periods after logging and thinning to analyse the rate of liana increase in relation to the respective extent of BA reductions. In the unadjusted analysis (Fig. 4, Table 2), the rate of liana increase during the first post-logging period (1983—1989) was 0.04 %pts/yr (95 % CI [-0.04, 0.13]) higher for each 1.0 m^2/ha increase in BA reduction. During the post-thinning period (1995—2003), the corresponding figure was four times higher, 0.25 %pts/yr (95 % CI [0.12, 0.39]).

In the adjusted analysis, the rate of liana increase in the first post-logging period was 0.06 %pts/yr (95 % CI [-0.02, 0.15]) higher for each additional 1.0 m^2/ ha of BA reduction. Of the adjusting variables,

Fig. 4. The observed dependence of the annual increase in liana prevalence on BA reduction in the Tapajós inventory area. The dependence is shown for the first post-logging period (1983–1989) and the post-thinning period (1995–2003). The shaded areas present the 95 % pointwise confidence intervals of the regression lines. The R^2 values were 0.02 (left panel) and 0.40 (right panel).

Table 2

The dependence of liana prevalence on BA reduction. Each estimate presents the increment in the annual increase rate of liana prevalence for a one-unit increase in the corresponding variable. For example, according to the adjusted analysis, logging 5 m^2/ha (equivalent to a 12–25 % logging intensity) would lead to 5*0.06 = 0.30 %pts/yr higher prevalence increase rate. After thinning, the rate would increase by 5*0.28 = 1.4 %pts/yr. An increase in tree basal area of 1 dm^2 represents the growth of a tree of DBH 20 cm to 23 cm.

	Post-logging 1983—1989		**Post-thinning 1995—2003**	
Unadjusted regression	Estimate (%pts/yr)	CI (95 %)	Estimate (%pts/yr)	CI (95 %)
Intercept	2.01	[1.30, 2.73]	0.90	[0.08, 1.71]
BA reduction (m^2/ha)	0.04	[−0.04, 0.13]	0.25	[0.12, 0.39]
Adjusted regression				
Intercept	3.38	[1.28, 5.49]	1.54	[−5.31, 8.4]
BA reduction (m^2 /ha)	0.06	[−0.02, 0.15]	0.28	[0.10, 0.45]
Pre-logging liana prevalence (%)	−0.05	[−0.09, −0.01]	0.02	[−0.06, 0.09]
Average tree basal area 1983 (dm^2)	−0.17	[−0.57, 0.23]		
BA reduction logging 1982 (m^2/ ha)			−0.01	[−0.12, 0.10]
Pre-thinning BA per ha (m^2/ha)			−0.03	[−0.21, 0.14]
Pre-thinning prevalence (%)			0.00	[−0.08, 0.08]

pre-logging liana prevalence had a statistically significant negative impact on liana prevalence, i.e., the higher the liana prevalence was initially, the slower it increased. The initial BA was highly collinear with BA reduction and was omitted from the analysis (VIF 8.8).

After thinning, the relationship between the annual liana prevalence increase rate and BA reduction was more pronounced than after logging. The adjusted rate of liana increase was 0.28 %pts/yr (95 % CI [0.10, 0.45]) higher for each additional 1.0 m^2 /ha of post-thinning BA reduction. The adjusting variables, pre-logging basal area, pre-thinning basal area, and pre-thinning liana prevalence, were not statistically significant. Forest density (DBH per plot) was omitted due to its collinearity with the thinning BA reduction (VIF 7.8). Post-thinning rate of liana increase was not affected by the logging BA reduction 12 years earlier.

4. Discussion

In this study, we investigated the dynamics of liana prevalence (proportion of trees with lianas) after first-cycle selective logging and subsequent thinning in Eastern Amazonia. After the initial surge in liana prevalence after logging, liana prevalence remained stable until thinning 12 years later, but rose again in the plots that were thinned. The rate of liana prevalence increase was proportional to the BA reduction after both logging and thinning. Liana prevalence increased annually with a similar rate after logging (1983–1995) by 2.3 %pts per year and after thinning (1995–2003) by 1.8 %pts per year. The BA reduction after thinning was smaller (5.2 m^2/ha, 20 % of pre-thinning BA) than at logging (6.8 m^2/ha, 24 % of pre-logging BA).

