Oecologia Australis
23(1):39-55, 2019
https://doi.org/10.4257/oeco.2019.2301.04

CLIMATIC CONDITIONS DRIVE THE ABUNDANCE AND DIVERSITY OF SPIDERS COMMUNITY IN AN ATLANTIC FOREST FRAGMENT

Renan de Brito Pitilin[1]*, *Jamir Prado-Junior*[1], *Antonio Domingos Brescovit*[2] & *Maria Luisa Tunes Buschini*[3]

[1] Universidade Federal de Uberlândia, Programa de Pós-Graduação em Ecologia e Conservação de Recursos Naturais, Campus Umuarama, bloco 2D, CEP 38405-320, Uberlândia, MG, Brazil.

[2] Instituto Butantan, Laboratório Especial de Coleções Zoológicas, Av. Vital Brasil, nº 1500, CEP 05503-900, São Paulo, SP, Brazil.

[3] Universidade Estadual do Centro-Oeste, Programa de Pós-Graduação em Biologia Evolutiva, Rua Simeão Varela de Sá, nº 03, CEP 85040-080, Guarapuava, Paraná, PR, Brazil.

E-mails: pitilin_tj@hotmail.com (*corresponding author); jamirjunior@yahoo.com.br; adbresc@terra.com.br; isatunes@yahoo.com.br

---

Abstract: Spiders are very sensitive to variations in abiotic conditions. Here, we evaluated to what extent the variation in monthly rainfall and mean temperature can affect spiders community attributes. To this aim, we conducted an inventory of spiders species in a mixed ombrophilous forest fragment, using three different methods (beating tray, nocturnal manual collection and pitfall traps) over July 2010 and June 2011. The influence of monthly rainfall and mean temperature in spiders richness and abundance were evaluated using linear mixed models. We sampled 5,416 spiders belonging to 142 morphospecies and 28 families. These values were higher than those found in other studies conducted in temperate regions, and similar to those values found in tropical regions. Monthly mean temperature positively affected abundance and richness of adults, and negatively affected the abudance of immature spiders. Monthly rainfaill was negatively related to abundance of immature individuals. Species composition also differed between the hottest and coldest months. Our study helps us to understand the role of climatic conditions on spiders communities, and highlights that even small variations in these conditions can directly affect richness, abundance and species composition of spiders.

Keywords: Araucaria Forest; community structure; Parque Municipal das Araucárias; spiders inventory; temperature.

INTRODUCTION

Climatic conditions have strong effects on the structure, diversity and species composition of natural communities (Chapin *et al.* 2000). Evaluating how differences in environmental conditions influence these communities attributes can help us to predict the impact of climate changes on biodiversity (Pecl *et al.* 2017). A general pattern commonly found is that water availability (*e.g.*, high rainfall and lower seasonality) and temperature play an important role as environmental filters, and are positively related to species diversity and abundance (Duivenvoorden *et al.* 2002, Raymundo *et al.* 2018), and to ecosystem productivity and dynamics (Prado-Junior *et al.* 2017).

Although some studies have evaluated the relationships between climatic conditions and populations of spiders (Romero & Vasconcellos-Neto 2003, Messas *et al.* 2017, Villanueva-Bonilha *et al.* 2018), we still poorly understand how these relationships occur at the community level. The influence of monthly rainfall and mean temperature in spiders communities may have multiple simultaneous effects. For instance, they can influence habitat structure and the selection of habitats by spiders (Uetz 1991), affecting the availability of prey and the establishment of different arthropods populations (Wise 1993, Arango & Rico-Gray 2000). Moreover, climatic variables can directly influence population dynamics and the reproductive and foraging periods of spiders (Romero & Vasconcellos-Neto 2003, Villanueva-Bonilha & Vasconcellos-Neto 2016).

Inventory studies on spiders diversity and biogeography have fastly improved in the last decades (Nogueira *et al.* 2006, Podgaiski *et al.* 2007, Ricetti & Bonaldo 2008, Rodrigues 2011). However, few studies have been conducted in the Brazilian mixed ombrophilous forest (also known as the Araucaria Forest; Baldissera *et al.* 2004, Baldissera *et al.* 2008, Indicatti *et al.* 2008). The Brazilian mixed ombrophilous forest is considered one the most threatened phytophysiognomy in Brazil (Medeiros 2005), and we must improve our data of spiders abundance and diversity in this phytophysiognomy. Moreover, the mixed ombrophilous forest evaluated in this study experience a subtropical climate, with weak seasonality in rainfall but a marked variation in monthly mean temperature, supporting interesting experiments to evaluate to what extent temperature and rainfall variations can affect spiders communities attributes.

In this study, we conducted the first standardized inventory of spiders in a fragment of a Araucaria Forest in the center-south region of the state of Paraná. Our aims were 1) to evaluate the spiders species composition and the community attributes (abundance, species richness and diversity) in the Parque Municipal das Araucárias over one-year sampling; and 2) evaluate to what extent the variation in monthly rainfall and mean temperature can affect these community attributes. We hypothesized that the abundance and richness of spider species would be positively related to monthly rainfall and mean temperature.

MATERIAL AND METHODS

Study area and sampling design

This study was conducted at the Parque Municipal das Araucárias (25º23’36”S, 51º27’19”W; altitude 1120 m a.s.l), located in the municipality of Guarapuava, Paraná state, Brazil. This park has approximately 104 ha, covered by several vegetation types, including Araucaria Forest (42.75%), gallery forest (10.09%), swamp (7.13%), open grasslands (6.8%), and altered areas (33.23%) (Maack 2012). The region experiences a subtropical climate, with warm summers and no dry season (Cfb, *sensu* Köppen-Geiger climatic classification). Mean annual rainfall is 1770 mm, and rainfall is well distributed over the year (Alvares *et al.* 2014). Monthly mean temperature during the summer and winter are 19.1°C and 14.4 °C, respectively (Alvares *et al.* 2014).

