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Diversity and Structure of Climbing Plants in an Urban Forest Fragment

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Abstract: Climbers are herbaceous or woody plants that germinate in the soil and remain rooted throughout their lives, needing other plants to support their development. The aim of this study was to analyze the edge effect on the climbing plant community in the forest fragment of the Federal University of Amazonas. Fifty plots were set up for sampling. The species were grouped and phytosociological parameters were calculated. A total of 613 individuals were recorded, represented by 13 families found inside and on the edges of the UFAM forest fragment. The family with the highest ecological importance value (IV) was Fabaceae. The genera Bauhinia and Derris had the highest ecological importance values, both at the edge and in the interior of the forest. The scandent climbing mode was the most important and was observed in 56 species. This study confirmed the diversity of climbing plants. Although there were more climbing plants at the edge of the forest than in the interior due to the greater luminosity, the scandent climbing habit was abundant in both environments. Climbing plants are a part of the native vegetation of the forest fragment with their richness and diversity. Among other roles, climbing plants contribute ecologically by providing food and shelter for living organisms.

Keywords: Forest fragment, Climbing plants, Ecological importance.

1. Introduction

The Amazon forest includes a series of plant communities that play vital roles in maintaining biodiversity (TerSteege et al., 2013, 2020) Tree communities dominate the vegetation (Ter Steege et al., 2020; Romero et al. 2021), but a community of climbing plants is part of the same forest and can be used as bioindicators of altered forests (Seger et al., 2017; Putz, 2011). Climbing plants are more common at the forest's edges, and as one advances deeper into the forest, they become scarcer (Gentry, 1991; Schnitzer & Bongers, 2002). In some cases, climbers reach the upper stratum of the forest, using trees as their host (Gentry, 1991; Darwin, 1865). Climbers are heliophilous plants found in either herbaceous or woody form, requiring other plants for their support and development (Darwin, 1865; Gentry, 1991; Campbell & Newbery 1993; Putz, 2011).

Vines can also interact with trees in a negative way, especially lianas (high-climbing woody vines). A high density of lianas can generate an excessively heavy load, breaking the branches of the trees, deforming their canopies and reducing their leaf area, growth, and fecundity (Putz, 1984; Engel et al., 1998). Lianas reproduce quickly and compete with trees for light, water and space, making lianas detrimental to the biodiversity of a site if present in large numbers, in which case it is necessary to manage these species to keep the vegetation balanced (Campbell & Newbery, 1993; Villagra & Neto 2010).

A very important characteristic of climbing plants is that they grow rapidly compared to tree species and can often dominate the crowns of supporting and neighboring trees (Campbell & Newbery, 1993; Udulutsch et al., 2010). Knowledge of this group of plants is of fundamental importance for the study of forest dynamics and management due to the group's diversity and ecological importance (Duarte, 2000; Wright, et al., 2004). Although their presence is more beneficial than harmful, a very high abundance of vines can interfere with the natural dynamics of these forest fragments (Campbell & Newbery, 1993; Weiser, 2007).

Studies on the importance of climbing plants to the forest community are still incipient (Gerwing et al., 2006). This lack of data may be related to the difficulty of collecting in the forest canopy (Schnitzer et al., 2008) and may also be associated with problems in identifying this diverse group (Gerwing et al., 2006). The present study aims to determine the horizontal structure of climbing plants in order to characterize their occurrence at the edge and in the interior of a forest fragment, as well as to classify their climbing mechanisms.

2. Materials and Methods

2.1. Study area

The study was carried out in the forest fragment of the Arthur Virgílio Filho University Campus at UFAM (Federal University of Amazonas) (03º04'34" South latitude; 59º57'30" West longitude)(Figura 1), located in the central Amazon in the municipality of Manaus, Amazonas, Brazil (Müller-Dombois & Ellenberg, 1974; Ducke & Black, 1954). The area of the UFAM fragment totals 6.7 million square meters, with a perimeter of 16.9 km (Caldas, 2016). This area is the largest natural fragment in an urban area in Brazil (Ribeiro, et al. 1999) and is part of the Floresta Manaós Environmental Protection Area (APA), a sustainable-use conservation unit (Pereira, 2022). The fragment contains five types of vegetation cover: alluvial dense ombrophilous forest, submontane dense ombrophilous forest, open ombrophilous forest, grassland and human-altered areas (Duarte, 2000; de Mendonça et al., 2022). It is an Environmental Unit (UNA) of the Municipality of Manaus created by Municipal Law No. 321 of December 20, 1995, with a large proportion of intact areas covered by forest in which there are altered areas used for the construction of buildings, roads and parking lots(de Mendonça et al., 2022; Pereira, 2022). The plant formations in the UFAM fragment produce a variety of microhabitats that harbor a diverse flora and fauna (Pereira, 2022; Lopes et al., 2022; Rubim et al., 2022). However, the forest is under constant threat from occupation and misuse from the surrounding urban neighborhoods (Ribeiro et al., 1999).

