LIANA DISTRIBUTION AND ABUNDANCE IN MOIST TROPICAL FOREST IN GHANA 40 YEARS FOLLOWING SILVICULTURAL INTERVENTIONS

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ABSTRACT

Lianas are an important structural aspect of tropical forest ecosystems, but may have negative impacts on tree growth and productivity. We censused lianas in plots that were subjected to three different types of silvicultural intervention in Bobiri forest in Ghana in order to answer two questions: 1) does liana cutting during the initial years of a cutting cycle influence liana densities, basal area and vine loads in tree crowns relative to unlogged forest?; 2) does the duration, intensity and sequence of silvicultural interventions in the initial years of a cutting cycle influence vine loads? Data were gathered from six one-hectare plots in each of the three silviculturally-treated stands, with comparative data collected from four one-hectare plots in an unlogged part of the same forest. Lianas were categorised into small (stems ≥2 - 5 cm DBH) and large sizes (DBH >5 cm) and censused in nested subplots within the one-hectare plots. The extent of liana loading or 'infestation' of individual trees ≥ 20cm DBH was investigated using a 5-point score 0, 1, 2, 3 and 4 within the plots. A total of 697 liana stems were inventoried in both the silviculturally-treated and the unlogged forest. The density of small lianas was relatively higher in the unlogged forest than in treated forest. However, mean densities of large lianas were similar across treatments. For all lianas with DBH ≥ 2 cm, mean densities were lower in the treated forest than in the unlogged forest. Liana loading or 'infestation' was dependent on silvicultural treatment consequent to the timing of interventions; while about 9% of stems were completely covered by lianas in forest where climber cutting followed timber harvesting; only about 1% of trees were completely covered by lianas in unlogged forest and forest where liana cutting preceded timber harvesting. Approximately 90% of trees DBH ≥ 20cm were free of lianas in forest where liana cutting preceded timber harvesting, with ~81% of stems in the same category free of lianas in unlogged forest. However, in forest where liana cutting followed timber harvesting only about 46% of stems were free of lianas. We conclude, from the lower densities of lianas in the silvicultural intervention sites relative to the unlogged sites that even 40 y later the impact of climber cutting was measurable. Although the density of large lianas was not distinct among the silviculturally-treated stands, the interventions promoted greater access to tree crowns by lianas when applied after timber harvesting. Thus the timing of silvicultural interventions in the initial years of a cutting cycle is important since it influences liana load in tree crowns in the long term.

Keywords: **Silvicultural systems, Liana load, Tropical Shelterwood System, Post-Exploitation System, Liana inventory**

INTRODUCTION

Lianas constitute an important structural aspect of the tropical forest ecosystem (Parren and Bongers, 2001; Schnitzer and Bongers 2002; Mascaro *et al.*, 2004; Phillips *et al.*, 2005). Apart from contributing to biological diversity in moist forests (Gentry, 1991; Hegarty and Caballé, 1991; DeWalt *et al.*, 2006), lianas serve many vital functions in tropical forest ecosystems. These functions include the provision of arboreal pathways for canopy vertebrates (Charles-Dominique *et al.*, 1981), and facilitating structural continuity of forest canopy over large distances (Parren and Bongers, 2001).

Although lianas are important in the forest ecosystem, they also have negative impacts on growth and productivity of tropical forest trees (Osafo, 1969; Putz, 1991; Laurence *et al.*, 2001; Schnitzer and Bongers, 2002). Lianas can affect tree growth, through competition for nutrients, light and other resources, or by delaying regeneration of trees following disturbance (*e.g.*, Schnitzer *et al.*, 2002). For this reason, lianas are cut as a silvicultural intervention in many managed tropical forests (*e.g.*, Parren and Bongers, 2001). Liana cutting combined with other silvicultural thinning and liberation operations result in canopy opening that facilitates regeneration and promotes tree growth. However, one of the unintended effects of the resulting increase in light availability is the chance for the regeneration/resprouting of lianas (*e.g.*, Hegarty and Caballé, 1991) as the increased availability of light may be an advantage for climber regeneration (*e.g.*, Putz, 1991; Schnitzer and Bongers, 2002). Indeed, some lianas may react to cutting by vigorous vegetative reproduction of many new stems that can eventually take over the openings created at the expense of the desired tree regeneration (Putz, 1991; Pinard and Putz, 1994).