Our sampling was carried out between July 2010 and June 2011 (all done by two collectors simultaneously), two expeditions in each month. To improve our sampling effort (as different spiders species occupy different habitats, such as arboreal, shrubby, and soil), we used three different sampling methods, as suggested by Coddington *et al.* (1991): beating tray (BT), nocturnal manual collection (NMC) and pitfall traps (PT). BT allows the access of tall herbs, small and medium-sized shrubs, small trees and large tree branches, and was used to sample mainly arboreal (Dias *et al.* 2006, Podgaiski *et al.* 2007). NMC was carried out using headlamps and was used to access animals active at night, including those that walk over soil or vegetation up to 2 m high (Brescovit *et al.* 2004, Dias *et al.* 2006). Both BT and NMC methods were conducted along three transects of 30 m (length) x 10 m (width), placed at least 200 m far from each other, and each transect represented a 50-minute period of search. Hence, our sampling effort for those methods resulted 72 sample units = 2 methods (BT and NMC) × 3 transects × 12 months. The third method (PT) was used to increase the number of spider records in the study area. It is an ideal method for wandering and tube spiders that move over the litter (Curtis 1980, Raub *et al.* 2014). There were four expeditions (July and October 2010, and January and May 2011), and 100 pitfall traps were used in each expedition. The traps were made with 500 ml plastic cups of 8 cm of opening diameter buried in the soil and kept in the field during five days. Ethanol at 70% was used as preserving solution. All these methods are described in detail by Coddington *et al.* (1991) and Brescovit *et al.* (2004).

Spiders were identified by Antonio Brescovit (third author of this manuscript) to species level when possible, and only adult specimens were considered. Immature individuals were identified to families level. The material yielded by this study was deposited in the collection of Arachnida of the Instituto Butantan (IBSP, curator: A. D. Brescovit).

Statistical analyses

To describe the attributes of spiders community at the Parque Municipal das Araucárias, we evaluated total abundance of spiders (immature and adult individuals, separately) and species diversity (adult spiders). We used three different diversity metrics: absolute species richness (S), Shannon diversity index (H'), and Chao1 estimator of richness. Absolute species richness is most often used, whereas H' also incorporates information on species abundance and equability. Chao1 estimator was performed using 100 permutations, and take into account the proportion of rare and abundant species, and are least-biased and an efficient method to estimate the total richness from a sampling area (Scharff *et al.* 2003).

To evaluate the relationships between climatic data (monthly rainfall and mean temperature) and spiders community attributes (abundance and species richness), we performed generalized linear mixed models (GLMM) including sampling method and transect as random effects (to account for the nestedness and the lack of independence among the sampling methods and transects among months). GLMM were fitted using a Poisson error distribution because they are better suited in dealing with count data and "zero observations" (O'Hara & Kotze 2010). The full model was therefore:

$$\text{Community attribute} = \beta_1\text{MMTemp} + \beta_2\text{MRain} + (1|\text{Transect}) + (1|\text{Method})$$

where Community attribute is the (1) abundance and (2) richness of adult spiders, or the (3) abundance of immature spiders; MMTemp is the monthly mean temperature; MRain = monthly rainfall; β are the standardized coefficients; and Transect and Method are the random effect terms of the linear mixed models.

We used all subsets multiple regression analysis and selected the models that had lowest corrected Akaike Information Criterion (AICc), considering the null model (only intercept). Models were considered to be equally supported if the difference in AICc was lower than two units. When models were equally supported, we selected the most parsimonious model (*i.e.*, with lowest number of predictors; Prado-Junior *et al.* 2016). The relative importance of each predictor (monthly mean rainfall and temperature) was compared based on their standardized regression coefficients (β) retained in the best multiple regression model. Monthly mean rainfall and temperature were obtained from the meteorological station SIMEPAR (Sistema Meteorológico do Paraná), located 3.9 km from our study area (Figure 1).

Differences in species composition among monthly mean temperature and rainfall were tested using a PERMANOVA (Anderson 2001) and based on an abundance species matrix comprising all adult individuals (999 permutations and Bray-Curtis as a distance measure). The null hypothesis is that there is no difference in species composition among different climatic conditions. To evaluate which species mostly contributed to differences in species composition between the hot (November 2010 to April 2011) and cold periods (July to October 2010, and May to June 2011; Figure 1), we performed a similarity percentages test (SIMPER, based on Bray-Curtis distances matrix and 999 permutations). This analysis compared the relative abundance of each species between the six hottest and six coldest months.

All statistical analyses were performed in R 3.1.2 (R Core Team 2017). Linear mixed models were performed using the "lme4" package (Bates *et al.* 2012) and all subsets regression analyses using the "MuMIn" package (Barton 2009). Chao1 estimator, PERMANOVA and SIMPER analyses were performed using the "vegan" package (Oksanen *et al.* 2014).

RESULTS

Abudance and diversity of spiders at the Parque Municipal das Araucárias

Over the whole year of sampling (July 2010 to July 2011) and using the three sampling methods, a total of 5,416 spiders were sampled, which 3,910

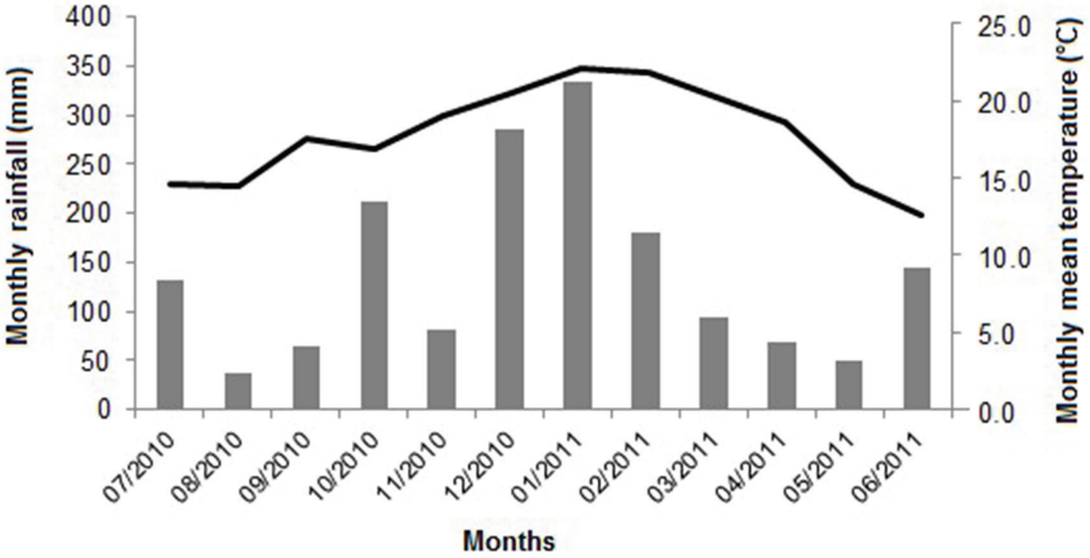

Figure 1. Monthly rainfall and mean temperature over the study sampling (July 2010 and June 2011) obtained from the meteorological station SIMEPAR (Sistema Meteorológico do Paraná). Bars indicate monthly rainfall and line indicate monthly mean temperature.