We found that the additive effect of per-unit BA reduction on the rate of liana prevalence increase was four times greater after thinning that followed previous logging than after the first-time logging. Liana proliferation and tree growth are significantly dependent on gap size (Schnitzer et al., 2004). We interpret the accelerated increase in liana prevalence after thinning ("liana sensitivity") to be related to the following factors:

1. The canopy may have been more open after thinning than after logging due to the slow recovery of the mid and top canopy. Based on the results of Hunter et al. (2015), only about 20 % of the canopy gap area would have closed in the 12 years between logging and thinning in Tapajós. At thinning, all sizes of trees were thinned. Consequently, new gaps appeared in the top and mid-canopies, still fragmented after logging.
2. Liana prevalence had doubled since logging. After tree girdling, liana stems could proliferate in defoliated trees without leaf competition.
3. Both logging and thinning favoured lianas by reducing below-ground competition (Schnitzer et al., 2005).

In the unthinned logged plots, the intact post-logging trees hindered liana increase, despite the remaining top canopy gaps. Putz (Putz, 1991) wrote that the “weed trees” (i.e. pioneer trees) are allies of the forester as they discourage liana growth.

The thinning treatment shares similarities with a second-cycle logging in managed forests. With logging cycles of 25–30 years in the Amazon, and a horizontal top canopy gap closure for this stretch of time of presumed 40–50 % in one logging cycle (Hunter et al.,2015), the annual increases in liana prevalence will likely be higher after the second logging cycle than after the first.

Our findings about the annual liana increase six years after logging are similar to those from Guyana (Zagt et al., 2003). However, lianas remained, on average, at a new, higher level in Tapajós until 20 years after logging. In contrast, in Guyana, prevalence returned to pre-logging levels in 13 years. This may be due to the higher logging intensity, likely more fertile soils (Quesada et al., 2011), the stronger seasonality and slightly lower rainfall in Tapajós than in Guyana. Agricultural expansion next to the Tapajós National Forest may have made the local climate drier (Reis et al., 2020), favouring lianas, which continue to grow during seasonal droughts when tree growth is minimal (Schnitzer et al., 2019).

In the unlogged plots, liana prevalence remained high (48 %) and relatively stable from 1983 to 2003. In contrast, the density of large lianas (DBH $\geq$ 10 cm) increased in undisturbed forests across Amazonia and Central America (Phillips et al., 2002). The absence of liana increase in the unlogged plots in Tapajós may reflect the forest’s successional stage following a likely but undocumented disturbance (Rueda-Trujillo et al., 2024).

The Tapajós Km114 inventory area was not established to investigate lianas, which entails some limitations on our study. First, due to the strong correlation between the study plots’ pre-logging basal area and the subsequent reduction in basal area, we were unable to discern their independent effects on the rate of liana increase. However, in the corresponding analysis after thinning, no correlation was found between these two variables. In our study, BA reduction can be seen as a proxy for the increase in light in the forest, and our results demonstrated a similar tendency as liana abundance increase in canopy gaps (Schnitzer et al., 2004).

The comparison of the increments in liana prevalence after the two treatments may be confounded by environmental and climatic factors. However, the stable liana prevalence in unlogged plots suggests that if any major climatic disturbances affected the region during the study period, they were averaged out across inventory intervals. Since the unlogged plots had a clearly higher liana prevalence than the treatment plots, they cannot serve as proper controls in the study.

In our analyses, we were able to adjust the comparisons with several variables specific to the study area, such as the levels of pre-logging and pre-thinning liana prevalence. However, uncertainties remain due to the limited number of plots, especially in the third study period, and the considerable variation between plots. Nevertheless, both the unadjusted and adjusted analyses pointed to a larger effect of BA reduction after logging+thinning than after just logging.

5. Conclusions and recommendations

Anthropogenic activities in tropical forests lead to changes in forest structure, which, together with a warming climate and deforestation, favour lianas. Lianas, in turn, reduce tree growth, affect forest structure and consequently, impact forest productivity and global carbon sequestration. Our results suggest that liberation of future crop trees by thinning should include an ecologically sound suppression of excessive liana proliferation. With an anticipated increase in lianas in the successive logging cycles, informed liana management methods should be developed to enhance growth in managed and degraded forests. These methods should be developed in collaboration with the forestry sector.

CRediT authorship contribution statement

Kari Auranen: Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Formal analysis. **Slätis Johan Robert:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Clementino José Bruno Nascimento:** Visualization, Software, Methodology, Formal analysis, Data curation. **Hanna Tuomisto:** Writing – review & editing, Writing – original draft, Supervision, Methodology. **Lucas José Mazzei de Freitas:** Supervision, Methodology, Investigation, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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