While Parren and Bongers (2001) argue that general climber cutting as a pre-logging silvicultural operation should be discontinued, purely on the grounds of their ecological value in contributing to total plant diversity in tropical forests and providing pathways for arboreal vertebrates, the fact still remains that lianas pose a serious threat to forest management (Putz, 1991). By infesting up to 80% or more of trees ≥ 10 cm DBH in some tropical forests, they not only compete with regenerating trees for resources, but also tend to suppress older trees which they may eventually either strangle or kill. They may also cause serious deformation to the stems of economic tree species, thereby reducing their economic value.

Interest in liana inventory has recently gained currency (*e.g.*, DeWalt *et* al., 2000; Muthuramkumar and Parthasarathy, 2001; Pérez-Salicrup *et al.*, 2001; Phillips *et al.*, 2002; Parren, 2003; Reddy and Parthasarathy, 2003; Kouamé *et al.*, 2004; Mascaro *et al.*, 2004; Parthasarathy *et* al., 2004; Rice *et al.*, 2004; Phillips *et al.*, 2005; DeWalt *et al.*, 2006). However, information on medium to long-term inventory is scanty in most cases (Phillips *et al.*, 2005). It is therefore important to examine the long-term effects of disturbance, such as silvicultural interventions, on the distribution and abundance of lianas in moist tropical forests.

In this paper we present results of an inventory of lianas in plots that were subjected to different types of silvicultural intervention in the early 1960s in Bobiri forest in Ghana. We answer two questions: 1) does liana cutting during the initial years of a cutting cycle influence liana densities, basal area and vine loads in tree crowns relative to unlogged forest?; 2) does the duration, intensity and sequence of silvicultural interventions in the initial years of a cutting cycle influence vine loads? Based on established knowledge, we predict that liana densities and basal area will be lower in silviculturally-treated forest than in unlogged forest, and similarly, levels of liana loading in tree crowns will be lower in the silviculturally-treated forest relative to unlogged forest.

MATERIAL AND METHODS

The Study Area and History of the Silvicultural Experiments

Data were collected from the research area of Bobiri forest reserve in the south-east sub-type of moist semi-deciduous (MSSE) forest in Ghana (Hall & Swaine 1981). Covering an area of approximately 5,445 ha, Bobiri forest was demarcated in 1936 and reserved in its pristine, unexploited state in 1939 (Foggie, 1947, Alder, 1993). It lies between latitudes 6^o 39’ and 6^o 44’N and longitudes 1^o 15’ and 1^o 23’W. The mean annual rainfall is about 1,500 mm.

The relief is characterised by gentle undulating terrain with a dominant slope of 6 - 7 per cent, sloping from north-west to south-east in the general direction of flow of all the streams in the reserve. Altitude varies between 183 m and 248 m. Texturally, the soils vary from sandy loams to clay loams, passing into a grey leached sandy or silty soil on the periodically waterlogged river valleys, flats and swamps. In his description of the condition of Bobiri forest in the days prior to silvicultural experimentation, Foggie, (1947) points out that there were no visible differences in the vegetation structurally or floristically between the different soil types of the higher elevations and the slopes. However, the permanently moist soil of the valley bottoms carried riparian vegetation
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The key silvicultural systems that were tried experimentally in Ghana were the Tropical Shelterwood System (TSS) and its variant Post-Exploitation System (PES). However, the Girth Limit Selection system (GLS), which remains the main management system in Ghana, was also tried experimentally but with harvesting followed by limited silvicultural operations to promote regeneration of the commercial crop.

