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ORIGINAL ARTICLE

Natural regeneration dynamics of three species of lianas in forest gaps - Moju, Pará state, Brazil

Dinâmica da regeneração natural de três espécies de cipós em clareiras, Moju-PA

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Rourea krukovii

ABSTRACT: Lianas or vines are forest components with poorly defined ecological function that intertwine the treetops, making logging difficult. This study evaluated the ecological behavior of *Rourea krukovii*, *Derris amazonica* and *Arrabidea nigrescens* species of lianas around gaps classified as small, medium and large, after logging. Around these gaps, 10 m x 50 m transects were installed from the borders into the forest. Each transect was divided into 10 m squared plots , numbered 1 to 5, in order to measure individuals with diameter at breast height (DBH) ≥ 5 cm. Sub-plots of 4 m^2 were installed in plots 1, 3 and 5 to measure individuals with total height ≥ 10 cm and DBH < 5 cm. The behavior of species was evaluated by the Natural Regeneration Rate (RR) related to the variables that indicate gradients of light, such as gap size, distance from the gap border, monitoring time, and Periodical Annual Increment in height (PAI). The species assessed presented different responses with respect to the light gradients established by the factors studied, and it was not possible to classify them as tolerant or intolerant species. None of the species showed significant influences of the factors gap size and distance from the gap border on the RR. However, *Arrabidea nigrescens* showed influence of monitoring time on these factors at the end of the study. PAI in height decreased over time for the three species studied, indicating the influence of the competition suffered by these species in relation to growth factors.

RESUMO: *Cipós ou lianas são componentes florestais com função ecológica pouco esclarecida, mas representam importante componente da estrutura das florestas, entrelaçando as copas das árvores e dificultando a exploração madeireira. É importante, para a silvicultura, o estudo do seu comportamento populacional. Neste estudo, avaliou-se o comportamento de Rourea krukovii, Derris amazonica e Arrabidea nigrescens, espécies de cipós, em torno de clareiras da exploração florestal, classificadas como pequenas, médias e grandes, em torno das quais foram instaladas faixas de 10 m x 50 m, da borda para dentro da floresta. Cada faixa foi dividida em parcelas quadradas de 10 m de lado, numeradas de 1 a 5, para amostrar os indivíduos com DAP ≥ 5 cm. Nas parcelas 1, 3 e 5, instalaram-se subparcelas de 4* m^2*, para amostrar indivíduos com altura total ≥ 10 cm e DAP < 5 cm. O comportamento das espécies foi avaliado por meio da Taxa de Regeneração Natural (TR) em relação a fatores que indicam gradientes de luz, como tamanho das clareiras e distância da borda das clareiras, o tempo de monitoramento e o Incremento Periódico Anual (IPA) em altura. As espécies estudadas apresentaram respostas variadas em relação aos gradientes de luz presumidos pelos fatores estudados, não se podendo classificá-las entre espécies tolerantes e intolerantes. Nenhuma das espécies apresentou influências significativas dos fatores tamanho de clareiras e distância da borda das clareiras sobre a TR. Todavia, Arrabidea nigrescens mostrou influência do tempo de monitoramento sobre esses fatores ao final do estudo. O IPA em altura diminuiu ao longo do tempo para as três espécies, indicando a influência da competição sofrida pelas mesmas em relação aos fatores de crescimento.*

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1 Introduction

Natural regeneration ensures the survival of forests, although some tree species present very small juvenile populations, which may be related to floristic diversity, ecological gradients, or pre-occupation of forest gaps by pioneer species, reflecting the successional stage (Venturoli et al., 2007). These gaps are discontinuities or openings in the canopy of a forest, caused by several factors such as the falling of tree branches or of one or more whole trees.

The size of these openings varies considerably depending on the causative agent, and their areas tend to grow with the size of fallen trees, but small gaps can be caused by falling tangles of lianas, falling branches, or by the gradual disintegration of crowns of dead standing trees (Lima, 2005). In any way, the size of the canopy opening is a parameter that must be taken into account in the study of forest dynamics, because it influences floristic composition, often determining the spatial distribution of species (Jardim et al., 2007).