(72.2%) were immature individuals, and 1,506 (27.8%) were adult individuals (Table 1). Among the 28 families sampled, four presented only immature individuals: Amaurobiidae, Miturgidae, Oxyopidae and Selenopidae. Among the 24 families represented by adult individuals, 142 morphospecies were recognized (Table 1). The richest and most abundant families were Theridiidae (N = 31 morphospecies), Araneidae (N = 26) and Salticidae (N = 22), covering together 68.8% of sampled adult individuals. The five most abundant species were *Gelanor* sp. 1, *Maeota dichrura*, *Mangora strenua*, *Acacesia* aff. *hamata* and *Alpaida grayi*, covering 32.6% of sampled individuals. Shannon diversity index was 3.95, and the estimated species richness for the studied area was 183 ± 18 species based on Chao1.

Table 1. Species/morphospecies list for spiders sampled in the Parque Municipal das Araucárias, municipality of Guarapuava, state of Paraná, Brazil, with their respective abundance. Immature individuals were identified to families level.

Taxon	Adults	Immature
Amaurobiidae		6
Anyphaenidae		488
Anyphaenoides clavipes (Mello Leitão, 1922)	1	
Aysha ericae Brescovit 1992	33	
Aysha gr. *brevimana*	4	
Aysha guarapuava Brescovit 1992	4	
Aysha tertulia Brescovit 1992	1	
Tasata sp. 1	1	
Araneidae		1093
Acacesia aff. *hamata*	89	
Alpaida grayi (Blackwall, 1863)	83	
Alpaida sp. 1	2	
Alpaida sp. 2	2	

Table 1. Continued on next page…

Table 1. ...Continued

Taxon	Adults	Immature
Alpaida sp. 3	2	
Araneus sp. 1	11	
Araneus vincibilis (Keyserling, 1893)	24	
Cyclosa fililineata (Hingston, 1932)	1	
Cyclosa sp. 1	7	
Eustala sp. 1	14	
Eustala sp. 2	1	
Mangora strenua (Keyserling, 1893)	99	
Micrathena crassispina (C.L. Koch, 1836)	19	
Micrathena nigrichelis (Strand, 1908)	72	
Micrathena sp. 1	6	
Micrathena sp. 2	5	
Micrathena sp. 3	1	
Micrathena sp. 4	1	
Micrathena spitzi (Mello-Leitão, 1932)	8	
Ocrepeira covillei (Levi, 1993)	6	
Parawixia audax (Blackwall, 1863)	24	
Parawixia sp. 1	1	
Parawixia velutina (Taczanowski, 1878)	1	
Verrucosa sp. 1	25	
Wagneriana iguape (Levi, 1991)	5	
Wagneriana sp. 1	15	
Corinidae		21
Castianeira sp. 1	1	
Corinna sp. 1	1	
Trachelas sp. 1	10	
Ctenidae		79
Phoneutria nigriventer (Keyserling, 1891)	1	
Deinopidae		16
Deinops sp. 1	19	
Dictynidae		
Dictyna sp. 1	1	
Dipluridae		11
Diplura sp. 1	2	
Linyphiidae		30
Anodoration sp. 1	1	
Dubiaranea sp. 1	3	
Linyphiidae sp .1	5	

Table 1. Continued on next page…

Table 1. …Continued

Taxon	**Adults**	**Immature**
Linyphiidae sp. 2	2	
Linyphiidae sp. 3	2	
Linyphiidae sp. 4	1	
Meioneta sp. 1	2	
Meioneta sp. 2	16	
Mermessus sp. 1	3	
Moyosi sp. 1	3	
Neomaso sp. 1	1	
Smermisia sp. 1	14	
Smermisia vicosana (Bishop & Crosby, 1938)	2	
Sphecozone novaeteutoniae (Baert, 1987)	5	
Sphecozone sp. 1	16	
Sphecozone sp. 2	2	
Theridion sp. 1	3	
Lycosidae		46
Aglaoctenus lagotis (Holmberg, 1876)	2	
Hogna sp. 1	3	
Lycosa gr. s*ericovittata* (Mello-Leitão, 1939)	12	
Mimetidae		326
Gelanor sp. 1	110	
Miturgidae		6
Mysmenidae		14
Mymena sp. 1	7	
Nemesiidae		
Stenoterommata sp. 1	1	
Nephiliidae		
Nephila clavipes (Linnaeus, 1767)	1	
Nesticidae		
Nesticus sp. 1	5	
Oonopidae		
Orchestina sp. 1	1	
Oxyopidae		18
Salticidae		451
Dendryphantinae sp. 1	28	
Formiciforme sp. 1	1	
Lyssomanes sp. 1	3	
Lyssomanes sp. 2	9	
Maeota dichrura (Mello-Leitão, 1917)	110	

Table 1. Continued on next page…

Table 1. ...Continued

Taxon	**Adults**	**Immature**
Salticidae sp. 1	25	
Salticidae sp. 2	9	
Salticidae sp. 3	3	
Salticidae sp. 4	1	
Salticidae sp. 5	1	
Salticidae sp. 6	1	
Salticidae sp. 7	1	
Salticidae sp. 8	2	
Salticidae sp. 9	3	
Salticidae sp. 10	2	
Salticidae sp. 11	2	
Salticidae sp. 12	1	
Salticidae sp. 13	1	
Salticidae sp. 14	1	
Salticidae sp. 15	2	
Thiodina sp. 1	13	
Thiodina sp. 2	1	
Scytodidae		51
Scytodes chapeco Rheims and Brescovit 2009	19	
Scytodes globula (Nicolet, 1849)	3	
Scytodes sp. 1	1	
Selenopidae		1
Senoculidae		30
Senoculus sp. 1	17	
Tetragnathidae		157
Chrysometa sp. 1	9	
Chrysometa sp. 2	3	
Leucauge sp. 1	6	
Leucauge sp. 2	9	
Leucauge sp. 3	2	
Tetragnatha sp. 1	2	
Theridiidae		545
Cryptachaea hirta (Taczanowski, 1873)	1	
Cryptachaea sp. 1	46	
Cryptachaea sp. 2	7	
Anelosimus sp. 1	2	
Argyrodes sp. 1	2	