The TSS was applied over 4,800 ha of forest (Osafo, 1969, 1970; Ghartey, 1990), and followed a protocol similar in all respects to the classical TSS as practised in Nigeria. Climber cutting and over-wood removal through poisoning of large non-economic tree species (DBH > 90 cm) were followed by a series of silvicultural thinning and liberation operations carried out prior to commercial harvesting, which took place in about the sixth year after initiation of the interventions.

A variant of the TSS was also initiated to determine whether sufficient regeneration could be obtained by opening the canopy after exploitation. This system became known as the Post-Exploitation System (PES). By contrast to the TSS, climber cutting, canopy opening and cleaning operations under the PES were carried out after commercial harvesting in the first year.

The third type of silvicultural intervention, the Girth Limit Selection System (GLS), was carried out to determine the effect of exploitation preceded by climber cutting. In the first year after commercial exploitation the felling gaps were treated by cutting up branches of felled trees and piling the slash in gaps. In addition, improvement cleanings were carried out entailing the cutting of all non-valuable trees and shrubs in the dense lower storey to attract new regeneration and to improve the existing crop by encouraging saplings, poles and middle size classes of valuable and non-valuable upper canopy species.

These interventions resulted in an average basal area reduction from *ca*. 30 m^2 ha^{-1} to 10 - 12 m^2 ha^{-1} under the TSS, PES and GLS. Consequently, there was very little shade from the shelterwood which consisted of the tall mature trees with crowns 24 m to 30 m above ground, poles with small crowns 12 m high and a sparse scattering of saplings and poles of valuable species with small crowns at lower levels. In effect, the interventions resulted in a more uniform structure in TSS and PES relative to the GLS forest. Also, treatment before harvesting in the TSS, and treatment after harvesting in the PES stands resulted in more drastic reductions in liana densities in those treated stands relative to the GLS forest. On this basis, we predict further that liana densities would be relatively higher in the GLS forest than in the TSS and PES stands 40 years after the interventions.

Although the silviculturally-treated forest stands are essentially the same forest which was subjected to the different types of interventions, for purposes of comparison we refer to the TSS, PES, and GLS as 'forest types' throughout this paper.

DATA COLLECTION

Data for the present study were gathered in six one-hectare plots in each of the three silviculturally-treated stands in the Bobiri forest reserve described above. Comparative data were also collected from four one-hectare plots in the relatively undisturbed, unlogged part of the same forest reserve (designated as UNL and also considered as a 'forest type' for purposes of comparison in this paper).

To address the question regarding the medium to long term effects of silvicultural interventions on liana populations, lianas were categorised into small (stems ≥ 2 - 5 cm DBH) and large sizes (DBH >5 cm). Small lianas were censused in 0.03 ha sub-plots in 2 x 2 m quadrats located at 10 m intervals along a 150-m transect demarcated in the centre of each of the one-hectare plots in the treated and unlogged 'forest types'. Conversely, large lianas were censused in 0.36 ha sub-plots measuring 60 x 60 m located in the central portion of each one-hectare plot. For both small and large lianas, every climbing stem above the minimum diameter was included, regardless of whether or not it represented a distinct genet (*e.g.*, a single individual with 10 stems > 2 cm DBH was included 10 times). Small lianas were measured by means of digital vernier callipers; for large lianas a diameter tape was used.

With regard to the second question, the extent of liana loading or 'infestation' of individual trees ≥ 20 cm DBH was investigated using a 5-point score 0, 1, 2, 3 and 4 within the one-hectare main plots. A tree was scored zero when it was completely free of lianas; a score of 1 was assigned if there were only a few lianas covering about 25% of the stem or crown; 2 when about 50% was covered, 3 for 75% coverage and 4 when it was entirely smothered both on the stem and crown by lianas. In all cases measurements were replicated over six plots in TSS, PES and GLS and four plots in UNL forest.