Lianas are forest components with ecological function poorly defined in the literature. It is possible to affirm that they play an important role as a source of food for wildlife, especially the aerial fauna, besides being an important component of the structure of forests (Jardim; Hosokawa, 1986). Generally speaking, lianas are woody vines that begin the cycle of life as terrestrial plants and to reach the forest canopy in search for light, depend on external support structures during their development (Vidal; Gerwing, 2003), which may cause deformation of stems (Yared, 1996).

In silviculture, lianas act as stabilizing elements of the canopy by interleaving the treetops, and this function is an obstacle to forest management because it hinders the operations of harvesting (Vidal et al., 2003). For this reason, vine cutting is recommended as an important mitigating action of the impacts of logging and, therefore, should be applied before exploitation (Silva et al., 2005). In this case, its application is not aimed directly at increasing the primary productivity of forests. Nevertheless, secondarily, this is a deemed effect, since its withdrawal alters the structure of the forest canopy by removing part of the phytomass, opening it and allowing the entry of photosynthetically richer radiation to the lowest strata of the forest.

The proliferation of lianas in forest gaps can reduce the growth of trees, increase their mortality by light interception and increased root competition, mechanically prevent trees to grow tall, and shelter predators of seeds and seedlings (Schnitzer et al., 2000).

Lianas showed variation in the estimated structural parameters over twelve years of monitoring of managed forest. However, the trend for this way of life was contrary to that observed in the community, with decreasing values until the third year and growing values as of the tenth year, except for the frequency parameter. This decreasing trend verified in the early years was attributed to an interaction between the heliophilous character of the species of this way of life and the closure of forest gaps, stabilizing in later years (Mendes et al., 2013). Nevertheless, specific studies on populations of lianas are scarce in the literature. More specific studies must be developed in managed forests, mainly regarding population dynamics, to give support to silvicultural decision.

The population dynamics of species expresses the interaction of the processes of recruitment, mortality, and growth. With this objective, the natural regeneration rate (RR) proposed by Jardim (1986) analyzed the population dynamics of species in forests, aggregating in one single expression the balance between recruitment and mortality. However, this expression presented problems of mathematical indeterminacy when assessing the recruitment of a new species in the sampling, which the author attributed conventionally to be 100%.

Therefore, a new expression was suggested for the RR (Mory, 2000), which has already been used in several studies on natural regeneration dynamics in the region of Moju, Pará state (Mory; Jardim, 2001; Jardim; Vasconcelos, 2006; Santos; Jardim, 2012; Viana; Jardim, 2013). This new RR eliminates the mathematical indeterminacy of the previous model (Jardim, 1986) with respect to the recruitment of a new species in the sampling and restricts the variation of the RR to the range between -100% (suppression of the species in the sample) and 100% (recruitment of a new species in the sample).

Lianas can also recruit in gaps through immigration (seed rain) and soil seed bank, or may resprout prolifically, producing many new branches (Schnitzer et al., 2000), indicating a basic similarity to trees in terms of population dynamics, which can facilitate silvicultural decisions in forest management.

The purpose of this study was to assess the regeneration rate, periodical annual increment in height, and natural regeneration dynamics of three species of lianas (*Derris amazonica* Killp – cipó derris, *Arrabidea nigrescens* Sandwith – cipó corimbó and *Rourea krukovii* Steyerm. ex Standl. – cipó cunário) with respect to gap size, distance from the gap boarder, and time of selective logging in the municipality of Moju, state of Pará, Brazil.

2 Materials and Methods

The study was carried out at the Experimental Field of 'EMBRAPA Amazônia Oriental', located at km 30 on highway PA 150 in the municipality of Moju, Pará state. The field comprises an area of 1059 ha situated at 2° 07' 30" S and 2° 12' 06" S latitudes and 48° 46' 57" W and 48° 48' 30" W longitudes.