Table 1. Continued on next page…

Table 1. ...Continued

Taxon	Adults	Immature
Argyrodes elevatus Taczanowski 1873	3	
Chrosiothes sp. 1	5	
Phycosoma altum (Keyserling, 1886)	1	
Dipoena sp. 1	8	
Dipoena sp. 2	1	
Dipoena sp. 3	3	
Dipoena sp. 4	3	
Dipoena woytkowskii Levi 1963	1	
Euryopis sp. 1	17	
Faiditus sp. 1	16	
Faiditus sp. 2	6	
Hetschkia gracilis Keyserling 1886	1	
Phoroncidia sp. 1	3	
Platnickina mneon (Bösenberg & Strand, 1906)	4	
Theridiidae sp. 1	1	
Theridiidae sp. 2	3	
Theridiidae sp. 3	1	
Theridiidae sp. 4	3	
Theridiidae sp. 5	4	
Theridiidae sp. 6	1	
Theridion calcynatum Holmberg 1876	39	
Theridion sp. 1	38	
Theridion sp. 2	4	
Thwaitesia affinis O. P.-Cambridge 1882	28	
Thymoites sp. 1	25	
Tidarren sisyphoides (Walckenaer, 1841)	12	
Theridiosomatidae		5
Naatlo sp. 1	1	
Thomisidae		400
Deltoclita sp. 1	10	
Epicadinus sp. 1	4	
Thomisidae sp. 1	7	
Misumena sp. 1	2	
Misumenops sp. 1	1	
Sidymella sp. 1	1	
Tmarus sp. 1	1	
Tmarus sp. 2	13	
Tmarus sp. 3	1	

Table 1. Continued on next page…

Table 1. ...Continued

Taxon	Adults	Immature
Tmarus sp. 4	8	
Uloboridae		108
Miagrammopes sp. 1	3	
Uloborus sp. 1	39	
Zosis sp. 1	8	
Zodariidae		8
Tenedos sp. 1	1	

Relationships between the climatic data and the richness and abundance of spiders

Multiple regression analysis indicated that abundance and richness of spiders were mostly affected by monthly mean temperature, and to a less extent to monthly rainfall (Figure 2, Appendix S1). Monthly mean temperature was positively related to adults abundance (β = 0.434) and richness (β = 0.302), and negatively to the abundance of immature individuals (β = -0.159). Monthly rainfall was negatively related to abundance of immature individuals (β = -0.0.50) (Figure 2, Appendix S1).

PERMANOVA detected significant species compositional differences among monthly mean temperatures (pseudo-$F_{1,11}$ = 2.18, $p < 0.05$), but not among monthly rainfall (pseudo-$F_{1,11}$ = 1.04, $p = 0.38$). The SIMPER analysis identified the species exhibiting an increased contribution to dissimilarity between the six months with lower mean temperature and six months with higher mean temperature (Table 2). The relative abundance of four species (*Acacesia* aff. *hamata*, *Cryptachaea* sp. 1, *Theridion calcynatum* and *Verrucosa* sp. 1) was significantly higher in the six hottest months, and none species had relative abundance significantly higher in the six coldest months.

DISCUSSION

We aimed to evaluate the abundance and diversity of spiders at the Parque Municipal das Araucárias (Paraná state), and assessed the relationships between the climatic data (monthly rainfall and mean temperature) and those metrics of spiders community. Our results indicated high values of richness and diversity of spiders, highlighting the importance of the Parque Municipal das Araucárias as a refugia for the regional pool of spiders species. Monthly mean temperature and rainfall were significantly related to abundance and richness of spiders, corroborating our hypothesis that climate conditions play and important role on the structure and richness of spiders communities.

Abudance and diversity of spiders at the Parque Municipal das Araucárias

Although the study area experience a subtropical climate, the richness and diversity of spiders were similar to some studies conducted in tropical regions (Bonaldo & Dias 2010, Cabra-Garcia *et al.* 2010) and higher than other studies conducted in Brazilian subtropical regions (Baldissera *et al.* 2004, Lopes *et al.* 2008, Baldissera & Silva 2010). According to Baldissera *et al.* (2008), variations in the structural complexity of each environment can influence the diversity of the araneofauna. The high diversity of spiders found in this study may be related to the use of different sampling methods (beating tray, nocturnal manual collection and pitfall traps), and the one-year round of sampling. This methodology allowed us to sample a wide diversity of spiders (composed by different guilds), and highlights the importance of applying seasonal samples and with different methods to reach accurate estimations of spiders community attributes. Moreover, as local biodiversity is usually higher inside than outside terrestrial protected areas (Gray *et al.* 2016), our results may indicate the importance of the Parque Municipal das Araucárias as a refugia for the regional pool of spiders species.

The most representative families (considering abundance and species richness) were Theridiidae, Araneidae and Salticidae. This pattern is usually found in most of the inventories carried out in Neotropical forests (Brescovit *et al.* 2011). Baldissera *et al.* (2004) and Podgaiski *et al.* (2007), for example, observed that more than 50% of the species sampled were represented by these three families in an Araucaria Forest and a deciduous forest, respectively. The widespread distribution of these families is related to their high species diversity and their ability to colonize different types of habitats both dense forests and more open environments (forests gaps and savannas) (Brescovit *et al.* 2009).

In our survey, the five most abundant species were *Gelanor* sp. 1, *M. dichrura, M. strenua, A.* aff. *hamata* and *A. grayi.* The high abundance of *Mangora strenua, Acacesia* aff. *hamata* and *Alpaida grayi* (all Araneidae) was also observed in other studies in the Brazilian southern region (Baldissera *et al.* 2004, Raub *et al.* 2014, Rodrigues *et al.* 2016), indicating that they are common species with high representativeness in this region. These species have predominantly nocturnal foraging and construct orbicular webs associated with the vegetation (Brescovit *et al.* 2009). The high abundance of *Gelanor* sp. 1 (Mimetidae) and *Maeota dichrura* (Salticidae) is a new result for the region. Both species are cursorial hunters and hunt down their preys without making use of the a spider web (Brescovit *et al.* 2009). Although species composition usually changes over different environments, future studies evaluating the abundance, diversity and species composition over a large scale are promising and necessary to improve our understanding in spiders species biogeography.

