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Original Paper

Ground-herb communities of *terra firme* riparian forests of the lower Tapajós River in the Brazilian Amazon

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Abstract

We conducted an inventory of the fern, lycophyte and non-palm monocotyledon ground-herbs of *terra firme* riparian forests in the lower Tapajós region of the Brazilian Amazon. Eight 1.5 × 250 m plots, totaling 0.3 hectares, were surveyed along the watersheds of the Cupari and Curuá-Una rivers, located at the Tapajós National Forest, Pará, Brazil. To characterize the ground-herb community, we calculated species richness, abundance and Fisher's alpha for each plot. To analyze turnover, we compared composition among plots by pairwise Bray-Curtis distance. In total, we sampled 3,130 individuals, 58 species, 27 genera and 20 families of riparian ground-herbs. Marantaceae (14 spp) was the richest family and Poaceae the most abundant family (738 individuals). The fern *Triplophyllum glabrum* (Tectariaceae) was the most frequent species, observed in 87.5 % of plots. Ground-herbs communities in the studied area have high species turnover, making it necessary to invest time and resources to adequately characterize and manage riparian habitats. The ground-herb community composition observed in the riparian zone here resembles that of other non-riparian forested sites in the Amazon with the plant families Marantaceae, Pteridaceae and Poaceae generally being the most commonly represented in the Amazonian ground-herb stratum. We highlight the importance of herb inventories, especially in conservation units.
Key words: ferns, lycophytes, monocotyledons, streams, Tapajós National Forest.

Resumo

Realizamos um inventário de herbáceas ripárias em uma floresta de *terra firme* da Amazônia brasileira localizada na região do baixo Rio Tapajós, para samambaias, licófitas e monocotiledôneas não-palmeiras. Oito parcelas de 1,5 × 250 m, totalizando 0,3 hectares, foram amostradas ao longo das bacias hidrográficas dos Rios Cupari e Curuá-Una, localizados na Floresta Nacional do Tapajós, Pará, Brasil. Para caracterizar a comunidade herbácea, calculamos a riqueza, a abundância e o alfa de Fisher para cada parcela. Para analisar a dissimilaridade, comparamos a composição de espécies entre parcelas através da distância Bray-Curtis par-a-par. No total, foram amostrados 3.130 indivíduos, 58 espécies, 27 gêneros e 20 famílias de herbáceas ripárias terrestres. Marantaceae (14 spp) é a família com a maior riqueza e Poaceae a mais abundante (738 indivíduos). A samambaia *Triplophyllum glabrum* (Tectariaceae) é a espécie mais comum entre as parcelas, observada em 87,5 % delas. As comunidades de herbáceas terrestres têm alta substituição de espécies na área estudada, mostrando a necessidade de investimento de tempo e de recursos para caracterizar e manejar habitats ripários. A composição das comunidades de herbáceas terrestres ripárias observada aqui se assemelha a de sítios de florestas de *terra firme* não ripárias na Amazônia, sendo as famílias Marantaceae, Pteridaceae e Poaceae geralmente as mais representativas do estrato herbáceo amazônico. Destacamos aqui a importância de inventários de herbáceas terrestres, particularmente em unidades de conservação.
Palavras-chave: samambaias, licófitas, monocotiledôneas, riachos, Floresta Nacional do Tapajós.

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Introduction

Ground-herbs are an important component of the vegetation that make up *terra firme* riparian forests. Riparian zones are the interface between riverine aquatic and terrestrial environments, and they are considered vulnerable to human actions and climate change (Capon *et al*. 2013). The structural, functional and ecosystemic characteristics of riparian zones are notable for their maintenance of rich biodiversity and their ecosystem services (Naiman *et al.* 1993; Pokrovsky 2016). It is therefore essential they are well inventoried to better understand their regional uniqueness for contemporary comparison, and as a baseline for future assessments under change scenarios. In Amazonia, the vegetation of the riparian zone is both non-forested and forested, with the forested regions comprised of flooded forests (*e.g.*, *várzeas*, *igapós*) and non-flooded (*terra firme*) (Martins 2007; Naiman *et al*. 2005).