The climate in the region is Am_i (hot and humid) according to Köppen classification, with average annual temperatures ranging from 25 to 27 °C; rainfall between 2000 and 3000 mm, and monthly insolation between 148.0 and 275.8 h. The relief of the area is flat, with small undulations and slope ranging from 0 to 3%. Yellow Latosol is predominant in the area (Santos et al., 1985).

An area of 200 ha, which underwent selective logging in October 1997, was selected in the Experimental Field of 'EMBRAPA Amazônia Oriental'. In this area, we selected nine gaps caused by logging with sizes ranging from 231 to 748 m^2, classified as small (200-400 m^2), medium (401-600 m^2), and large (>600 m^2).

Around each selected gap, 10 x 50 m transects were installed from the border into the forest in the North, South, East and West directions, that is, four transects per gap. Each transect was divided into 10 m squared plots, which were numbered 1-5, from the gap into the forest. Sub-plots of 4 m^2 were installed in plots 1, 3 and 5 to measure individuals with total height ≥ 10 cm and DBH < 5 cm (Figure 1).

We conducted a quarterly monitoring from March 1998 to March 2001 of all individuals with total height (H_t) greater than or equal to 10 cm and DBH smaller than 5 cm, in a total of 13 surveys, in addition to two other measurements in March and October 2007, totaling 15 measurements. Another measurement was performed in 2010, totaling 16 measurements, thus completing 12 years of monitoring. This study considered the measurements with intervals of three, 9.5, and 12 years.

The behavior of species was evaluated by the natural regeneration rate (RR), defined as the ratio between the absolute abundance resulting from dynamic regeneration process (recruitment, growth and mortality) and the absolute abundance at the study baseline, expressed as percentage and represented by the expression (Mory, 2000):

$$RR = [(A_1 - A_0)/(A_1 + A_0)] \times 100$$

Where:

- RR= Natural regeneration rate in percentage;
- A_0= Initial absolute abundance;
- $A_1 = A_0 + nr - ne$ = Final absolute abundance;
- nr = nº of individuals that entered the study (recruitment);
- ne = nº of individuals that exit the study by mortality or change in size category.

The gaps were classified according to the size in area as: small (231-340 m^2), medium (437-600 m^2), and large (666-748 m^2).

Growth in height was analyzed by the periodical annual increment (PAI) in the different time periods (t) (3; 9.5 and 12 years).

$$IPA = \frac{(altura\ final - altura\ inicial)}{t}$$

To compare the means of RR in the treatments (gap size, monitoring time, and distance from the border), we used a random sample analysis through analysis of variance in the General Linear Model, with the aid of Minitab Release 14 software (McCkenzie; Goldman, 2004). In this context, the following hypotheses were considered:

- H_0: there is no influence of gap size, distance from the border, and time on the RR: $\mu_1=\mu_2$;
- H_1: RR is influenced by gap size, distance from the border, and time, and at least one of the means is different from the others: $\mu_1 \neq \mu_2$. The Tukey test at 5% significance level ($p > 0.05$) was used to compare the means of treatments.

3 Results and Discussion

Over a 12-year period, the monitoring of the *Rourea krukovii* species population showed variation of natural regeneration rate (RR) from a negative value of –33.3%, after 12 years in small gaps, to a positive value of 85.7%, after 9.5 years in medium gaps (Figure 2a). However, these differences in RR were not significant ($p > 0.05$) throughout the monitoring period regarding the variables gap size and distance from the gap border, which also ranged from a negative rate of –33%, at the gap border, to a positive rate of 100%, 40 m from the border (Figure 2b).