Table 2. SIMPER (Similarity Percentages) analysis for the twenty most abundant spiders species sampled in the Parque Municipal das Araucárias, and their relative contribution to the dissimilarity in species composition between the six hottest and coldest months. Contribution = Species percentage contribution to dissimilarity; Cumulative = Cumulative dissimilarity contribution; Period = Average species abundance in hot (November 2010 to April 2011) and cold periods (July to October 2010, and May to June 2011; p-value = Permutation p-value (bold numbers indicate significant differences in relative abundance considering an alpha of 0.05).

Species	Contribution	Cumulative	Period		p-value
			Cold	Hot	
Gelanor sp.1	0.060	6.535	1.244	1.180	0.83
Maeota dichrura	0.058	12.869	0.854	1.500	0.48
Mangora strenua	0.048	18.099	0.244	1.780	0.22
Acacesia aff. *hamata*	0.044	22.892	0.195	1.620	**0.01**
Micrathena nigrichelis	0.044	27.674	0.634	0.920	0.88
Alpaida grayi	0.043	32.300	0.415	1.320	0.10
Theridion sp. 1	0.028	35.377	0.293	0.580	0.32
Cryptachaea sp. 1	0.026	38.188	0.000	0.920	**0.01**
Theridion calcynatum	0.023	40.707	0.098	0.700	**0.04**
Uloborus sp.	0.022	43.086	0.293	0.540	0.69
Dendryphantinae sp. 1	0.021	45.339	0.195	0.400	0.38
Euryopis sp.1	0.020	47.555	0.171	0.180	0.28
Aysha ericae	0.018	49.522	0.024	0.640	0.08
Salticidae sp. 1	0.016	51.280	0.073	0.440	0.09
Thwaitesia affinis	0.016	53.006	0.171	0.420	0.58
Lycosa sericovittata	0.015	54.644	0.049	0.200	0.08
Thymoites sp. 1	0.014	56.198	0.171	0.160	0.60
Scytodes chapeco	0.014	57.687	0.122	0.280	0.50
Verrucosa sp. 1	0.013	59.107	0.024	0.480	**0.02**
Parawixia audax	0.013	60.514	0.244	0.280	0.81

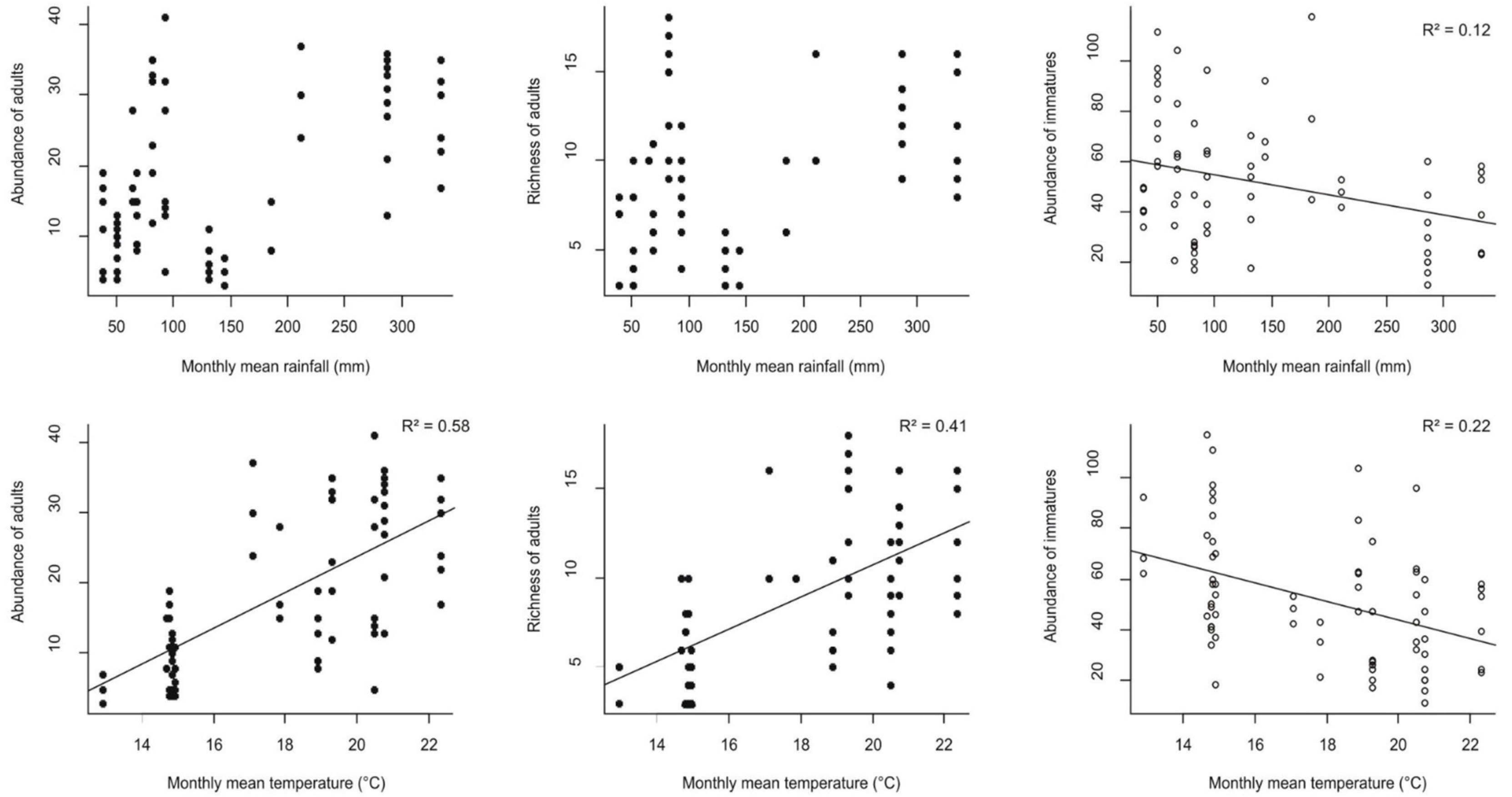

Figure 2. Relationships between monthly rainfall and mean temperature and the spiders community attributes (abundance and richness) for adults (closed circles) and immature individuals (open circles). Richness of immature individuals was not included as they were identified into family level.