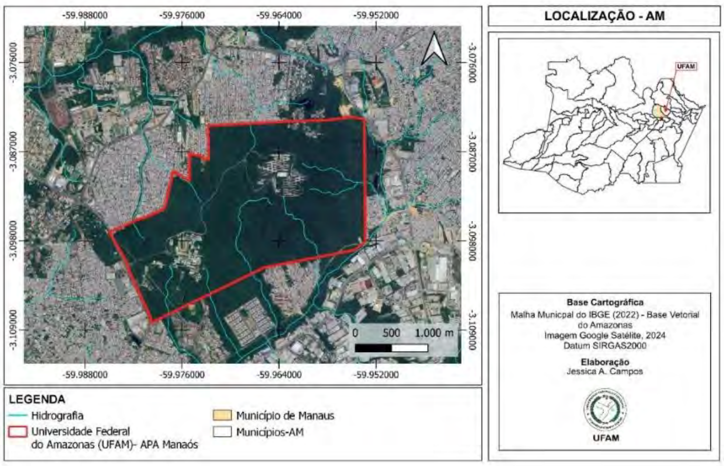

Figura 1: UFAM Campus location map

2.2. Sample design

In this study the term "climber" is used as proposed by Weiser (Peixoto & Gentry, 1990) to designate autotrophic, vascular plants that germinate in the soil and maintain contact with it throughout their life cycle, which lose the ability to support themselves as they grow and require mechanical support for their development. To sample the individuals, 50 plots measuring 10 m × 20 m (10,000 m² total) were set up inside the forest, 100 m from the edge and with a 5-m distance between plots. Similarly, 50 plots measuring 10 m × 20 m (10,000 m² total) were set up at the edge of the forest, 20 m from a road (Morellato & Leitão Filho, 1996; Parren & Bongers, 2005).

2.3. Measurement characteristics and identification of climbing plants

Climbing plants with stems ≥ 1 cm DBH (Diameter at Breast Height measured 1.30 m above the ground) were included in the sampling (Morellato & Leitão Filho, 1996; Maia, 1991). For the measurements, protocols proposed by Maia (1991) and Laurance, et al. (2014) were adopted, and the DBH and climbing mechanism was recorded for each individual. The compositional analyses cover the inner part of the forest, where measurements were taken at 1.30 cm above the main rooting point. To determine the phytosociological parameters of the creepers, the following values were

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calculated: absolute density (AD), relative density (RD), absolute frequency (AF) and relative frequency (RF) (Fearnside, 2013; Romero, et al. 2020). Excel software and the R program were used to process and analyze the data (Romero, et al. 2020). Species identification was carried out by a parabotanist, followed by verification based on the book Flora da Reserva Ducke (Phillips et al., 2002) and subsequent confirmation in the herbarium of the Federal University of Amazonas.

2.4. Analysis of climbing mechanisms

For each individual, the main form of ascent to the canopy was observed. Adding these observations to data from the literature, the species were grouped into three categories: voluble vines, prehensile vines and climbing vines. Voluble plants were those that wrap themselves around the supporting vegetation by means of branches, stems and/or petioles. Prehensile plants are those that reach the canopy by attaching themselves to their support by means of modified structures such as tendrils Scandent plants are those that climb by leaning passively on a support, according to the protocol of Gerwing et al. (1991).

3. Results and Discussion

A total of 613 individuals were cataloged, representing 13 families. The family with the highest ecological importance value (IV) was Fabaceae in both the interior (21.1%) and the edge (21.1%). It should be noted that the IVs of the families were affected by the number of individuals found in the plots in both environments. The ecological importance values of plant families in the two environments are detailed in Table 1.