Herbaceous plants in forest formations typically include herbs, sub-shrubs and seedlings (Gilliam *et al*. 1995; Zickel 1995; Costa 2004). In this study we focus on herbaceous species that spend their entire life cycle on the forest floor (Cestaro *et al*. 1986; Costa 2004). In tropical forests, herbs correspond from 8% up to 29% of the total species (Gentry & Dodson 1987; Gentry & Emmons 1987; Spicer *et al.* 2020), and in some hyperdiverse regions previously inventoried, such as the Ecuadorian Amazon, they reach about 100 species per hectare (Poulsen & Balslev 1991). In Central Amazonia, the diversity within this forest component is dominated by non-palm monocotyledons, ferns and lycophytes (Drucker *et al*. 2008; Moulatlet *et al*. 2014).

Amazon *terra firme* streams can hold a very diverse terrestrial herb community along their riverscapes (Drucker *et al*. 2008). Studying herbs along streams is crucial for understanding any Amazon diversity pattern, since it is estimated that small streams represent two-thirds of the total length in a river network (Leopold *et al*. 1964) and an area of one million square kilometers in the Amazon basin (Junk 1993). Riparian forests associated with streams can vary significantly through the landscape due to topographic and hydrological local changes, creating dynamic mosaics in terms of herbs community composition (Schietti *et al*. 2013), where no site is a replicate of another.

Amazonian riparian forests are protected by Brazilian Forest Code (Law 12.651/25/2012) aiming to maintain hydrological, edaphic and ecological services provided from biological processes of species that inhabit this aquatic-terrestrial interface. Unfortunately, riparian zones have become linear remnants throughout the Amazon basin due to its disordered human colonization history (Fearnside 2003). Recently, the Amazon has been experiencing rising deforestation rates and devastation from river dam constructions, which alter stream and river connectivity in several ways, affecting both upstream and downstream freshwater ecosystems (Macedo & Castello 2015).

In the Amazon Rainforest, knowledge on plant diversity distribution is extremely biased around very few relatively well-collected areas, while modelled diversity is uniformly high across most of the basin (Hopkins 2007), indicating that plant inventories are currently at insufficient density to represent Amazonian diversity patterns. Recent surveys targeting the ground-herb communities highlight the floristic and ecological importance of these growth forms in forest ecosystems of the region (*e.g*., Costa 2004; Drucker *et al*. 2008; Zuquim *et al.* 2012; Moulatlet *et al.* 2014). Moreover, it is important to recognize riparian specimens within this group, both because of its ecological role and habitat conservation implications. Here, we present an inventory of riparian ground-herb of the poorly known lower Tapajós region.

Material and Methods

Study area

This study was conducted in the Brazilian national sustainable use protected area Floresta Nacional do Tapajós (FLONA Tapajós hereafter), located on the right bank of the Tapajós River, Brazilian Amazon (4.022310-3.744208 degrees South, 54.921920-55.392877 degrees West, <https://www.icmbio.gov.br/flonatapajos/mapas-e-limites.html>). FLONA Tapajós covers 527,319 hectares (Ibama 2004) and is mostly vegetated by Dense Ombrophilous Forest (Veloso *et al.* 1991) over Dystrophic Yellow Latosols, deep and low cation exchange soils (Hernandez *et al.* 1993). Three distinct drainages occur within FLONA Tapajós: the Tapajós, Curuá-Una and Cupari River basins (Silva-Oliveira *et al*. 2016, Fig. 1). The Cupari River is the right tributary of the lower Tapajós River, and its main tributaries are the Braço Leste and Braço Oeste rivers (Riós-Villamizar *et al*. 2014), with part of its basin located in the FLONA Tapajós area. The Curuá-Una River is a tributary of the Amazon River and has several protected headwaters in FLONA Tapajós (Fig.

