REVISTA DE CIÊNCIAS AGRÁRIAS
Amazonian Journal
of Agricultural and Environmental Sciences
www.ajaes.ufra.edu.br

ORIGINAL ARTICLE

Fragmentation influences the diversity of riparian vegetation in the Eastern Amazon

A fragmentação influencia a diversidade da mata ciliar na Amazônia oriental

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ABSTRACT: Fragmentation is a consequence of anthropic actions that cause changes in land use and cover. Owing to the conversion of forest areas into agricultural use areas, riparian vegetation becomes susceptible to the effects of fragmentation. This generates changes that affect the structure and composition of vegetation in the forest remnants. Therefore, this study aimed to analyze the structure and floristic composition of riparian vegetation with 30 m in a fragmented matrix. Accordingly, adult vegetation (DBH ≥ 5 cm) and regeneration (height ≥ 10 cm, diameter < 5 cm) in 10 x 30 m plots were sampled in three stretches of riparian vegetation, two stretches in a pasture matrix and one stretch in matrix with native vegetation. Compared to the area with matrix of native vegetation, the vegetation of riparian areas immersed in pasture matrix showed a floristic composition dissimilarity and some structural similarity. In the regeneration, a high abundance of the species *Olyra* cf. *ecaudata* Döll (Poaceae) and *Asplenium* cf. *inaequilaterale* Willd. (Aspleniaceae) was observed. Our results provide evidence that the structure of riparian areas with 30 m in the pasture matrix was preserved. However, the performance of the ecological functions of riparian vegetation could be affected over time due to the effects of fragmentation that are influencing the diversity of these areas.

KEYWORDS
Remaining forest
Riparian forest
Pasture
Extinction debt

RESUMO: *A fragmentação é uma consequência de ações antrópicas que causam mudanças no uso e cobertura do solo. Com a conversão de áreas florestais em áreas de uso agrícola, a mata ciliar torna-se suscetível aos efeitos da fragmentação. Isso gera mudanças que afetam a estrutura e composição da vegetação dos remanescentes florestais. Portanto, este estudo teve como objetivo analisar a estrutura e composição florística de mata ciliar com 30 m em uma matriz fragmentada. Assim, a vegetação adulta (DAP ≥ 5 cm) e regeneração (altura ≥ 10 cm, diâmetro < 5 cm) em parcelas de 10 x 30 m foram amostradas em três trechos de mata ciliar, sendo dois trechos em uma matriz de pastagem e um trecho em matriz com vegetação nativa. Comparada à área com matriz de vegetação nativa, a vegetação de matas ciliares imersa em matriz de pastagem apresentou dissimilaridade de composição florística e alguma similaridade estrutural. Na regeneração, uma grande abundância das espécies Olyra cf. ecaudata Döll (Poaceae) e Asplenium cf. inaequilaterale Willd. (Aspleniaceae) foi observada. Nossos resultados fornecem evidências de que a estrutura das matas ciliares de 30 m na matriz de pastagem estava preservada. Porém, o desempenho das funções ecológicas da mata ciliar também pode ser alterado ao longo do tempo devido aos efeitos da fragmentação que estão influenciando a diversidade dessas áreas.*

PALAVRAS-CHAVE
Floresta remanescente
Mata ciliar
Pastagem
Débito de extinção

ASSOCIATE EDITOR
Allan Klynger da Silva Lobato

Received: 24/08/2021
Accepted: 04/11/2021

1 Introduction

Amazon occupation and deforestation have intensified in the last decades and, since then, this region of Brazil has been explored for agricultural exploration use. Modification of tropical landscapes is a significant threat because it influences biodiversity patterns (Pardini *et al.*, 2017). The state of Mato Grosso is located in the central west region and comprises the Amazon, Cerrado, and Pantanal biomes. According to the data from Embrapa Monitoramento por Satélite (Miranda *et al.*, 2017), 24.50% of the territory in the state is occupied by pasture, 10.39% by agricultural crops, 45.72% by preserved vegetation in rural properties, and 19.1% by preserved vegetation in conservation units.

Between years 2008 and 2019, 15,192.26 km² of forest was suppressed in the state, representing the second highest rate of deforestation during this period (Inpe, 2020). Consequently, continuous forests were converted to fragmented landscapes, in which fragments of native vegetation are immersed in matrices of agricultural lands, cattle pastures, and human settlements (Arroyo-Rodríguez *et al.*, 2017). This results in biodiversity loss, population isolation, changes in migration and dispersion patterns, and changes in inter-species interactions (Laurance *et al.*, 2002; Machado & Massoli Junior, 2017).