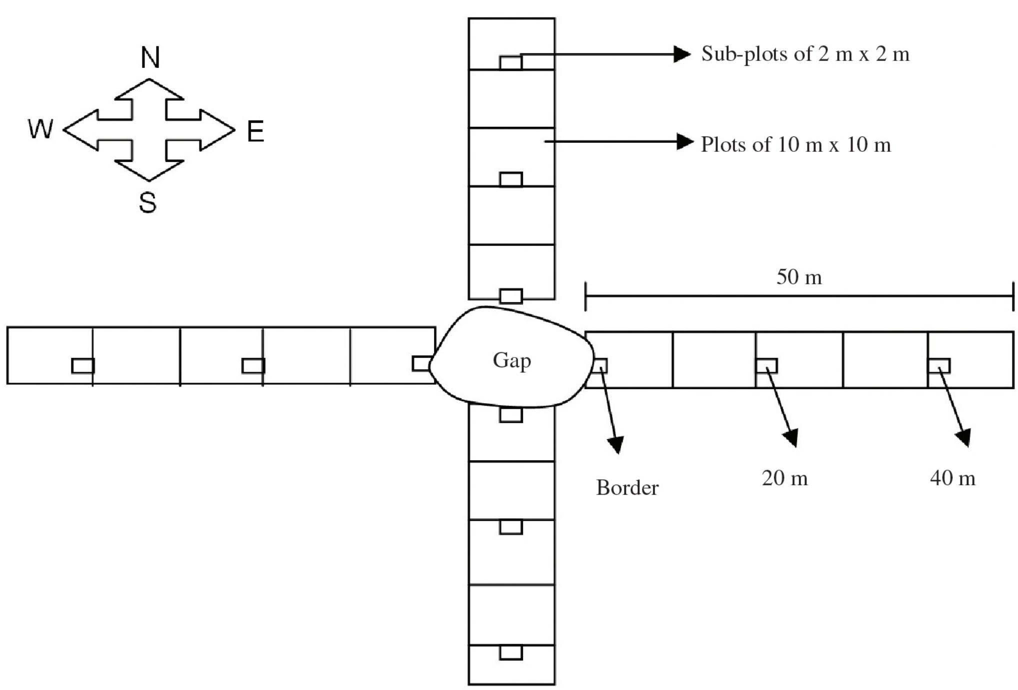

Figure 1. Spatial distribution of samples of natural regeneration in relation to the gap.