The data were aggregated by plot in SPSS® 13.0 for Windows and the densities per hectare were calculated and examined graphically. The Kolmogorov - Smirnov tests for normality and Levene's test for homogeneity of variance (Zar, 1999) were also carried out. No significant departures from normality and homoscedasticity were observed, therefore the mean values from the treatments were compared by analysis of variance (ANOVA) followed by Tukey's HSD tests. Liana 'infestation' levels were tested for independence between 'forest types' by Pearson's chi-squared tests for contingency tables (Zar, 1999).

RESULTS

Altogether, a total of 697 liana stems were inventoried in both the silviculturally-treated and the unlogged forest. Seven liana species were identified to species level, namely *Acacia pennata* Willd., *Combretum smeathmannii* G. Don., *Griffonia simplicifolia* (Vahl *ex* D.C.) Baill., *Hippocratea africana* (Willd) Loes., *Landolphia owariensis* P. Beauv and *Stachyanthus occidentalis* (Keay and Miège) Boutique. However, 80% of the lianas measured could not be positively identified. For the two species with more than 20 stems identified (*A. pennata* and *G. simplicifolia*), frequency was independent of forest type (p> 0.05).

Liana Density and Distribution

The unlogged forest had a higher density of small lianas per hectare (ANOVA $F_{(3,18)} = 4.92$; $P = 0.011$) with correspondingly higher mean basal area than in treated forest (ANOVA $F_{(3,18)} = 6.64$; $P = 0.003$). However, mean densities of large lianas were similar across treatments (ANOVA $F_{(3,18)} = 0.412$; $P = 0.584$), as was total basal area (ANOVA $F_{(3,18)} = 0.841$; $P = 0.490$) (Table 1 and Figure 1). When all lianas DBH ≥ 2 cm were pooled and densities adjusted for plot size, mean densities were 569 stems ha^{-1} in GLS, 575 stems ha^{-1} in PES, 633 stems ha^{-1} in TSS and 1120 stems ha^{-1} in UNL forest; these mean values were statistically distinct between the silviculturally-treated forest on one hand, and the unlogged forest on the other (ANOVA $F_{(3,18)} = 4.07$; $P = 0.023$; Table 1).

Table 1: Densities of small and large lianas in treated (TSS, PES, GLS; N = 6) and unlogged (UNL; N = 4) stands in Bobiri forest. The letters *a* and *b* distinguish mean values that are different from each other in each liana size category by Tukey's HSD test.

Category	Liana density (Stems ha^{-1} ±SD)			
	TSS	PES	GLS	UNL
Small (2-5 cm DBH)	567 ±270*b*	511 ±211*b*	544 ±248*b*	1083 ±311*a*
Large (DBH > 5 cm)	39 ±16	41 ± 19	28 ± 13	37 ± 14
DBH ≥ 2 cm	633 ±320*b*	575 ±233*b*	569 ±263*b*	1120 ±281*a*