Table 1. Ecological importance values of the species (climbers) collected in the two environments in 100 sampling plots in the UFAM fragment. RD (Relative Density), RDo (Relative Dominance), RF (Relative Frequency) and IV (Importance Value).

Family	Environment	N	RD (%)	Rdo (%)	RF (%)	IV (%)
Fabaceae	Interior	166	27.080	9.280	27.080	21.147
Fabaceae	Edge	148	24.144	38.822	0.464	21.143
Dilleniaceae	Edge	53	8.646	31.550	0.144	13.447
Bignoniaceae	Edge	61	9.951	6.838	0.188	5.659
Dilleniaceae	Interior	43	7.015	1.392	7.015	5.141
Bignoniaceae	Interior	23	3.752	0.777	3.752	2.760
Hippocrateaceae	Edge	28	4.568	3.471	0.086	2.708
Menispermaceae	Edge	16	2.610	2.778	0.040	1.809
Hippocrateaceae	Interior	21	3.426	1.772	0.127	1.775
Malpiguiaceae	Interior	19	3.100	0.247	0.775	1.374
Convolvulaceae	Edge	8	1.305	0.984	0.021	0.770
Malpiguiaceae	Edge	4	0.653	0.883	0.009	0.515
Menispermaceae	Interior	6	0.979	0.395	0.032	0.469
Sapindaceae	Edge	2	0.326	0.552	0.004	0.294
Convolvulaceae	Interior	3	0.489	0.114	0.070	0.225
Sapindaceae	Interior	3	0.489	0.067	0.082	0.213
Apocynaceae	Interior	3	0.489	0.012	0.029	0.177
Polygalaceae	Interior	2	0.326	0.026	0.036	0.130
Polygonaceae	Interior	1	0.163	0.002	0.082	0.082
Rubiaceae	Interior	1	0.163	0.025	0.007	0.065
Apocynaceae	Edge	1	0.163	0.009	0.003	0.058
Verbenaceae	Interior	1	0.163	0.003	0.007	0.058
Total		**613**	**100**	**100**	**100**	**100**

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The family Fabaceae had the highest IV both inside and on the edge of the forest in the UFAM fragment. These results, when compared with other studies in central Amazonia, show the same behavior and predominance of this family (Schnitzer & Bongers, 2011; Wright et al., 2004). However, they differ in the forest environments. In the present study, Fabaceae was found on terra firme (unfooded uplands). This family is known to occupy both plateaus and slopes and has various types of plant habit (Schnitzer & Bongers, 2011). Fabaceae (Schnitzer & Bongers, 2011). This suggests that Fabaceae can adapt to different environments.

Other families, such as Dilleniaceae, Bignoniaceae, Apocynaceae, Malpighiaceae and Sapindaceae, contribute almost half of the genera and species (Gentry, 1991). Bignoniaceae is one of the richest and most common families in Neotropical forests, especially in dry forests (da Silva et al., 2021). We found 120 species totaling 613 individuals in our 100 plots.

3.1. Ecological importance values of the species collected in the interior and at the edge

In the 50 plots within the forest, a diverse array of climbing plants was identified, encompassing a total of 34 types and comprising 292 individuals. Notably, the ecological significance was most pronounced in three genera: Bauhinia (29.5%), Derris (15%), and Doliocarpus (10.4%), as outlined in Table 2. The number of individuals was higher at the edge of the forest than in the interior, which is justified by the shading that occurs in the interior. The greater abundance of lianas at the edges can be both a cause and a result of the greater light availability at the edge.

Members of the genus Bauhinia with a climbing habit have an impressive capacity to entwine and ascend other vegetative structures, such as trees or shrubs, in pursuit of support for their growth. The distinctive morphological characteristics of this genus encompass bilobed leaves reminiscent of boat hulls, along with vibrant flowers in hues of white, pink, lilac, or purple. The fruits, which are often of the pod type and common across diverse Bauhinia species (Wang et al., 2014), encapsulate seeds dispersed through various mechanisms, including the wind (Jia et al., 2022). Certain climbing Bauhinia species have developed adaptations that allow them to flourish in shady environments under the dense forest canopy. Bauhinia flowers are regularly pollinated by insects, particularly bees, and the fruits attract birds or other animals for seed dispersal (Wang et al., 2014; Jia et al., 2022).