Some of the effects of fragmentation are related to physical and biotic changes associated with artificially generated abrupt margins of fragments (Laurance *et al.*, 2017). Compared to the interior regions of the fragment, the species at the edge have different densities and distributions and the mortality rate of tree species is intensified near the edge (Laurance & Vasconcelos, 2009; Ewers *et al.*, 2017). Another effect is characterized by the invasion of exotic grass and the dominance of some lianas or thin trees, making it difficult to establish individual trees (Rodrigues *et al.*, 2009; Vanmelis *et al.*, 2020).

The riparian vegetation is an important component of the landscape in the conservation and connectivity of different habitat fragments (Santos *et al.*, 2019) and the protection of hydric resources. With the conversion of forest areas into agricultural areas, the vegetation surrounding of riparian are reduced. These thin strips of vegetation are generally susceptible to fragmentation effects that influence the richness and composition of community trees as well as species richness of seedlings and saplings (Maracahipes-Santos *et al.*, 2020).

Therefore, understanding the behavior of tropical riparian vegetation in fragmented landscapes is necessary because these areas play an important role in the ecosystem. Based on the assumption that the structure and floristic composition of the vegetation are influenced by fragmentation, the objective of this study was to analyze the structure and floristic composition of the riparian vegetation with 30 m in a fragmented matrix.

2 Material and methods

The riparian areas selected for study are located in private properties in the northeastern region of Mato Grosso, near 57º5'10.325" W 10°46'47.717" S (Figure 1A). The climate of the region is Am, according to Köppen (Alvares *et al.*, 2013), with average annual temperatures above 26 ºC and rainfall ranging from 2500 to 3100 mm. It is located in the Amazon biome in a contact area between sub-montane seasonal semi-deciduous forest, forested savanna and sub-montane dense ombrophilous forest.

The vegetation of three riparian vegetation stretches of two streams (second order) in the Apiacás Microbasin, Teles Pires River were sampled (Figure 1B). Two of these stretches (namely, FRA-1 and FRA-2, with a spatial extension of approximately 3.1 and 2.7 km, respectively) had a surrounding matrix characterized by pasture. According to the information obtained from LANDSAT-5 satellite images, the vegetation of the matrix in the areas surrounding this riparian vegetation were suppressed between years 2001 and 2002 stretch FRA-1 and between years 2004 and 2005 stretch FRA-2. However, the strips of riparian vegetation were preserved with least 30 m width, because the streams were approximately 4 m wide. The third stretch had a surrounding matrix characterized by native forest vegetation (namely RRA with a length of 2.1 km – which was considered as the reference riparian vegetation).

Six plots of 10 x 30 m were delimited in three stretches of riparian vegetation, totaling 18 sampling units. The plots were measured 30 m from the riverbed and 10 m in parallel. They were alternately distributed on the two sides of the streams (Figure 1C). The diameter and height of the adult tree vegetation (plants with diameter at breast height DBH ≥ 5.0 cm) were determined.

Natural regeneration plants (height ≥ 10 cm, diameter < 5.0 cm) (Nemer, 2014), were measured in three small sub-plots (2 x 2 m), located at the left interior of each plot and at distances of 10, 20 and 30 m from the line parallel to the streams. Botanical materials were collected for species identification. Species listing was conducted using Flora do Brasil data (http://reflora.jbrj.gov.br/).

To verify the representativeness of the data, the observed species richness was compared with that estimated by *Jackknife* (I) (Oksanen *et al.*, 2019). This was the only analysis in which adults and regenerants were grouped. Other statistical analyses were performed separately for each vegetation layer (adult and regeneration).

The possible differences in the vegetation structure of the stretches were verified by comparing species diversity through diversity profiles based on Hill's numbers (Melo, 2008); density of individuals, proportion of species in ecological groups (pioneer, secondary and climax); dispersal syndrome (anemochoric, autochoric and zoochoric), diameter and height distributions. The density of individuals, proportion of species in ecological groups, and dispersal syndrome were compared using analysis of