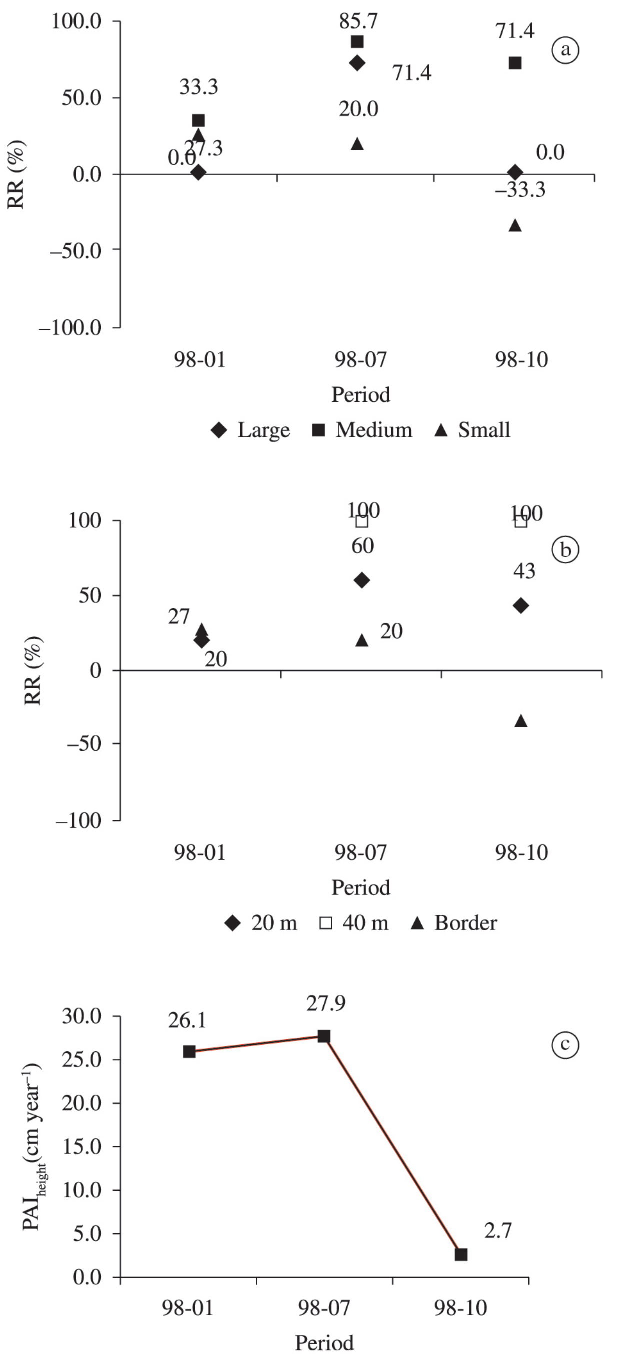

Figure 2. Natural regeneration rate (RR) dynamics of *Rourea krukovii* liana species in relation to gap size (a), distance from the border (b), and periodical annual increment (PAI) in height (c).

It is possible to observe that the studied population of *R. krukovii* species does not show any dependence on the light gradients presumed by the variables assessed: gap size, distance from the gap border, and closing time of gaps. In all the environments evaluated, there was strong recruitment in the population between 2001 and 2007, but it was not sustained in 2010, eventually being surpassed by the mortality of individuals of the species at the border of small gaps.

In the medium and large gaps, RR behavior presented the same trend over time, with higher values for the medium gaps (Figure 2a). On the other hand, in the beginning of the monitoring under canopy (20 and 40 m), there were individuals of this species, which arose only in the 2007 and 2010 measurements (Figure 2b).

Regarding the periodical annual increment (PAI) in height, *R. krukovii* species presented higher value 9.5 years after logging, with 27.9 cm year^{-1}, followed by three years of monitoring (26.0 cm year^{-1}), and lower value 12 years after logging, with 2.7 cm year^{-1} (Figure 2c), indicating that the canopy closing and the consolidation of the forest as a result of advancement in succession around the gaps affected the species growth. In this case, factors such as interspecific competition for water, light and nutrients may have influenced the species growth.

These results confirm the indifference of this species in relation to the light gradients presumed, indicating shade-tolerant behavior in the interior of the forest. The *R. krukovii* species population showed some relation with the light gradient associated with the course of time. At the beginning of the monitoring period, when the gaps presented increased light and changes in their quality (Whitmore, 1978), a positive RR of 27% was observed, declining to 20% after 9.5 years, and then to a negative value of –33% after 12 years with the gaps already closed, indicating predominance of mortality of the species individuals. For this reason, this decrease in the RR value was attributed to other factors, such as increased competition for water and nutrients over time.

The monitoring of the *Derris amazonica* species population indicated differences ($p < 0.05$) in the RR in relation to gap size (Table 1) and distance from the gap border (Table 2) at the end of the study.

At the end of the monitoring of the *D. amazonica* species population, gap size varied from a negative RR of –467%, in medium gaps, to –100%, in small gaps (Figure 3a). They also varied from a negative RR of –38.5%, at the gap border, to –100%, 40 m from the border (Figure 3b).

RR values were positive only at the beginning of the monitoring period, with 10% and 4.3% for large and medium gaps, respectively; indicating that in the first years after logging, *D. amazonica* species benefited from the opening of the canopy. This dependence on light is ratified in the small gaps, where the species has shown negative RR since the beginning, and over time in the middle and large gaps (Figure 3a), with negative RR at the end of the study period (after 12 years), which means a thinning of this species population.

These findings regarding the light gradients presumed: gap size, distance from the gap border, and closing time of the canopy; although not conclusive, indicate a strong demand for light for *D. amazonica* species.

Positive RR values indicate densification of the species population, while negative RR values indicate thinning of the species population. A null RR value represents a dynamic equilibrium in the species population, where mortality is compensated by recruitment at the same proportions (Mory; Jardim, 2001). The positive RR found in the large and medium gaps in the beginning of the monitoring period (Figure 3a)

Table 1. Natural regeneration rate (RR) of *Derris amazonica* liana species with respect to the size of gaps.