Oliveira et al. (2008a,b) also recorded the genus Bauhinia. with the highest VI in a study conducted 90 km northwest of Manaus. Likewise, Maia (1991), evaluating the phytosociological aspects of lianas in terra firme forest in the Manaus region, recorded Bauhinia as one of the genera with the highest importance values. Similarly, Ziccardi et al. (2019), in their assessment of the phytosociological aspects of lianas in terra firme in Acre, highlighted Bauhinia as one of the genera with notably high importance values. Bauhinia stands out as the predominant genus in the UFAM forest fragment.

In general, the 36 genera of lianas found in the forest edge can employ rapid growth strategies to reach the light at the top of the forest. A distinctive feature of these genera is their ability to harbor rich biodiversity, including insects, birds, and other types of plants. Moreover, they play a crucial role in forest ecology by contributing to the maintenance of the forest structure and actively participating in ecological dynamics. It is worth noting that the diversity among the different genera in this environment is significant, and specific characteristics can vary considerably among these liana genera. A more detailed analysis is necessary to identify a specific species and understand their particular characteristics in the Amazon region.

Table 2. Ecological importance values of climbers collected in 50 sampling plots in the interior of the UFAM fragment. RD (Relative Density), RDo (Relative Dominance), RF (Relative Frequency) and IV (Importance Value).

Genus	Environment	N	RD (%)	Rdo (%)	RF (%)	IV (%)
Bauhinia	Interior	63	21.6	45.3	21.6	29.5
Derris	Interior	53	18.2	9.7	17.1	15.0
Doliocarpus	Interior	29	9.9	8.4	13.0	10.4
Acacia	Interior	20	6.8	7.0	7.1	7.0
Machaerium	Interior	20	6.8	2.7	6.0	5.2
Memora	Interior	10	3.4	3.9	4.4	3.9
Tontelea	Interior	10	3.4	2.7	4.4	3.5

Banisteriopsis	Interior	14	4.8	0.8	3.1	2.9
Tetracera	Interior	12	4.1	1.1	3.0	2.7
Cheiloclinium	Interior	4	1.4	4.9	1.9	2.7
Abuta	Interior	6	2.1	2.8	3.0	2.6
Hylenaea	Interior	3	1.0	4.4	1.0	2.2
Dalbergia	Interior	8	2.7	0.2	1.6	1.5
Peritassa	Interior	4	1.4	0.5	1.7	1.2
Mascagnia	Interior	3	1.0	0.6	1.8	1.1
Distictella	Interior	3	1.0	0.7	1.2	1.0
Mimosa	Interior	2	0.7	0.9	1.2	0.9
Arrabidaea	Interior	3	1.0	0.4	1.1	0.8
Odontadenia	Interior	3	1.0	0.1	1.0	0.7
Pinzona	Interior	2	0.7	0.4	1.1	0.7
Paullinia	Interior	2	0.7	0.5	0.7	0.6
Mezia	Interior	2	0.7	0.4	0.4	0.5
Dicranostyles	Interior	1	0.3	0.7	0.3	0.5
Pleonotoma	Interior	2	0.7	0.2	0.4	0.4
Mansoa	Interior	1	0.3	0.3	0.5	0.4
Martinella	Interior	3	1.0	0.0	0.1	0.4
Maripa	Interior	2	0.7	0.1	0.2	0.3
Securidaca	Interior	1	0.3	0.2	0.4	0.3
Malanea	Interior	1	0.3	0.2	0.3	0.3
Petrea	Interior	1	0.3	0.0	0.3	0.2
Moutabea	Interior	1	0.3	0.0	0.1	0.2
Serjania	Interior	1	0.3	0.0	0.1	0.1
Coccoloba	Interior	1	0.3	0.0	0.0	0.1
Pyrostegia	Interior	1	0.3	0.0	0.0	0.1
Total		**292**	**100.0**	**100.0**	**100.0**	**100.0**

In 50 plots in the edge environment, 25 genera of climbing plants were identified in total, amounting to 321 individuals. Particularly noteworthy were the genera *Derris* (18%), *Doliocarpus* (14.4%), and *Dalbergia* (8.2%), which exhibited the most favorable results for phytosociological parameters. Among them, *Derris* and *Doliocarpu*s stood out with the highest importance values (IVs), as detailed in Table 3.