Relationships between the climatic data and the richness and abundance of spiders

We hypothesized that the abundance and richness of spider species would be positively related to monthly rainfall and mean temperature, as spiders are very sensitive to abiotic conditions, mainly climatic (Wise 1993). We indeed found higher abundance and richness of adult spiders with increasing monthly mean temperature, while we found no relationships with monthly rainfall. Similar results were found in other studies conducted in southern Brazil, indicating higher abundance and richness of adult individuals in the warmer compared to the colder period (Baldissera *et al.* 2004, Podgaiski *et al.* 2007, Rodrigues 2011). According to Dias *et al.* (2006) the influence of temperature and rainfall variation in spiders communities change according to the vegetation type and geographical region. For instance, in areas with markedly rainfall seasonality, higher abundance and species richness were found during the rainy season (Azevedo *et al.* 2014). Seasonal patterns for spider assemblages may vary even in different regions of the same state but that are composed of different environments (Rodrigues *et al.* 2016), indicating that each biome has species specifically adapted to survive under the climatic and environmental constraints of the habitat in which they occur. Our results highlight that monthly mean temperature, independent of rainfall, play an important role in the abundance and diversity of spiders community structure and diversity (even when seasonality in rainfall is weak or absent). The annual variation in spider's abundance and richness is probably related to their reproductive period, when most groups of spiders, especially those with short life cycle and low survival rates, concentrate their reproductive events in hotter periods, when the food availability is higher (Lubin 1978, Azevedo *et al.* 2014).

When considering the abundance of immature spiders, however, an opposite trend was found compared to the adult spiders, *i.e.*, we found more immature spiders in months with lower mean temperature and rainfall. Similar results were found by Arango & Rico-Gray (2000) and Rodrigues (2011), where the pattern of abudance diverges from adults being more abundant in autumn and less abundant in spring. According to Villanueva-Bonilla *et al.* (2018) the peak of adult abundance (reproductive period) of some species occurs in the spring, followed by the deposition of the egg-sacs, with juvenile occurrence in late summer and autumn and subadult in winter. However, for spiders *Misumenops argenteus* the peak of young was found in warm months (February and March) with decline in winter (July). The seasonality of young spiders varies according to the phenology of each species and closely follows the changes in the physical environment of each site (Uetz 1991, Rodrigues 2011).

As monthly mean temperature was the strongest predictor of adults' abundance and richness, we assessed the differences in species composition between the warmer and colder periods. We found that species composition was different between hotter and dryer periods, and the relative abundance of six species (*A.* aff. *hamata*, *Cryptachaea* sp. 1, *T. calcynatum*, *A. ericae*, *Verrucosa* sp. 1 and Salticidae sp. 1) was significantly higher in the hotter period. Our findings could be possibly related to a well-defined reproductive period for these species, in which sexually active males are only available for a few months (Merrett 1967) or when the availability of prey should be greater (Romero & Vasconcellos-Neto 2003). On the other hand, for other abundant species such as *Gelanor* sp. 1, *M. dichrura, M. strenua* and *A. grayi*, the relative abundance was not different over the year. Our results indicate distinct thermal preferences among spider species (Almquist 1970, Frick *et al.* 2007). According to Chatzaki *et al.* (2005), the seasonality in spiders activities is mainly influenced by photoperiod and temperature, and the relationships between those climatic conditions and the physiological tolerances are strongly different among the species.

Although most spider species are frequently recorded during the entire year (*e.g.*, Rodrigues 2005, Podgaiski *et al.* 2007, Rodrigues 2011), some species are more active during hot periods, when they hunt more actively, feed and reproduce, being able to explore different microhabitat in each season trying to escape adverse conditions (Arango & Rico-Gray 2000, Avalos *et al.* 2007, Azevedo *et al.* 2014). As our study area usually experience frosts during the cold period (according to the Sistema Meteorológico do Paraná, SIMEPAR), the higher abundance of some species during periods of high temperature could be a strategy to compensate the harsh conditions over the cold period. Seasonal changes in community structure (*e.g.*, fluctuation in species composition throughout the year) can affect the whole food chain of an environmental.

Recent studies show that natural communities are shifting in species composition due to climatic changes (Raymundo *et al.* 2018). Our study indicates that the abundance and richness of spiders' communities is related to variations in mean temperature. Spiders play a significant ecological role in ecosystems as they are part of the diet of many birds and lizards species (Spiller & Schoener 1998, Gunnarsson 2007), and are important predators of arthropods, controlling the population of herbivorous insects (Polis & Strong 1996). Understanding how differences in temperature conditions influence spiders communities (and consequently the related food chain) can help us to predict the impact of climate changes on biodiversity. Future studies at large scales on biogeography and dynamics of spiders communities and their relationships with climatic variation are needed, and could provide more insights into these communities responses and resilience to global change.

ACKNOWLEDGEMENTS

We are thankful for the financial support provided by CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) and the logistical support provided by Programa de Pós-Graduação em Biologia Evolutiva UEPG/UNICENTRO (Guarapuava – PR, Brazil), Programa de Pós-Graduação em Ecologia e Conservação de Recursos Naturais, Universidade Federal de Uberlândia (UFU) and CNPq (grant to ADB, PQ 301776/2004-0). We also thank to two anonymous reviwers for their helpful comments in our manuscript, and to João Lucas, Talissa Calikevstz, Cristiano Pereira, Huilquer Volguel e Cris Hiert, for their help in the field sampling.