Monitoring period	RR (%)
1998-2001	1.33 a
1998-2007	–2.77 ab
1998-2010	–5.46 b

Values followed by the same letter do not differ significantly by the Tukey test ($p < 0.05$).

Table 2. Natural regeneration rate (RR) of *Derris amazonica* liana species regarding the distance from the border.

Monitoring period	RR (%)
1998-2001	–3.21 a
1998-2007	–6.67 ab
1998-2010	–8.33 b

Values followed by the same letter do not differ significantly by the Tukey test ($p < 0.05$).

shows a strong densification of the species population in the area, which was reversed by the large mortality in 2007 in all gap sizes, mainly in the small ones, as well as in the plots under closed canopy (20 and 40 m) (Figure 3b).

Derris amazonica species showed higher periodical annual increment in height in the beginning of the monitoring period (19.1 cm year^{-1}), with a decreasing trend over time: 13.1 cm year^{-1} after 9.5 years and 7.3 cm year^{-1} after 12 years (Figure 3c). This trend can be explained by a shade-intolerant behavior of the species, considering that there is a trend to canopy closing in the successional process in gaps, with increased interspecific competition for growth factors such as light, water and nutrients.

The monitoring of the *Arrabidea nigrescens* species population over 12 years did not indicate statistically significant difference ($p > 0.05$) in RR values with respect to the variables gap size and distance from the gap border.

Arrabidea nigrescens species presented positive RR in almost all monitoring periods, mainly in large and small gaps, where the population consolidation occurred in 1998 and 2001 was maintained over time (Figure 4a). In the medium gaps, however, all the population densification effect produced by the high recruitment in the 1998-2001 period was nullified by the high mortality occurred as of 9.5 years of monitoring.

Regarding the factor distance from the gap border, a strong densification of the *A. nigrescens* species population was verified 20 m from the gap border during the whole monitoring period. However, at the gap border and 40 m from the gap border, the recruitment occurred during the 1998-2007 period was reversed to the initial levels of 1998 by an equivalent mortality of individuals, resulting in a dynamic equilibrium of the species population, verified in the survey by Viana and Jardim (2013) after 12 years of monitoring (Figure 4b).

Regarding growth in height, *Arrabidea nigrescens* species presented an increment similar to that of *D. amazonica* species, with a higher value observed three years after logging (16.8 cm year^{-1}), which decreased over time, reaching 9.3 cm year^{-1} at the end of the study (Figure 4c).