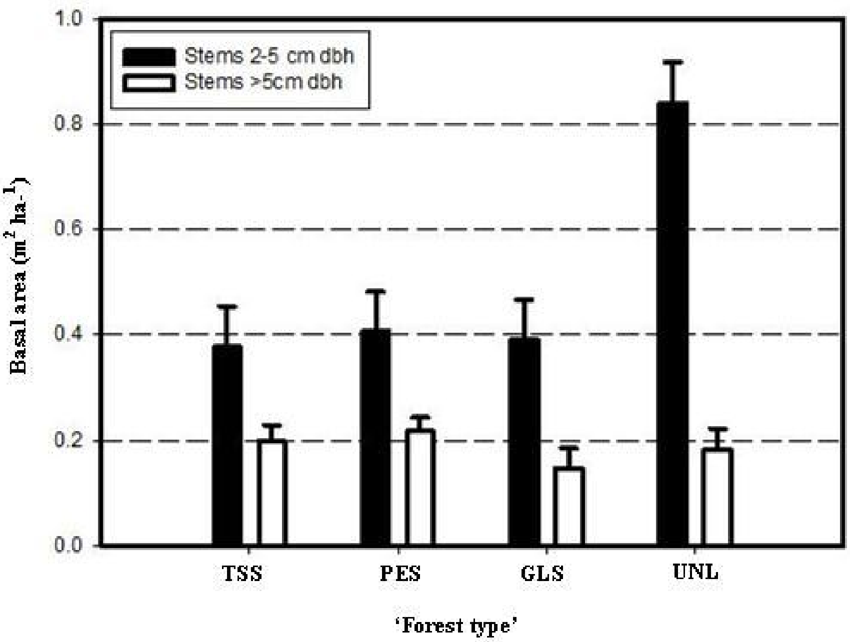

Figure 1: Mean basal area (m^2 ha^{-1}) of small and large lianas in treated (TSS, PES, GLS; N=6) and unlogged (UNL; N=4) stands in Bobiri Forest Reserve. Small and large lianas were counted in 0.03 ha and 0.36 sample plots, respectively. The errors bars show 95% CI.

Liana Infestation following Silvicultural Interventions

Liana loading or 'infestation' was dependent on forest type (Pearson χ^2 = 1197; df =12; P < 0.001; Figure 2). While about 9% of stems in PES and GLS were completely covered by lianas, only about 1% of trees in TSS and unlogged forest were completely covered by lianas. Approximately 90% of trees ≥ 20cm DBH in TSS were free of lianas, with ~ 81% of stems in the same category in unlogged forest. In PES and GLS forest, however, only about 46% and 41% respectively of stems were free of lianas.

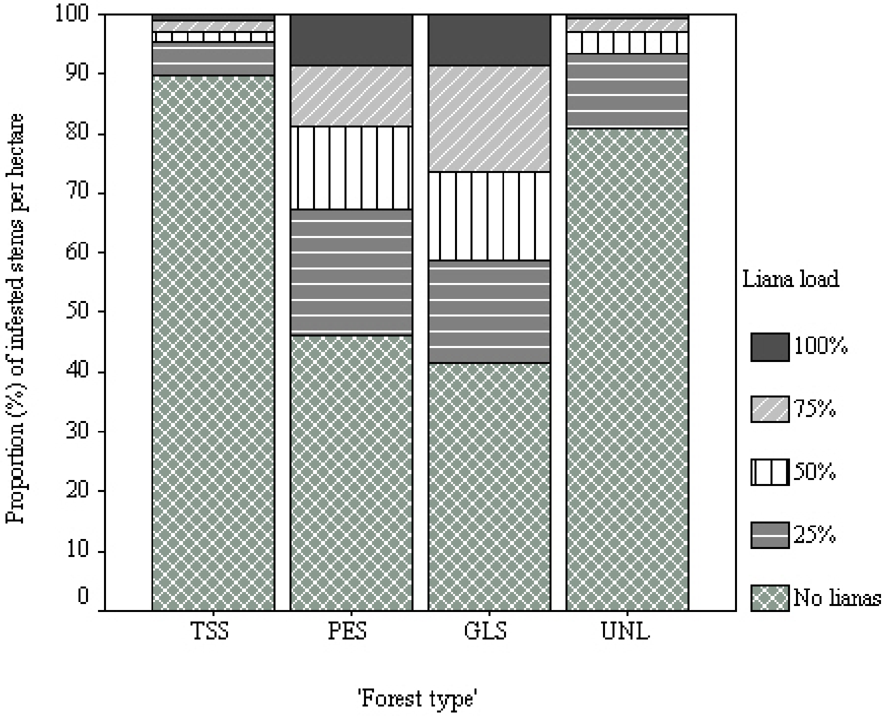

Figure 2: Intensity of liana loading on trees DBH>20 cm in treated (TSS, PES, GLS) and unlogged (UNL) forest, showing proportions (%) of individuals per ha that were either completely free of lianas or totally smothered. Intensity of infestation was assessed on a 5-point scale: 0 = no lianas; 1 = 25% of crown covered; 2 = 50% covered; 3 = 75% covered; 4 = 100% covered).