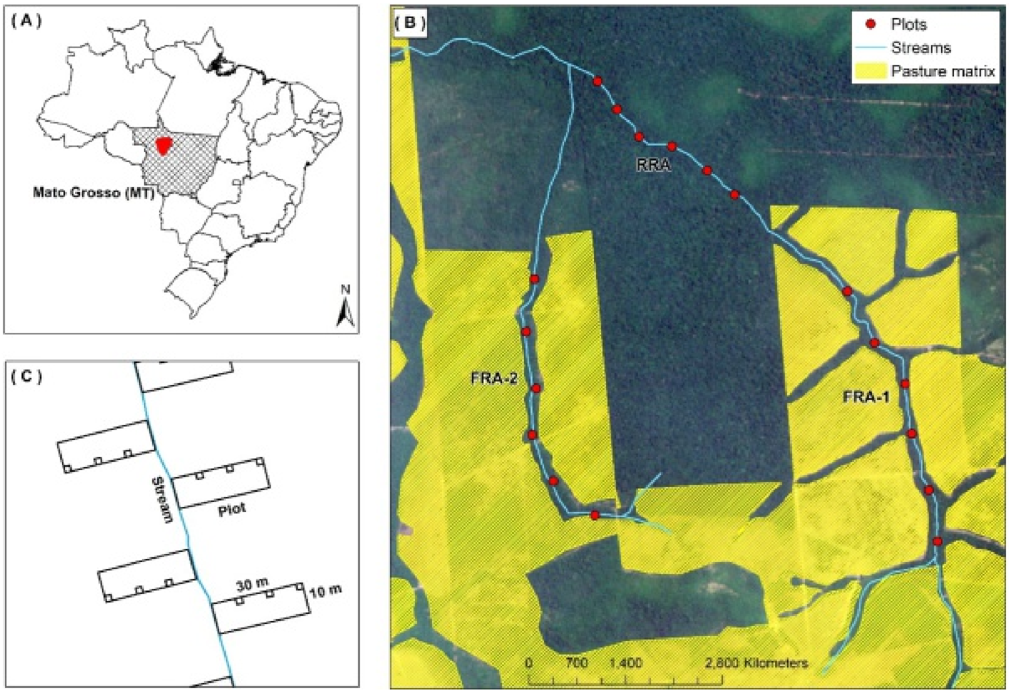

Figure 1. Sketch of the vegetation sampling in the municipality of Juara, northwest of Mato Grosso. A: Location of the study site in the state of Mato Grosso-Brazil. B: Location of sampled riparian vegetation stretches (FRA-1 and FRA-2: riparian vegetation stretches in pasture matrix; RRA: reference riparian vegetation), and plots. C: Distribution of plots along the stream.

Figura 1. Esquema da amostragem da vegetação no município de Juara, noroeste de Mato Grosso. A: Localização da área de estudo no estado de Mato Grosso-Brasil. B: Localização dos trechos de mata ciliar amostrados (FRA-1 e FRA-2: trechos de mata ciliar em matriz de pastagem; RRA: mata ciliar de referência) e parcelas. C: Distribuição das parcelas ao longo do córrego.

variance (α: 0.05) and Tukey's test (α: 0.05). For adults, the diametric distribution comprised classes of 5 cm in diameter and vertical stratification was performed in classes of 5 m.

Richness and the mix-quotient of Jentsch (Q) (Brower & Zar, 1984) were used to determine the differences in composition of stretches. To test the differences in floristic composition between the stretches, nonmetric multidimensional scaling (nMDS) and analysis of similarities (ANOSIM) were performed using species abundance data (Oksanen *et al.*, 2019). A similarity percentage (SIMPER) analysis was performed to determine the species with the greatest distribution and dissimilarity within the groups of the nMDS order (Oksanen *et al*., 2019). The data were submitted to the Bray-Curtis index (Oksanen *et al*., 2019). The analyses were performed using the R 3.6.1 program, with the vegan package 2.5-5 (Oksanen *et al.*, 2019).

3 Results and Discussion

A total of 930 adult individuals were registered, distributed across 136 species and morpho-species, including 323 individuals observed in FRA-1, 291 individuals in FRA-2 and, 316 individuals in RRA. The richest families were Fabaceae (19 species), Arecaceae, Lauraceae, Melastomataceae, Moraceae (7 species each) and Annonaceae, Burseraceae and Rubiaceae (6 species each), representing approximately 48% of the species and 57% of the individuals. The highest abundance occurred in the genera *Euterpe* (117 individuals), *Tachigali* (70), *Metrodorea* (40), *Miconia* (39), *Xylopia* (38), *Pseudolmedi*a (34) and *Inga* (32).

A total of 1898 individuals, comprising 122 species and morpho-species from the regeneration were registered. A total of 382 individuals were found FRA-1, 927 in FRA-2, and 589 in RRA. Approximately 52% of the individuals belonged to the families Poaceae (451 individuals and 2 species), Fabaceae (274 individuals and 19 species), and Aspleniaceae (265 individuals and 1 species). The most abundant genera were *Olyra* (451 individuals), *Asplenium* (265), and *Inga* (109).

In FRA-1, 133 species were sampled, representing 74% of the potential richness estimated by *Jackknife* (I) (180 species); in FRA-2, 142 species, representing 71% of the estimates (199 species); and in RRA 129 species, representing 78% of the estimates (164 species).

The highest richness and diversity of adult vegetation was observed in FRA-1 (100 species), followed by FRA-2 (88 species), and the lowest was in RRA (79 species) (Figure 2A). A balance was observed in the distribution of individuals between species across all stretches. The mix-quotient was 1/3, 1/3, and 1/4, respectively, indicating the absence of dominant species.