REFERENCES

Almquist, S. 1970. Thermal tolerances and preferences of some dune-living spiders. Oikos, 21(2), 230–235. DOI: 10.2307/3543678

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Gonçalves, J. L. D. M., & Sparovek, G. 2014. Köppen's climate classification map for Brazil. 22(6), 711–28. DOI: 10.1127/0941-2948/2013/0507

Anderson, M. J. 2001. A new method for non-parametric multivariate analysis of variance. Austral Ecology, 26(1), 32–46. DOI: 10.1111/j.1442-9993.2001.01070.pp.x

Arango, A. M., & Rico-Gray, V. 2000. Population structure, seasonality, and habitat use by the green lynx spider *Peucetia viridians* (Oxyopidae) inhabiting *Cnidoscolus aconitifolius* (Euphorbiaceae). Journal of Arachnology, 28, 185–194. DOI: 636/0161-8202(2000)028[0185:PSSAHU]2.0.CO

Avalos, G., Rubio, G. D., Bar, M. E., & González, A. 2007. Arañas (Arachnida: Araneae) associadas a dos bosques degradados Del Chaco húmedo em Corrientes, Argentina. Revista de Biología Tropical, 55(3–4), 899–909. DOI: 10.1111/icad.12061

Azevedo, G. H. F., Faleiro, B. T., Magalhães, I. L. F., Benedetti, A. R., Oliveira, U., Pena Barbosa J. P. P., Santos, M. T. T., Vilela, P. F., De Maria, M., & Santos, A. J. 2014. Effectiveness of sampling methods and further sampling for accessing spider diversity: a case study in a Brazilian Atlantic rainforest fragment. Insect Conservation and Diversity, 7, 381–391. DOI: 10.1111/icad.12061

Baldissera, R., & Silva, V. R. 2010. Diversidade e composição de aranhas arbustivas em um fragmento de Mata Atlântica e duas áreas adjacentes. Neotropical Biology and Conservation, 5(2), 77–85. DOI: 10.4013/nbc.2010.52.02

Baldissera, R., Bach, R., Lima, R. P., Menegassi, A., Piovesan, A. R., & Fonseca, G. C. 2008. Distributionn of understorey web building spiders along an interface area of Araucaria forest and *Pinus* plantation in southern Brazil. Neotropical Biology and Conservation, 3, 3–8. DOI: 10.1636/P15-24

Baldissera, R., Ganade, G., & Fontoura, S. B. 2004. Web spider community response along an edge between pasture and Araucaria forest. Biological Conservation, 118, 403–409. DOI: 10.1016/j.biocon.2003.09.017

Barton, K. 2009. MuMIn: multi-model inference, R package version 0.12. 0. http://r-forge. r-project.org/projects/mumin/.

Bates, D., Maechler, M. & Bolker, B. 2012. lme4: Linear mixed-effects models using S4 classes. R package version 0.999375-42; 2011. Reference Source.

Bonaldo, A. B., & Dias, S. C. 2010. A structured inventory of spiders (Arachnida: Araneae) in natural and artificial forest gaps at Porto Urucu, Western Brazilian Amazonia. Acta Amazonica, 40, 357–372. DOI: 10.1590/S0044-59672010000200014

Brescovit, A. D, Rheims, C. A., & Indicatti, R. P. 2009. Aranhas (Arachnida) de Paranapiacaba. In: M. I. M. S. Lopes, M. Kirizawa & M. M. R. F. Melo (Eds.), Patrimônio da Reserva Biológica do Alto da Serra de Paranapiacaba. A antiga Estação Biológica do Alto da Serra. pp. 503–527. São Paulo: Instituto de Botânica.

Brescovit, A. D., Bertani, R., Pinto-da-Rocha, R., & Rheims, C. A. 2004. Aracnídeos da Estação Ecológica Juréia-Itatins: inventário preliminar e história natural. In: Marques O. A. V. & Duleba, W. (Eds.), Estação Ecológica Juréia-Itatins: ambiente físico, flora e fauna. pp. 198–221. Holos: Ribeirão Preto Press.

Brescovit, A. D., Oliveira, U., & Santos, A. J. 2011. Aranhas (Araneae, Arachnida) do Estado de São Paulo, Brasil: diversidade, esforço amostral e estado do conhecimento. Biota Neotropica, 11(1), 1–31. DOI: 10.1590/S1676-06032011000500035

Cabra-Garcia, J., Chacón, P., & Valderrama-Ardila, C. 2010. Additive partitioning of spider diversity in a fragmented tropical dry forest (Valle del Cauca, Colombia). Journal of Arachnology, 38, 192–205. DOI: 10.1636/P09-68.1

Chapin, F. S., Zavaleta, Erika S., Eviner, V. T., Naylor, R. L., Vitousek, P. M., Reynolds, H. L., Hooper, D. U., Lavorel, S., Sala, O. E., H., Sarah E., Mack, Michelle C., & Díaz, S. 2000. Consequences of changing biodiversity. Nature, 405, 234–242. DOI: 10.1038/35012241.

Chatzaki, M., Markakis, G., & Mylonas, M. 2005. Phenological patterns of ground spiders (Araneae, Gnaphosidae) on Crete, Greece. Ecologia mediterranea, 31(1), 33–53. Retrived from http://ecologia-mediterranea.univ-avignon.fr/wp-content/uploads/sites/25/2017/07/Ecologia_mediterranea_2005–31_1__02.pdf#page=33

Coddington, J. A., Griswold, C. E., Dávila, D. S., Peñaranda, E., & Larcher, S. F. 1991. Designing and testing sampling protocols to estimate biodiversity in tropical ecosystems. In: E. C. Dudley (Eds.), The Unity of Evolutionary Biology: Proceedings of the Fourth International Congress of Systematic and Evolutionary Biology. pp. 44–60. Dioscorides: Portland University Press. DOI: 10.1007%2F978-94-015-7358-0

Curtis, D. J. 1980. Pitfalls in spider community studies (Arachnida, Araneae). Journal of Arachnology, 8, 271–280. DOI: 10.1.1.538.6359&rep=rep1&type=pdf

Dias, S. C., Brescovit, A. D., Couto, E. C. G., & Martins, C. F. 2006. Species richness and seasonality of spiders (Arachnida, Araneae) in an urban Atlantic Forest fragment in Northeastern Brazil. Urban Ecosystems, 9, 323–335. DOI: 10.1007/s11252-006-0002-7

Duivenvoorden, J. F., Svenning, J. C., & Wright, S. J. 2002. Beta diversity in tropical forests. Science, 295, 636–637. DOI: 10.1126/science.295.5555.636