1). Plots were implemented in the Curuá-Una and Cupari basins within the protected area with the view to maintain these plots for long term studies. Riparian plots were randomly selected considering at least 1 km minimum distance. Sampling size was balanced between the two drainages in our study site exclusively to improve ecological and spatial heterogeneity.

Sampling and data analysis

Plant sampling occurred in May, November and December 2018 and February and May 2019. For community assessment, eight riparian plots were installed in permanent streams of *terra firme* forest, four plots in the Curuá-Una River basin and four plots in the Cupari River basin. Ground-herbs were collected according to the Protocol for Surveys of Ferns and Lycophytes in PPBio RAPELD Modules (available at <https://ppbio.inpa.gov.br/>), in 1.5 × 250 m plots, with the longer axis parallel and adjacent to stream's left or right margin. The assemblages surveyed here were classified as a set of vascular ground-herb species, including only those species that germinate and spend their entire life cycle on the forest floor (Poulsen 1996), belonging to the lineages of ferns, lycophytes and monocotyledons. Palms (Arecaceae Bercht. & J. Presl) were excluded because even the more herbaceous life-forms tend to occupy shrub or even tree forest strata at some point in their life cycle. In each riparian plot, all individuals taller than 5 cm and rooted within the plots were counted and identified at the lowest possible taxonomic level. Voucher specimens for every individual were collected. We followed Costa *et al*. (2005) to distinguish and count individuals, considering groups of stems or leaves/fronds that were at least 20 cm apart. For species that occur in high density in a small area (*e.g.*, *Adiantum* and *Selaginella*), forming large mats, impeding distinction between individuals, we counted each stem as an individual, following Moulatlet *et al*. (2014). All fertile botanical material was deposited at the HSTM herbarium, Universidade Federal do Oeste do Pará (barcode numbers 13,332–13,375 and 13,983–13,993).

The identification of species was based on the PPBio / INPA Identification Guides (<https://ppbio.inpa.gov.br/guias>) for Marantaceae (Costa *et al*. 2008), Zingiberales (Costa *et al.* 2011) and Ferns