Among the regenerants, FRA-2 and RRA exhibited higher richness, with 84 and 83 species, respectively (Figure 2B). Among the riparian stretches in the pasture matrix, FRA-1 (72 species and Q: 1/5) had greater equability than FRA-2 (Q: 1/11). These stretches had ecological dominance of *Olyra* cf. *ecaudata* Döll (grass)

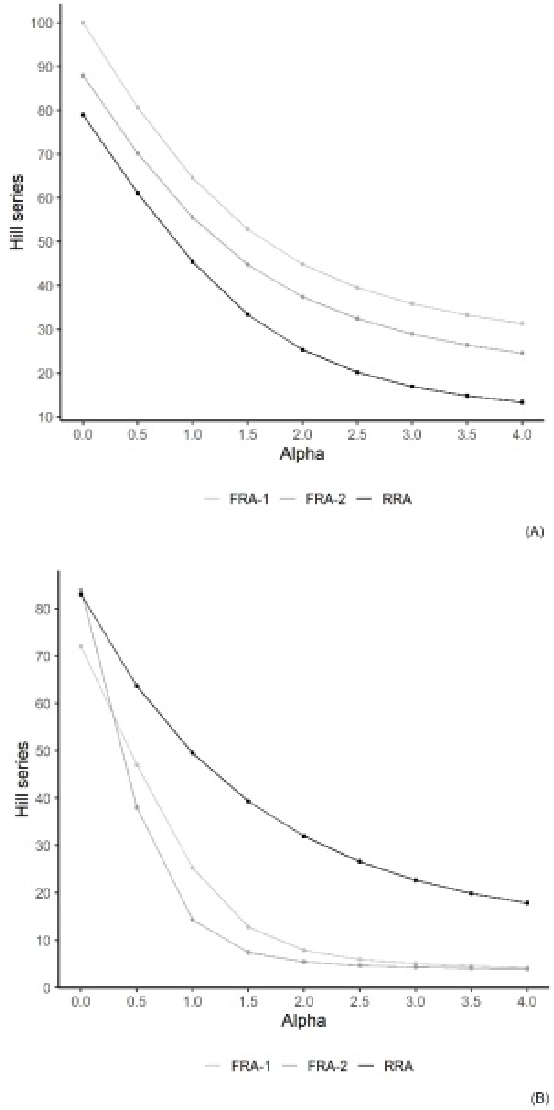

Figure 2. Diversity profiles of the sample areas considering the abundance of adult individuals (A) and regeneration (B). FRA-1 and FRA-2: riparian vegetation stretches in pasture matrix; RRA: reference riparian vegetation.

Figura 2. Perfis de diversidade das áreas amostrais considerando a abundância de indivíduos adultos (A) e regeneração (B). FRA-1 e FRA-2: trechos de mata ciliar em matriz de pastagem; RRA: mata ciliar de referência.

e *Asplenium* cf. *inaequilaterale* Willd. (fern), representing approximately 52% of the individuals in the stretches, and lower diversity (Figure 2B). In the FRA-1 stretch 131 individuals of *Olyra* cf. *ecaudata* were sampled. In the FRA-2 stretch 295 individuals of the same species and 259 individuals of *Asplenium* cf. *inaequilaterale* were determined. In the RRA stretch 25 individuals of *Olyra* cf. *ecaudata* and six individuals of *Asplenium* cf. *inaequilaterale* were sampled. The RRA, even with a Q of 1/7, was more diverse because there was a higher number of species with a large abundance.

The nMDS (Figure 3) indicated that the riparian vegetation stretches varied significantly in floristic composition (adults: stress value 0.21; regeneration: stress value 0.19), as confirmed by ANOSIM. The highest dissimilarity among the adult vegetation occurred between stretches RRA and FRA-2 (R: 0.43, *p*: 0.009), followed by RRA and FRA-1 (R: 0.27, *p*: 0.019). No difference was observed between FRA-1 and FRA-2 (R: 0.11, *p*: 0.516). Dissimilarities between all stretches were observed in the regeneration, and the dissimilarity between RRA and FRA-1 was 0,69 (*p*: 0.009); RRA and FRA-2, 0.60 (*p*: 0.011); and FRA-1 and FRA-2 0.51 (*p*: 0.019).