Climbers in the genus *Derris* exhibit a remarkable capability to entwine and ascend other plants, seeking support for their growth (Oliveira et al., 2008a,b). Their growth pattern is intricately adapted to vertically navigate the forest environment (Oliveira et al., 2008a,b). *Derris* lianas commonly have leaves displaying morphological variations, which may take on alternate or opposite arrangements, contingent on the species. The shape and size of the leaves can vary distinctly among different species (Ribeiro et al., 1999).

Derris flowers emerge in distinct inflorescences, presenting a diverse range of colors and structures among species. Some varieties may have small discreet flowers, while others stand out for their more showy and attractive flowers (Ribeiro et al., 1999; Hopkins, 2005). As for fruits, diversity is evident among the various types of *Derris* vines (Ribeiro et al., 1999). Some produce fruits or capsules that house seeds, and their dispersal can occur through several mechanisms, including wind (Hopkins, 2005; Zang et al., 2021). These distinctive characteristics of *Derris* lianas not only highlight their skillful adaptation to the environment, but also underline the morphological and reproductive diversity present in this botanical group (Oliveira et al., 2008a; Zang et al., 2021).

In general, the 25 genera of vines in the UFAM fragment exhibit a greater abundance at the forest edge compared to the interior. Safeguarding the edges is imperative for maintaining the equilibrium and functionality of the forest in this fragment. This protective measure is essential to prevent the overgrowth of lianas (Ngute et al., 2024), thereby mitigating potential adverse impacts on overall local biodiversity.

Table 3. Ecological importance values of climbers collected in 50 sampling plots at the edges of the UFAM fragment. RD (Relative Density), RDo (Relative Dominance), RF (Relative Frequency) and IV (Importance Value).

Genus	Environment	N	RD (%)	Rdo (%)	RF (%)	IV (%)
Derris	Edge	56	17.4	18.7	17.7	18.0
Doliocarpus	Edge	28	8.7	25.0	9.4	14.4
Dalbergia	Edge	27	8.4	7.4	8.6	8.2
Machaerium	Edge	28	8.7	4.1	7.9	6.9
Acacia	Edge	17	5.3	9.7	5.4	6.8
Mimosa	Edge	20	6.2	5.3	6.2	5.9
Memora	Edge	21	6.5	3.9	6.6	5.7
Arrabidaea	Edge	23	7.2	1.7	6.7	5.2
Davilla	Edge	8	2.5	7.6	3.1	4.4
Abuta	Edge	16	5.0	3.2	4.6	4.3
Cheiloclinium	Edge	15	4.7	2.4	5.1	4.1
Tetracera	Edge	13	4.0	2.8	3.7	3.5
Adenocalymna	Edge	7	2.2	0.6	2.1	1.6
Cydista	Edge	5	1.6	1.4	1.8	1.6
Dicranostyles	Edge	5	1.6	1.0	1.8	1.5
Tontelea	Edge	7	2.2	0.4	1.6	1.4
Pinzona	Edge	4	1.2	1.3	1.2	1.3
Hylenaea	Edge	4	1.2	0.9	1.4	1.2
Mascagnia	Edge	4	1.2	1.0	1.1	1.1
Martinella	Edge	4	1.2	0.3	1.1	0.9
Paullinia	Edge	2	0.6	0.6	0.7	0.6
Maripa	Edge	3	0.9	0.2	0.8	0.6
Prionostema	Edge	2	0.6	0.3	0.8	0.6
Leucocalantha	Edge	1	0.3	0.0	0.2	0.2
Odontadenia	Edge	1	0.3	0.0	0.2	0.2
Total		**321**	**100**	**100**	**100**	**100**

Lianas are increasing in tropical forests worldwide as a result of their benefiting more from the increasing concentrations of atmospheric CO_2 as compared to trees (Schnitzer & Bongers, 2002; Parren & Bongers, 2005; Hegarty, 1991b; Lima-Ribeiro, 2008). Lianas are more abundant in parts of Amazonia where the climate is dryer than in the Manaus area, such as Maranhão, and this means that they are expected to increase in the region as a result of predicted climate change, adding to their role in a positive feedback process causing forest degradation (Murcia, 1995; Fearnside, 2013). In southwestern Amazonia another group of climbing plants plays a role similar to lianas: the climbing bamboos of the genus *Guadua* (locally known as "taboca") invade forest edges and disturbed areas within the forest, where they damage and kill trees (Greig-Smith, 1964; Laurance et al., 2001; da Silva et al., 2021).