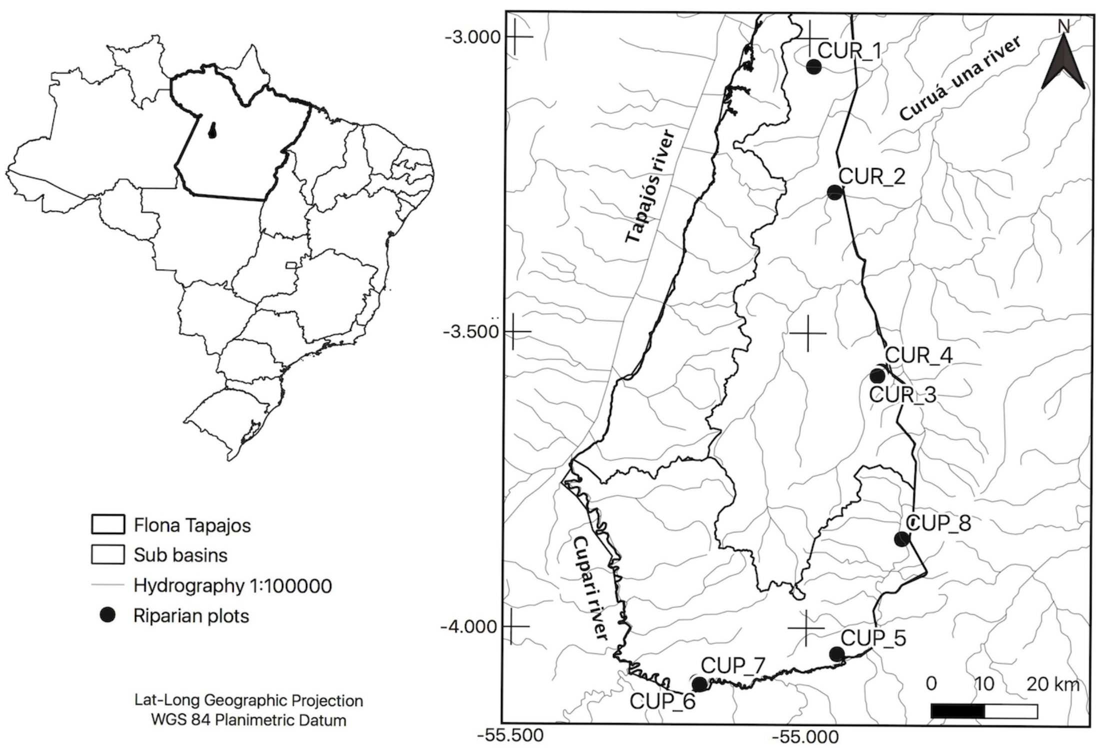

Figure 1 – Study area. Codes in the bigger map correspond to ground-herb riparian plots.

and Lycophytes (Zuquim *et al*. 2008). Identification keys were also used (Kramer 1957; Alston *et al.* 1981; Tryon & Stolze 1989a, 1989b; Tuomisto & Groot 1995; Steyermark *et al.* 1995; Windisch 1996; Mori *et al.* 1997; Prado & Moran 2008) as was consultation with specialists and identified material already deposited in herbaria.

For each plot, we calculated species richness, overall abundance and Fisher's alpha (Magurran 2004). Species composition of each plot was compared by pairwise Bray-Curtis distances. Species accumulation curves were constructed to verify sampling effort. All estimates were calculated with the vegan package version 2.5 (Oksanen *et al*. 2019) in R (R Development Core Team 2020).

Results

A total of 3,130 individuals and 58 ground-herb species belonging to 27 genera and 20 families were recorded in riparian plots in the lower Tapajós River region (Tab. 1). The richest families were: Marantaceae (14 spp; 24.14%), Pteridaceae (7 spp; 12.07%), Poaceae (4 spp; 6.9%), Lomariopsidaceae (4 spp; 6.9%), Costaceae (4 spp; 6.9%) and Hymenophyllaceae (4 spp; 6.9%) that together comprise 63.79% (37 spp) of all species

Table 1 – Riparian ground-herbs of lower Tapajós region, *terra firme* forests, Brazilian Amazon. Species from eight 1.5 × 250 m plots. Abun = abundance (total individual number per species); F% = species frequency (number of plots in which the species occurred).

	Family	Species	Abun	F%
Ferns and Lycophytes*				
	Aspleniaceae	*Asplenium stuebelianum* Hieron.	49	25.0
	Blechnaceae	*Telmatoblechnum serrulatum* (Rich.) Perrie, D.J. Ohlsen & Brownsey	10	37.5
	Cyatheaceae	*Cyathea microdonta* (Desv.) Domin	6	25.0
		Cyathea sp.	5	25.0
	Dennstaedtiaceae	*Dennstaedtia cicutaria* (Sw.) T.Moore	6	50.0
	Dryopteridaceae	*Ctenitis refulgens* (Klotzsch *ex* Mett.) C. Chr. *ex* Vareschi	3	12.5
		Mickelia guianensis (Aubl.) R.C. Moran, Sundue & Labiak	19	12,5
		Polybotrya pubens Mart.	41	37.5
	Hymenophyllaceae	*Trichomanes elegans* Rich.	7	25.0
		Trichomanes pinnatum Hedw.	26	62.5
		Trichomanes vittaria DC. *ex* Poir.	5	12.5
		Trichomanes sp.	1	12.5
	Lomariopsidaceae	*Lomariopsis japurensis* (Mart.) J.Sm.	14	50.0
		Lomariopsis cf. *nigropaleata* Holttum	31	50.0
		Lomariopsis prieuriana Fée	25	37.5
		Lomariopsis sp.	10	25.0
	Lygodiaceae	*Lygodium venustum* Sw.	4	25.0
	Pteridaceae	*Adiantum argutum* Splitg.	386	37.5
		Adiantum glaucescens Klotzsch	2	12.5
		Adiantum humile Kunze	10	25.0
		Adiantum obliquum Willd.	62	37.5
		Adiantum terminatum Kunze *ex* Miq.	33	37.5