For the adult vegetation, according to SIMPER analysis, the species with the highest contribution to the differentiation of stretches (Table 1), were *Euterpe longibracteata* Barb. Rodr, which was more abundant on the RRA stretch, and *Metrodorea flavida* K. Krause, which was more abundant on the FRA-1 and FRA-2

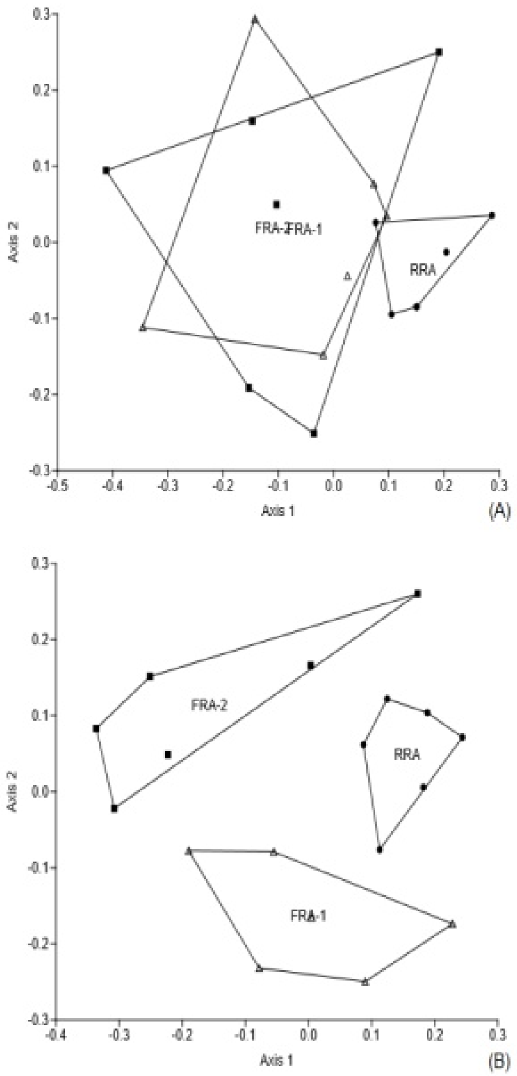

Figure 3. nMDS ordination through the Bray-Curtis index of the adults (A) and regeneration (B). FRA-1 and FRA-2: riparian vegetation stretches in pasture matrix; RRA: reference riparian vegetation.

Figura 3. Ordenação nMDS pelo índice de Bray-Curtis dos adultos (A) e regeneração (B). FRA-1 e FRA-2: trechos de mata ciliar em matriz de pastagem; RRA: mata ciliar de referência.

stretches. For regeneration, the species that contributed the most to the differentiation of stretches were *Olyra* cf. *ecaudata* and *Asplenium* cf. *inaequilaterale*, which were more abundant on FRA-1 and FRA-2 stretches, and *Psychotria* sp., which was more abundant on the RRA stretch.

Table 1. Species that most contribute to the dissimilarity between stretches according to SIMPER analysis.
Tabela 1. Espécies que mais contribuem para a dissimilaridade entre os trechos conforme análise SIMPER.

Adults species	FRA-1 and FRA-2	FRA-1 and RRA	FRA-2 and RRA
	% contribution of each species*		
Euterpe longibracteata Barb. Rodr	-	6.71	6.96
Metrodorea flavida K. Krause	-	3.72	5.18
Dialium guianense (Aubl.) Sandwith	-	2.97	-
Pseudolmedia macrophylla Trécul	-	2.9	2.77
Xylopia frutescens Aubl	-	2.89	3.54
Euterpe precatoria Mart.	-	2.84	3.87
Tachigali chrysaloides van der Werff.	-	2.01	2.64
Astrocaryum gynacanthum Mart.	-	2.2	-
Tachigali paniculata Aulb.	-	2.44	-
Matayba arborescens (Aubl.) Radlk.	-	2.61	2.32
Inga thibaudiana DC	-	-	2.43
Theobroma speciosum Mart	-	-	2.42
Regenerants species	**FRA-1 and FRA-2**	**FRA-1 and RRA**	**FRA-2 and RRA**
	% contribution of each species*		
Olyra cf. *ecaudata* Döll	23.36	14.62	20.16
Asplenium cf. *inaequilaterale* Willd.	20.49	-	17.56
Psychotria sp.	-	7.91	5.26
Inga sp.	-	2.9	-
Tachigali aurea Tul.	-	2.37	-
Trichilia sp.	-	2.21	-

Cut off for low contributions: 30%*
Corte para baixas contribuições: 30%*

No difference was observed in the abundance of individuals and in the proportion of ecological groups between the stretches in the adult vegetation (Figure 4A, 4C). Zoochoric dispersion was predominant among the species, and it was higher in the vegetation of the RRA and FRA-1 stretches (Figure 4E). The highest proportion of autochoric species was observed in FRA-2 (Figure 4E). In regeneration, the highest abundance of individuals was found in FRA-2, and the proportion of ecological groups was not significantly different (Figure 4B, 4D). No significant difference was found in the type of dispersion between the regenerated species (Figure 4F).