Canopy closure and shading control liana infestation (Campbell & Newbery, 1993; Campbell et al., 2018). Edge effects involve changes in the abundance and distribution of species caused by

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abiotic factors in the vicinity of edges, such as increased plant density due to increased solar radiation (Campbell & Newbery, 1993; Villagra, 2008). Interspecific competition is expected to be greater in these environments, which leads populations to present increasingly aggregated spatial patterns. The abundance of vines is known to be positively associated with forest edges and areas of disturbance (da Silva et al., 2017). In large tracts of forest, vines (lianas) act as bandages that mend treefalls and seal the forest edge (Campbell & Newbery, 1993).

The vines in the fragment are indicators of natural disturbance, and, if a fragment is subjected to additional fragmentation, the vines that take advantage of spaces and light (clearings) become more numerous and can penetrate deeper into the interior of these forests (Campbell & Newbery, 1993). Lianas can kill trees or cause them to store less carbon, and their presence can also affect the diversity of tree species in the forest, thereby transforming the habitat for local animals. Changes in the growth and number of lianas can therefore cause fundamental changes in the structure of a forest and its functioning, which adds to the importance of protecting forest edges (Campbell & Newbery, 1993).

3.2. Types of climbing mechanisms inside and on the edge of the fragment

The results depicted in Figure 2 shed light on the diversity of climbing habits among plant species in the studied fragment. Notably, the scandent climbing mode emerged as the dominant strategy, being observed in 56 species. In contrast, the prehensile mode was noted in 12 species, while the voluble mode manifested in 11 species. Delving into the specifics of the forest interior, an intriguing pattern emerged, with 70.89% of climbers employing the scandent climbing mechanism, underscoring its prevalence. Meanwhile, 15.19% exhibited the prehensile mode, and 13.52% embraced the voluble mode in this environment. At the forest edge, a nuanced shift in climbing strategies was observed, with 60.98% adopting the scandent mode, 31.71% opting for the prehensile mode, and 7.32% favoring the voluble mode.

Figure 2. Climbing mechanisms.

The prominence of certain species at the forest edge further illuminates the intricate dynamics of climbing habits. Derris floribunda and the genera Bauhinia and Doliocarpus stood out, collectively representing a higher number of scandent, prehensile, and voluble species, emphasizing the adaptability of these plants to edge conditions. On the other hand, within the forest interior, the genera Derris, Mimosa and Acacia took the lead, each exhibiting a distinct climbing strategy, the scandent mode dominating with 53 individuals, followed by the voluble mode with 20, and the prehensile mode with 17. These findings prompt a discussion on the ecological implications of climbing habits, raising questions about the adaptive strategies of these plants in response to varying light conditions and resource availability. The prevalence of certain climbing mechanisms at different locations within the forest fragment provides valuable insights into the complex interplay between plant species and their environment.

In a research endeavor conducted in the state of São Paulo, all three climbing mechanisms were identified, with the voluble mode being the most prevalent (Villagra, 2008; Villagra & Neto, 2010). However, our study reveals a notable departure from this trend, as the scandent mode emerges as the predominant climbing strategy in both the forest edge and interior environments. This observation hints at the possibility that climbing plants might adapt and create distinct climb-

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ing patterns based on the specific characteristics of their surroundings. This finding opens up intriguing challenges and avenues for further exploration in the realm of plant adaptation and ecological dynamics.

4. Conclusions

The diversity of climbing plants was confirmed in the UFAM fragment, with more individuals of climbing plants at the edge of the forest than in the interior. This is because there is more light at the edge of the forest and, consequently, the number of individuals increases. Lianas are indicators of disturbance in forest fragments, and it is necessary to guarantee the balance and functionality of the forest in this fragment to avoid liana infestation in the fragment's interior and to prevent greater impacts on the fragment's biodiversity of tree species. Lianas were abundant in both interior and edge environments, with Fabaceae being the most common liana family. From a phytosociological point of view, climbing plants play an essential role in the diversity and richness of plant species in the forest fragment of the Federal University of Amazonas. In balance with the forest, climbing plants also contribute ecologically by providing food and shelter for wildlife and other living organisms, as well as organic matter, among other components. However, this balance can be disturbed, leading to increased infestation by lianas and further degradation of the forest.

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