	Family	Species	Abun	F%
		Adiantum tomentosum Klotzsch	19	37.5
		Adiantum sp.	4	12.5
	Selaginellaceae	*Selaginella breynii* Spring	25	25.0
		Selaginella conduplicata Spring	574	75.0
	Tectariaceae	*Triplophyllum glabrum* J.Prado & R.C.Moran	214	87.5
		Triplophylum sp.	14	25.0
	Thelypteridaceae	*Meniscium chrysodioides* Fée	5	25.0
Monocotyledons**				
	Amaryllidaceae	*Hippeastrum* sp.	2	12.5
	Commelinaceae	*Trandescantia* sp.	2	12.5
	Costaceae	*Costus scaber* Ruiz & Pav.	1	12.5
		Costus sprucei Maas	31	37.5
		Costus amazonicus subsp. *krukovii* Maas	23	37.5
		Costus arabicus L.	8	25.0
	Cyperaceae	*Cyperus* sp.1	1	12.5
		Cyperus sp.2	23	50.0
		Cyperus sp.3	7	12.5
	Heliconiaceae	*Heliconia acuminata* Rich.	25	50.0
	Marantaceae	*Goeppertia altissima* (Poepp. & Endl.) Borchs. & S. Suárez	3	12.5
		Goeppertia micans (L.Mathieu) Borchs. & S.Suárez	90	25.0
		Goeppertia taeniosa (Joriss.) Borchs. & S.Suárez	33	37.5
		Goeppertia zingiberina (Körn.) Borchs. & S.Suárez	12	12.5
		Ischnosiphon arouma (Aubl.) Körn.	80	62.5
		Ischnosiphon gracilis (Rudge) Körn.	72	37.5
		Ischnosiphon hirsutus Petersen	3	12.5
		Ischnosiphon martianus Eichler *ex* Petersen	111	62.5
		Ischnosiphon obliquus (Rudge) Körn.	2	25.0
		Ischnosiphon petiolatus (Rudge) L. Andersson	81	37.5
		Ischnosiphon puberulus Loes.	74	75.0
		Monotagma plurispicatum (Körn.) K. Schum	13	25.0
		Monotagma secundum (Petersen) Schum.	30	37.5
		Monotagma ulei K. Schum. *ex* Loes.	23	12.5
	Poaceae	*Ichnantus* sp.	40	50.0
		Olyra sp.	78	25.0
		Pariana sp.	497	75.0
		Piresia goeldii Swallen	123	12.5
	Zingiberaceae	*Renealmia floribunda* K. Schum.	32	50.0
	Classification follows *PPGI (2016) and **APGIV (2016)			

recorded. The remaining families had one to three species, comprising 36.21% of the total richness (Fig. 2). Considering the abundance of species, the families Poaceae (738 indiv.), Marantaceae (627), Selaginellaceae (599) and Pteridaceae (516) corresponded to 79.23% of the total number of individuals (Fig. 3).

The most frequent species was the fern *Triplophyllum glabrum* (Tectariaceae), distributed in seven of the eight plots (88%). Three other species were distributed in six plots (75%): *Selaginella conduplicata*, *Pariana* sp. and *Ischnosiphon puberulus*. The most abundant species were *Selaginella conduplicata* (574), *Pariana* sp. (497), *Adiantum argutum* (386), *Triplophyllum glabrum* (214), *Piresia goeldi* (123) and *Ischnosiphon martianus* (111), which together account for 60.86% of the total inventoried individuals (Tab. 1).

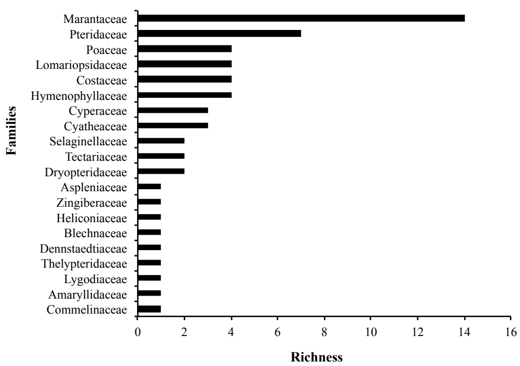

Figure 2 – Species richness for each riparian ground-herb family in the lower Tapajós region, *terra firme* forests, Brazilian Amazon.