The horizontal structure (Figure 5) had a larger number of individuals with lower DBH, and the number decreased as the diameter increased. This behavior is commonly observed in native forests. The vertical structure of adults was similar between stretches (Figure 6). RRA had an average height of 11.13 m (standard deviation 4.80), FRA-1 of 10.42 m, and FRA-2 of 10.45 m (standard deviation 4.97 and 5.57, respectively).

We found that the riparian vegetation stretches surrounded by pasture have some similarity in the structure and floristic composition dissimilarity with the stretch surrounded by native vegetation. The higher diversity of adult vegetation observed in the vegetation surrounded by pasture could attributed to the intermediate disturbance theory (Connell, 1978). According to this theory, communities that have suffered an intermediate level of disturbance have a higher diversity of species than those that have low or high rates or frequencies of disturbance. This can be explained by the successional sequence caused by land use and related pressures that generate changes in the composition and structure of the community, and consequently increase the abundance of widespread species (Newbold *et al.*, 2018). Thus, the results observed in these stretches might be because of fragmentation effects. The matrix was altered for the use of livestock, causing changes in abiotic factors (light, wind, and temperature) that favored immediately higher dynamics and colonization of other species adapted to the new conditions, and added value to the diversity indices.

Some plots were composed up to 41% of the adult pioneer species. In riparian vegetation, abiotic changes, such as removal of surrounding vegetation and availability of resources drive community dynamics (Magnabosco Marra *et al.*, 2018). Therefore, forests with more pioneer trees are more vulnerable to disturbances such as drought, fire, land use, and fragmentation (Magnabosco Marra *et al.*, 2018).

In regeneration, the ecological dominance of *Olyra* cf. *ecaudata* Döll and *Asplenium* cf. *inaequilaterale* influenced the equability and diversity in the stretches surrounded by pasture. These species were the most important in the structure of natural regeneration because