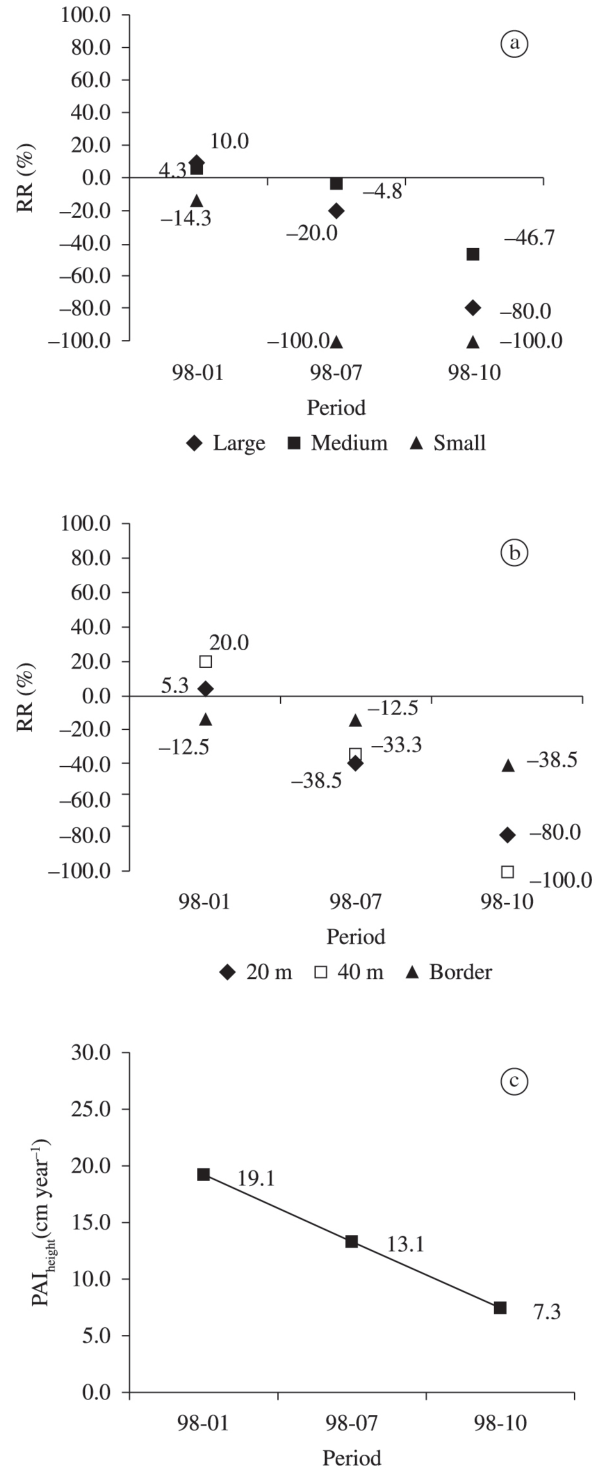

Figure 3. Natural regeneration rate (RR) of *Derris amazonica* liana species in relation to gap size (a), distance from the border (b), and periodical annual increment (PAI) in height (c).

There are few studies on the behavior of species of this type of life in managed forests in Amazonia; studies of this sort are more common on arboreal species. Lianas present the same basic form of growth as trees, mainly considering the ecophysiological demands of the ecological groups to which arboreal species belong and the juvenile developmental stage