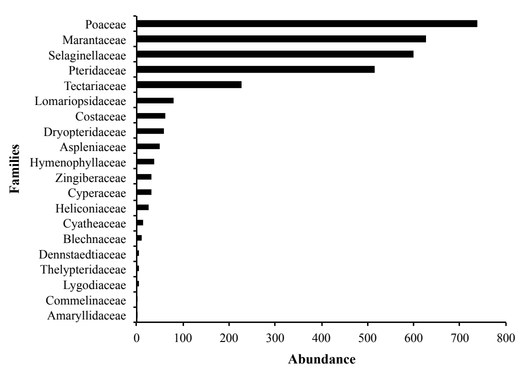

Figure 3 – Species abundance for each riparian ground-herb family in the lower Tapajós region, *terra firme* forests, Brazilian Amazon.

Riparian ground-herb floristic dissimilarity matrix reveals high complementarity among plots, for both quantitative and qualitative data inputs using Bray Curtis distance (Fig. 4). The species accumulation curve shows a steady and gradual rise in the number of species per additional plot and a tendency to asymptote species number for our data based on richness estimators (Fig. 5).

Discussion

Riparian ground-herbs are an important component of *terra firme* forests in the lower Tapajós River region, given their large species representativeness. We identified 58 species in

	P1	P2	P3	P4	P5	P6	P7	P8
P1		0.91	0.92	0.89	0.96	0.93	0.87	0.84
P2	0.81		0.41	0.60	0.83	0.94	0.78	0.86
P3	0.72	0.29		0.61	0.87	0.98	0.74	0.89
P4	0.78	0.43	0.36		0.82	0.96	0.70	0.80
P5	0.77	0.64	0.69	0.79		0.61	0.79	0.83
P6	0.74	0.67	0.86	0.83	0.44		0.90	0.86
P7	0.87	0.48	0.60	0.59	0.70	0.67		0.67
P8	0.91	0.66	0.76	0.71	0.75	0.71	0.38	

Figure 4 – Riparian ground-herb dissimilarity matrix (Bray Curtis distances) from eight plots in the lower Tapajós region, *terra firme* forests, Brazilian Amazon. Darker cells indicate higher dissimilarity. Lower diagonal cells are Bray Curtis distances calculated from quantitative data, while upper diagonal cells are binary Bray Curtis distances, which considers species presence/absence only.

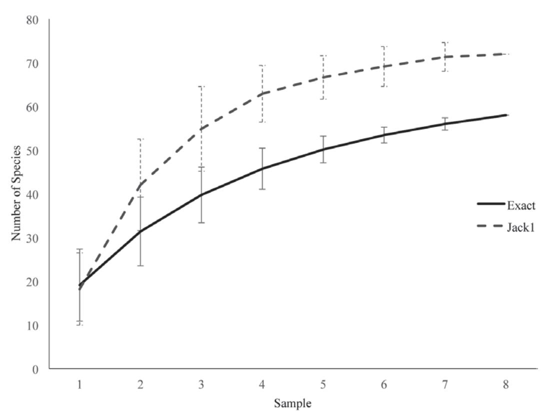

Figure 5 – Species accumulation curves from eight riparian ground-herb community plots in the lower Tapajós region, *terra firme* forests, Brazilian Amazon. Solid line for exact and dashed line for Jackknife 1 estimator.

8 plots (summing 0.3 ha). The richest families in this inventory, *i.e.* Marantaceae, Pteridaceae, Poaceae, Lomariopsidaceae, Costaceae and Hymenophyllaceae, are also the richest in environments including non-riparian forests of Central and Eastern Amazon (Costa 2004; Zuquim *et al*. 2008; Costa & Pietrobom 2010; Pallos *et al*. 2016).