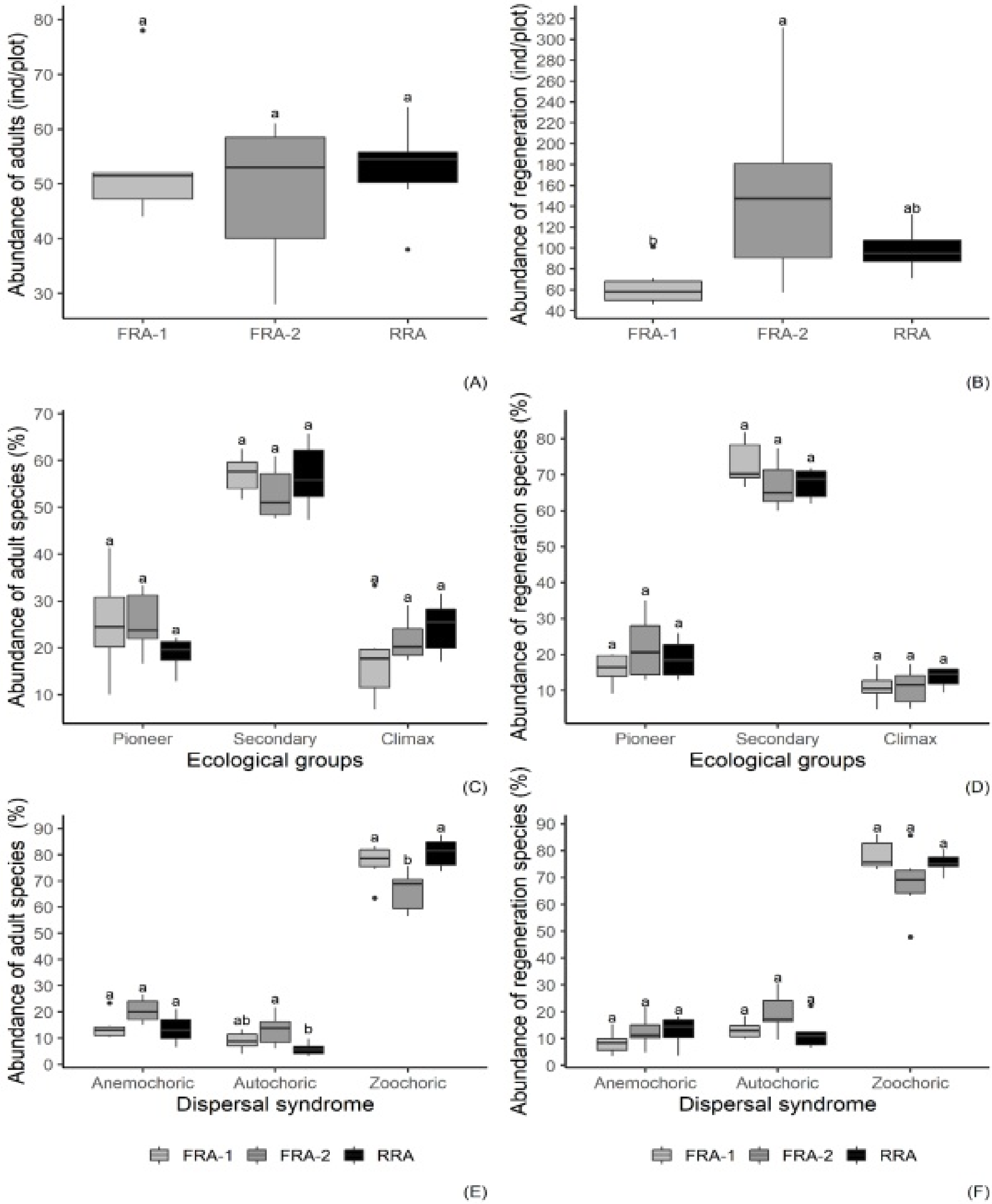

Figure 4. Comparisons of vegetation structure and composition. (A) Abundance of adult individuals in the plots. (B) Abundance of regeneration in the plots. (C) Proportion of adult species according to the ecological group. (D) Proportion of regeneration species according to the ecological groups. (E) Proportion of adult species according to the ecological dispersal syndrome. (F) Proportion of regeneration species according to the ecological dispersal syndrome. FRA-1 and FRA-2: riparian vegetation stretches in pasture matrix; RRA: reference riparian vegetation. Different letters indicate significant differences, considering $p < 0.05$.

Figura 4. Comparações da estrutura e composição da vegetação. (A) Abundância de indivíduos adultos nas parcelas. (B) Abundância de regeneração nas parcelas. (C) Proporção de espécies adultas de acordo com o grupo ecológico. (D) Proporção de espécies em regeneração de acordo com os grupos ecológicos. (E) Proporção de espécies adultas de acordo com a síndrome de dispersão ecológica. (F) Proporção de espécies em regeneração de acordo com a síndrome de dispersão ecológica. FRA-1 e FRA-2: trechos de mata ciliar em matriz de pastagem; RRA: mata ciliar de referência. Letras diferentes indicam diferenças significativas, considerando $p < 0,05$.

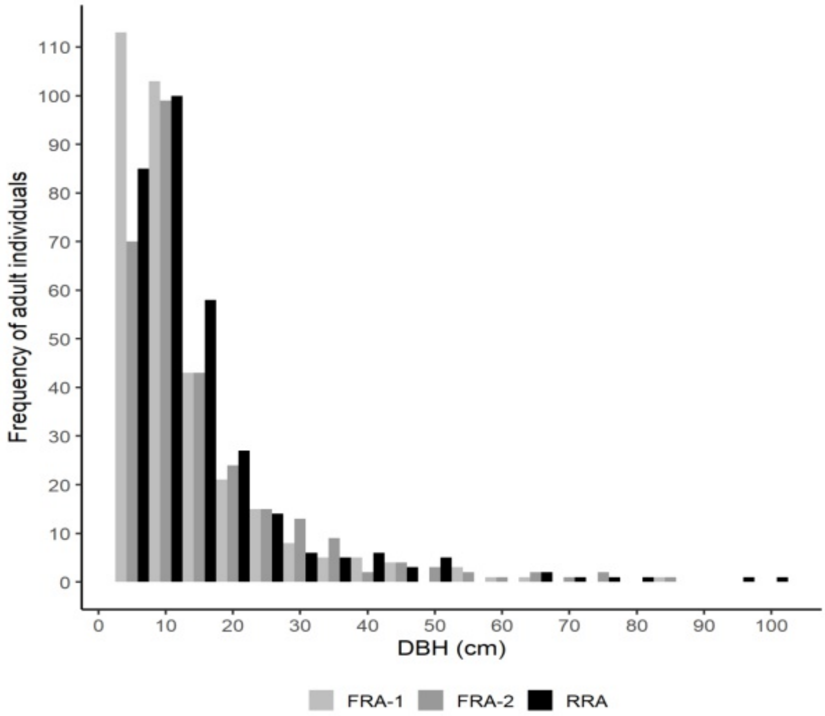

Figure 5. Diametric distribution of adult individuals by area. FRA-1 and FRA-2: riparian vegetation stretches in pasture matrix; RRA: reference riparian vegetation.
Figura 5. Distribuição diamétrica de indivíduos adultos por área. FRA-1 e FRA-2: trechos de mata ciliar em matriz de pastagem; RRA: mata ciliar de referência.