DISCUSSION

The results suggest that liana cutting, as a silvicultural intervention, affects small liana populations, although there is no distinction in the densities of large lianas between silviculturally-treated and unlogged forest if treatment is not repeated within a forty-year period. The preponderance of small lianas in unlogged forest could be the result of no intervention, or perhaps because they may be shade tolerant species that may have persisted in the understorey for many years. As noted by Putz (1990) while liana genets are extremely long-lived, diameter growth can be extremely slow and variable within and among species. In a study of 189 lianas representing 15 species in nine families in natural forest on Barro Colorado Island in Panama over an eight-year period, Putz (*ibid*) observed diameter growth rates ranging between 0.23 mm yr^{-1} (± 0.206 SD) and 5.82 mm yr^{-1} (± 0.593 SD), with a mean growth rate of 1.37 mm yr^{-1} (± 1.374 SD). He attributed the slow and variable rates of growth in diameter to variation in the amount of light available, noting that shaded individuals are likely to grow more slowly. This phenomenon probably explains the preponderance of small lianas in the unlogged forest in Bobiri reserve.

In a recent study carried out in Bobiri forest in comparatively smaller (50 m x 50 m) sample plots, Addo-Fordjour e*t al*. (2009) also reported a larger number of small lianas (2 - 5 cm) in the silviculturally treated plots. However, they concluded that larger diameter lianas were more abundant in the PES forest relative to the TSS forest. In the present study which was carried out on larger (one-hectare) sample plots, however, there was inadequate statistical evidence to suggest any difference in the density of large lianas in the silviculturally-treated stands. Furthermore, the present study is superior to the work of Addo-Fordjour and his colleagues, in that this study compared the effects of the silvicultural interventions on liana densities with liana populations in unlogged forest.

Intriguingly, the densities of large lianas in the silviculturally-treated stands did not differ from liana density in unlogged forest. One of the key objectives of the silvicultural interventions was to eliminate lianas and other non-commercial tree species in favour of the commercially important timber species. For this reason, the expectation is that large lianas would be completely absent. It is likely, however, that the interventions, which resulted in the creation of gaps, could have facilitated the re-sprouting /coppicing and regeneration of fast-growing lianas. Given that the interventions were only applied in the first few years of experimentation and not followed through in succeeding years as should have been done, this could have encouraged the fast-growing lianas to establish themselves during the 40 years. Even so, the densities of large lianas across treatments were much lower than the smaller diameter lianas in both treated and unlogged forest.

The intensity of infestation of trees by lianas was less severe in TSS and UNL forest relative to GLS and PES forest. Notably, though, liana infestation on individual trees was unrelated to the number of lianas in a plot. As was often the case, there were lianas in the forest that were not attached to trees because they were free standing or self-supporting. This could be related to the different disturbance regimes in the treated and unlogged forest or site conditions, or could even be attributable to the innate characteristics of those liana species. However, this would require further study for elaboration.

Foggie (1947) noted the presence of about 13 species of lianas, climbers, scramblers and epiphytes in Bobiri forest prior to silvicultural activities there. However, no data are available in respect of their densities for comparison with the present condition of the forest. Despite that, the results show that the densities of lianas are higher in Bobiri forest in Ghana relative to other logged-over tropical forests in Cameroon, Gabon and Malaysia (Table 2), probably as a result of differences in the levels of disturbance in these forests. Comparisons with other tropical and neo-tropical forests are presented elsewhere (*e.g.*, Gentry, 1982; Putz and Chai, 1987; Rice *et al*., 2004).

Table 2: Comparison of liana densities in logged-over forest in Cameroon (Parren, 2003), Gabon (Rollet, 1974 in Parren, 2003) and Pahang Malaysia (Appanah and Putz, 1984) with Bobiri forest in Ghana.