Marantaceae is an important component of this inventory, having 14 species and three genera, and represented in 627 individuals. This family is characteristic of neotropical forests understory (Gentry & Emmons 1987; Kennedy 2000). *Ischnosiphon* is the richest genus of this family in our study site. Studies conducted in riparian zones of Central Amazon, in permanent plots of the Adolpho Ducke Forest Reserve north of Manaus and in BR-319 in the Purus-Madeira interfluve, also found Marantaceae as a component of relative importance for ground-herb diversity, reaching the highest species richness values in both areas (Costa 2004; Drucker *et al*. 2008; Moulatlet *et al*. 2014).

Our study demonstrates the importance of herbs that constitute large population densities in the riparian vegetation of *terra firme* forests. The families Poaceae (738 ind. and 4 spp), Selaginellaceae (599 ind. and 2 spp) and Pteridaceae (516 ind. and 7spp), are three of the most abundant and represent 59.2% of the individuals and 22.4% species of ground-herbs studied here. The Poaceae occurred in almost all plots, often forming dense clusters. Its species produce large quantities of flowers and seeds and the family was also the one with the highest density of 1 ha in Ecuador (Poulsen & Balslev 1991). Pteridaceae and Selaginellaceae are families that are related to wet soils, as the banks of rivers and streams (Paixão *et al*. 2013), which could be the reason for its high density in riparian areas. The genera *Adiantum* and *Selaginella*, the only representatives of these families in the present study, are among the most representative fern genera in the Brazilian Amazon and were find as most abundant groups in other inventories (*e.g*., Zuquim *et al*. 2009, 2014; Pansonato *et al*. 2013).

Local diversity (Fisher's alpha, Tab. 2) is highly variable among plots, probably as a result of local environmental characteristics. Soil type and light conditions, for example, can vary broadly, since our samples were distributed along headwaters of two watersheds and comprise an area with a radius of about 115 km and different geological formation (Tuomisto *et al*. 2019). Additionally, we found great complementarity among the riparian herb communities, observed here by means of pairwise dissimilarity (Fig. 4) and the estimated number of species (Fig. 5). This high community species turnover has been already documented for Central Amazonia (Schietti *et al*. 2013), where waterlogged areas accumulate more community dissimilarity than upper and dryer areas into the same watershed. This finding highlights the relevance of including riparian environments in botanical and ecological inventories, in such a threatened habitat.

We found 58 species of understory ground-herbs in just 0.3 ha at lowland riparian forests located in the Tapajós National Forest. For instance, Drucker *et al*. (2008) found 75 species in 40 plots (2 × 100 m, 0.8 ha) at Reserva Florestal Adolpho Ducke, north of Manaus, where most species (61)

Table 2 – Riparian ground-herb *richness*, *abundance* and *Fisher's alpha* of the lower Tapajós region, *terra firme* forests, Brazilian Amazon.

Plot	Latitude	Longitude	Richness	Abundance	Fisher's alpha
P 1	-3.84832	-54.83891	12	74	4.059
P 2	-4.09234	-55.18439	31	649	6.780
P 3	-4.09691	-55.18029	31	948	6.144
P 4	-4.04414	-54.94772	25	642	5.178
P 5	-3.56383	-54.87569	15	259	3.172
P 6	-3.57190	-54.88198	11	76	3.532
P 7	-3.26089	-54.95631	19	374	4.228
P 8	-3.04794	-54.99303	10	108	2.690

were recorded within the riparian zone, of which 29 species did not occur elsewhere; and Moulatlet *et al*. (2014) reported 148 species in 88 plots (2 × 250 m, 4.4 ha) at BR-319 highway sites in a flat regional landscape. These results reiterate the importance of standardized inventories by area (such as RAPELD plots, Magnusson *et al*. 2005), particularly in conservation units, for the advance of scientific knowledge and for subsidizing biodiversity monitoring and conservation practices.

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