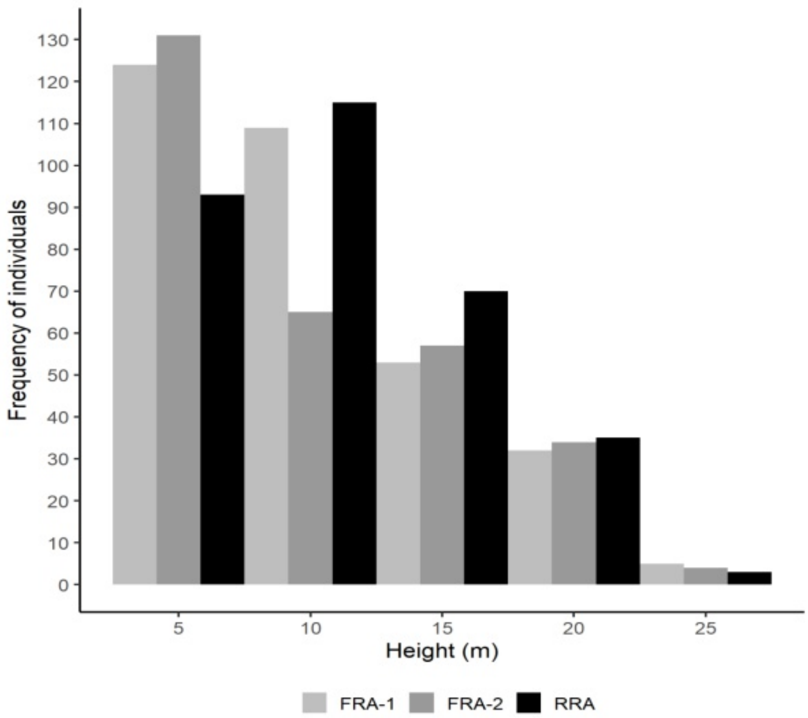

Figure 6. Vertical stratification of adult vegetation by area. FRA-1 and FRA-2: riparian vegetation stretches in pasture matrix; RRA: reference riparian vegetation.
Figura 6. Estratificação vertical da vegetação adulta por área. FRA-1 e FRA-2: trechos de mata ciliar em matriz de pastagem; RRA: mata ciliar de referência.

of their higher abundance. In areas occupied by grass, fern, and monodominant native tree species, natural regeneration is affected. They hinder the establishment of other species and impair the diversity necessary for the evolution of forest fragments (Simonelli *et al.*, 2021). This suggested that regeneration in these areas did not reflect the previous generation, indicating that removal of surrounding vegetation affected the regeneration process and maintained the species dominance of the genera Poaceae and Aspleniaceae. Consequently, the future of these woody plant communities tends to have a lower diversity than the original structure (Belchimor *et al.*, 2017).

Although similarities in the structure and ecological groups were observed between the three stretches, the effects of disturbances resulting from the fragmentation process must still be considered. The presence of adult individuals of climax species is reflex of the ancient landscape which may be the result of an extinction debt. FRA-1 and FRA-2 may be experiencing extinction debt, which occurs when the ecological response to a disturbance only becomes apparent over a considerable amount of time. Thus, species start to disappear over time when the limiting condition for survival is no longer met (Halley *et al.*, 2017). The responses of plant communities vary according to several factors, such as the long-life cycle of some species, which results in slower responses to these events (Kuussaari *et al.*, 2009).

4 Conclusion

The areas exhibited similarity in the abundance of individuals, proportion of ecological groups, type of dispersion, and horizontal and vertical structure. This indicated that riparian vegetation with 30 m in the fragmented areas in pasture matrix have their structure preserved, even with dissimilar floristic composition. However, this may be altered over time due to the predominance of regenerant species *Olyra* cf. *ecaudata* Döll and *Asplenium* cf. *inaequilaterale* Willd. that are affecting the diversity.

The constant influence of external stimuli due to fragmentation favored the colonization of species that might impact regeneration of tree vegetation in the long term. This is an important factor that affects the performance of the ecological functions of these riparian areas.

Acknowledgements: This research was partly funded by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES)- Finance Code 001.

Contribution of the authors: Maristela Volpato: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Roles/Writing - original draft, Writing -review & editing. Rômulo Môra: Conceptualization, Formal analysis, Methodology, Roles/Writing - original draft. Silvia da Luz Lima Mota: Conceptualization, Formal analysis, Methodology, Roles/Writing - original draft. Fábio Henrique Della Justina do Carmo: Conceptualization, Formal analysis, Methodology, Roles/Writing - original draft, Writing -review & editing. Dienefe Rafaela Giacoppini: Data curation, Investigation.

Sources of funding: This research was partly funded by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

Conflict of interest: The authors declare no conflicts of interest.

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