Location	Liana density (stems ha^{-1})	
	Small (DBH 2 - 5 cm)	Large (DBH > 5cm)
Cameroon	408	113
Gabon	272 - 304	78 - 126
Malaysia (Pahang)	197 - 370	81 – 191
Ghana (Bobiri, TSS)	567	39
Ghana (Bobiri, PES)	511	41
Ghana (Bobiri, GLS)	544	28
Ghana (Bobiri, UNL)	1,083	37

These results imply therefore that the silvicultural interventions, which had been aimed at promoting regeneration of desirable commercial species through targeted removal of all lianas and other undesirable tree species, were largely successful in the TSS forest given that liana infestation was lower in that forest type relative to the PES and GLS forest. Also, the higher density of small lianas in unlogged forest relative to the silviculturally-treated forest is suggestive that the treatments were effective, although complete elimination of lianas could not be achieved by silvicultural intervention. Clark (1996) observed that large lianas are characteristic of old growth forests and that in high-graded or logged forest their density is variable, depending on the history. Some authors contend that liana density may generally be higher in disturbed forest (*e.g.*, Putz, 1984; Putz and Chai, 1987; DeWalt *et al*., 2000; Ibarra-Manríquez and Martínez-Ramos, 2002), although Rice *et al*. (2004) reported more liana stems in less disturbed forest than in relatively more disturbed forest in Puerto Rico. The Bobiri results corroborate Rice and her colleague's results when all lianas DBH ≥ 2cm are considered, even though they measured lianas down to 1 cm DBH and the forests they sampled had been subjected to relatively more intense disturbances, unlike in Bobiri forest.

The higher levels of 'infestation' of trees by lianas in PES and GLS relative to TSS and unlogged forest may be ascribed to the relative timing of cleaning and regeneration, especially in the treated stands. In the PES and GLS forest where timber harvesting preceded cleaning operations it is likely that the conditions created must have been favourable for the regeneration of lianas; more so, the regenerating climbers did not lack climbing support that was available in the residual stand. By contrast, the trees that would have provided climbing support in the TSS forest were removed earlier during timber harvesting and subsequent cleaning operations. In effect, the regenerating lianas, apart from having much less favourable opportunities in terms of mechanical climbing support from the young regeneration, must also have suffered undue competition for resources from the more or less uniform stand of vigorously regenerating trees. Further studies will however be required to elucidate and/or corroborate these suggestions.

Studies conducted in other tropical forests seem to suggest that liana infestation of large trees is a common phenomenon. For instance, in Barro Colorado Island in Panama Putz (1984) observed that about 43% of trees DBH ≥ 20 cm were infested with lianas. Similarly, more than 50% of trees DBH ≥ 20 cm were reportedly infested with lianas in Sabah, Malaysia (Putz and Chai, 1987; Campbell and Newbery, 1993), whereas Pérez-Salicrup *et al*. (2001) reported that 86% of trees DBH ≥ 10 cm were infested in Amazonian forest in Bolivia. The present study has shown that about 44% and 49% of trees DBH ≥ 20 cm treated under the PES and GLS, respectively, were infested with lianas in Bobiri forest. Trees in the TSS and UNL forest recorded the least levels of infestation, with only 10% and17.3% of trees infested in those forest types. The higher levels of infestation in the post exploitation treated plots (PES and GLS) suggests that the timing of interventions, *i.e*., climber cutting and silvicultural tending after tree harvesting probably favours the preponderance of lianas in treated forest. This may be the result of the increased availability of resources, e.g., light and tree trellises that support the regenerating lianas.

CONCLUSION

The results of the present study lead to the conclusion that the intervention sites had lower densities of lianas relative to the unlogged sites, implying that even 40 y later the impact of climber cutting was measurable. Also, although liana density was not distinct among the silviculturally treated stands, the interventions used in PES and GLS promoted greater access to tree crowns by lianas. This implies that the timing of silvicultural interventions in the initial years of a cutting cycle is important since it influences the level of liana loads in tree crowns in the long term. For management purposes the techniques adopted under the TSS is demonstrably more effective at reducing liana load in tree crowns and is therefore the preferred option.

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