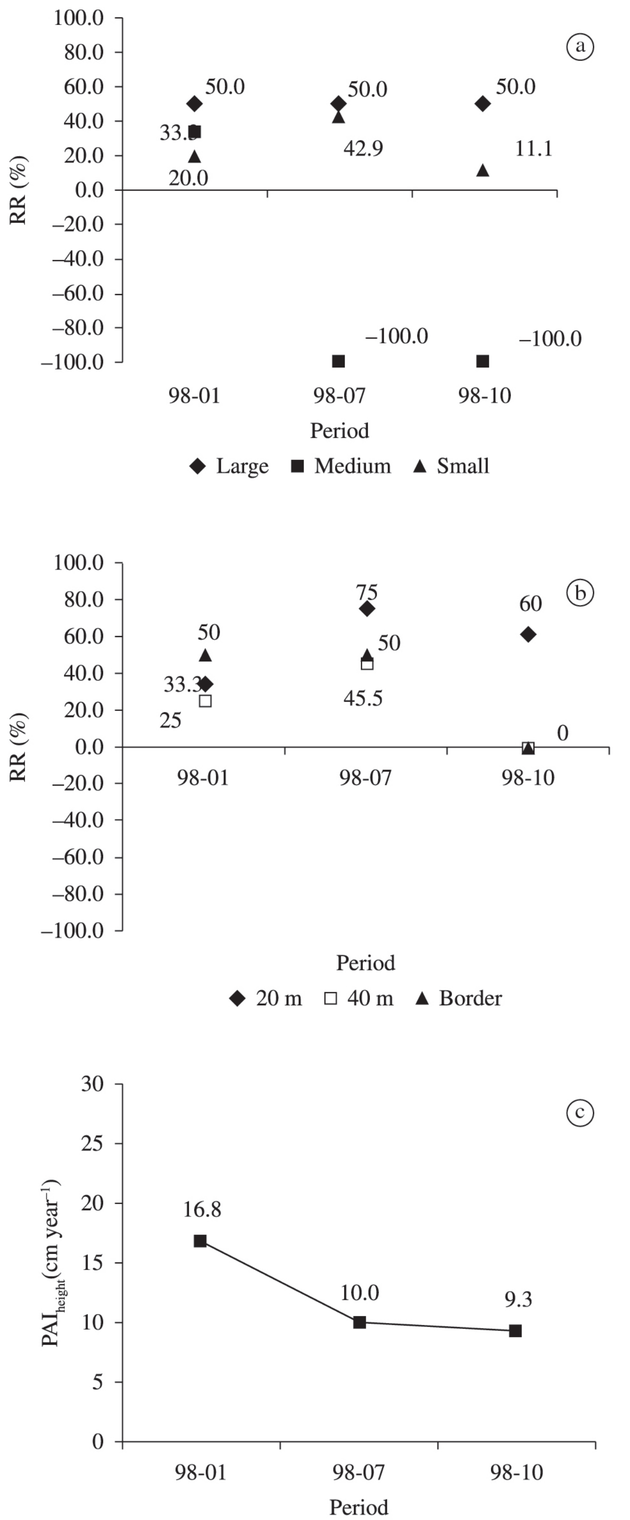

Figure 4. Natural regeneration rate (RR) of *Arrabidea nigrescens* liana species in relation to gap size (a), distance from the border (b), and periodical annual increment (PAI) in height (c).

of the liana species assessed. Based on these facts, it is possible to establish a comparison between tree species and the liana species investigated in the present study, which interact in the same way as tree species with the light gradients presumed: gap size, distance from the gap border, and closing time of gaps.

The arboreal species *Eschweilera coriacea* presented an RR value of –100% for 30 cm ≤ height < 1.5 m individuals in a secondary forest in a two-year monitoring period (Rayol et al., 2006). This elimination of individuals of the species in the samples is similar to the behavior of *D. amazonica* and *A. nigrescens* species in the present study, but this fact was only verified herein after 9.5 and 12 of monitoring.

A study carried out with commercial timber species in the same area (Nascimento; Jardim, 2002), with a monitoring period of three years, showed an RR value of 21.73% for *Couratari guianensis* species and a null RR value for *Manilkara huberi* species, similar to that of *R. krukovii* species in the present study; *Vouacapoua americana* species with an RR value of –10.76% was similar to that of *D. amazonica* species in the present study after 9.5 and 12 years of monitoring.

For *R. krukovii* and *A. nigrescens* species, the H_0 hypothesis was considered, where the factors monitoring time, distance from the gap border, and gap size did not influence the natural regeneration rate (RR). For *D. amazonica* species, the variable monitoring time influenced the species establishment.

Regarding growth, the three species analyzed showed the same trend, with faster growth after logging and reduction as the gaps were being closed. *Rourea krukovii* species presented the greatest reduction in the PAI in height, which decreased from 26.1 to 2.7 cm year^{-1}.At the end of twelve years of monitoring, the highest PAI in height was observed for *A. nigrescens* species (9.3 cm year^{-1}), followed by *D. amazonica* species with 7.31 cm year^{-1}.

4 Conclusions

The species of lianas assessed present different responses with respect to the light gradients established by the factors studied: gap size, distance from the gap border, and time of succession around the gap. Therefore, it is not possible to classify them as tolerant or intolerant to low insolation levels at this stage of development, although *D. amazonica* species preliminarily shows intolerant behavior.

The variables gap size and distance from the gap border do not influence the regeneration rate of the species investigated in their early monitoring phases. However, *A. nigrescens* species is significantly influenced by monitoring time with respect to these variables only at the end of the study period.

Regarding growth, however, it is evident that the periodical annual increment in height decreases over time for the three species studied, indicating the influence of the competition suffered by these species with respect to growth factors (water, light, nutrients, etc.). Nevertheless, a longer monitoring period is required to confirm this influence.

Liana species pose no problems for silvicultural management, because even their largest growth does not generate obstacles to the development of commercial tree species, and the population of lianas has not undergone substantial increases in density 12 years after logging.

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