Frick, H., Kropf, C., & Nentwig, W. 2007. Laboratory temperature preferences of the wolf spider *Pardosa riparia* (Araneae: Lycosidae). Arachnology, 14(1), 45–48. DOI: 10.13156/arac.2007.14.1.45

Gray, C. L., Hill, S. L. L., Newbold, T., Hudson, L. N., Börger, L., Contu, S., Hoskins, A. J., Ferrier, S., Purvis, A., & Scharlemann, J. P. W. 2016. Local biodiversity is higher inside than outside terrestrial protected areas worldwide. Nature Communications, 7, 12306. DOI: 10.5519/0095544

Gunnarsson, B. 2007. Bird predation on spiders: Ecological mechanisms and evolutionary consequences. Journal of Arachnology, 35, 509–529. DOI: 10.1636/RT07-64.1

Indicatti, R. P., Lucas, S. M., Ott, R., & Brescovit, A. D. 2008. Litter dwelling mygalomorph spiders (Araneae: Microstigmatidae, Nemesiidae) from Araucaria forests in southern Brazil, with the description of five new species. Revista Brasileira de Zoologia, 25, 529–546. DOI: 10.1590/S0101-81752008000300021

Lopes, J., Santos, F. P., Marcal, V. V. M., Nunes, M. P. B. P., & Catelli, L. L. 2008. Araneofauna capturada na mata e área aberta adjacente, no norte do Paraná, Brasil. Semina: Ciências Biológicas e da Saúde, 29, 41–46. DOI: 10.5433/1679-0367.2008v29n1p41

Lubin, Y. D. 1978. Seasonal abundance and diversity of web-building spiders in relation to habitat structure on Barro Colorado Island, Panama. Journal of Arachnology, 6, 31–51. DOI: jstor.org/stable/3705347

Maack, R. 2012. Geografia física do Estado do Paraná.

J. Olympio (Ed.). 4th ed. Ponta Grossa: Editora UEPG: p.526.

Medeiros, J. D. D. 2005. Seleção de áreas para criação de Unidades de Conservação na Floresta Ombrófila Mista. Biotemas, 18(2), 33–50. DOI: dx.doi.org/10.5007/%25x

Merrett P. 1967. The phenology of spiders on heath land in Dorset. Journal of Animal Ecology, 36(2), 363–374. DOI: 10.1111/j.1469-7998.1969.tb01704.x

Messas, Y. F., Souza, H. S., Gonzaga, M. O., & Vasconcellos-Neto, J. 2017. Population dynamics of the bark-dwelling spider *Eustala perfida* Mello-Leitão, 1947 (Araneidae) Journal of Natural History, Retrieved from https://doi.org/10.1080/00222933.2017.1388859

Nogueira, A. A., Pinto-da-Rocha, R. & Brescovit, A. D. 2006. Comunidade de aranhas orbitelas (Araneae, Arachnida) na região da Reserva Florestal do Morro Grande, Cotia, São Paulo. Revista de Biologia Neotropical, 6(2), 1–24. DOI: 10.1590/S1676-06032006000200010

O'Hara, R. B., & Kotze, D. J. 2010. Do not log-transform count data. Methods in Ecology and Evolution, 1, 118–122. DOI:10.1111/j.2041-210X.2010.00021.x

Oksanen, J., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, R., O'Hara, R. B., Simpson, G. L., Solymos, P., Stevens, M. H. H., & Wagner, H. 2014. Package vegan: Community ecology package. R package version 2.2-0. Available at: https://cran.r-project.org/web/packages/vegan/ (accessed in 06 July 2018).

Pecl, G. T., Araújo, M. B., Bell, J. D., Blanchard, J., Bonebrake, T. C., Chen, I.-C., Clark, T. D., Colwell, R. K., Danielsen, F., Evengård, B., Falconi, L., Ferrier, S., Frusher, S., Garcia, R. A., Griffis, R. B., Hobday, A. J., Janion-Scheepers, C., Jarzyna, M. A., Jennings, S., Lenoir, J., Linnetved, H. I., Martin, V. Y., McCormack, P. C., McDonald, J., Mitchell, N. J., Mustonen, T., Pandolfi, J. M., Pettorelli, N., Popova, E., Robinson, S. A., Scheffers, B. R., Shaw, J. D., Sorte, C. J. B., Strugnell, J. M., Sunday, J. M., Tuanmu, M.-N., Vergés, A., Villanueva, C., Wernberg, T., Wapstra, E., & Williams, S. E. 2017. Biodiversity redistribution under climate change: impacts on ecosystems and human well-being. Science, 355(6332), eaai9214. DOI: 0.1126/science.aai9214

Podgaiski, L. R., Ott, R., Rodrigues, E. N. L., Buckup, E. H., & Marques, M. A. L. 2007. Araneofauna (Arachnida; Araneae) do Parque Estadual do Turvo, Rio Grande do Sul, Brasil. Revista de Biologia Neotropical, 7(2), 197–212. DOI: 10.1590/S1676-06032007000200023

Polis, G. A., & Strong, D. R. 1996. Food web complexity and community dynamics. The American Naturalist, 147(5), 813–846. DOI: 10.1086/285880

Prado-Junior, J. A., Schiavini, I., Vale, V. S., Arantes, C. S., van der Sande, M. T., Lohbeck, M., & Poorter, L. 2016. Conservative species drive biomass productivity in tropical dry forests. Journal of Ecology, 104(3), 817–827. DOI: 10.1111/1365-2745.12543

Prado-Junior, J., Schiavini, I., Vale, V. S., Raymundo, D., Lopes, S. F., & Poorter, L. 2017. Functional traits shape size-dependent growth and mortality rates of dry forest tree species, Journal of Plant Ecology, 10(6), 895–906. DOI: 10.1093/jpe/rtw103

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: https://www.R-project.org/

Raub, F., Höfer, H., Scheuermann, L., & Brandl, R. 2014. The conservation value of secondary forests in the southern Brazilian Mata Atlântica from a spider perspective. Journal of Arachnology, 42, 52–73. DOI: 10.1636/P13-47.1

Raymundo, D., Prado-Junior, J., Carvalho, F. A., Vale, V. S., Oliveira, P. E. & van der Sande, M. T. 2018. Shifting species and functional diversity due to abrupt changes in water availability in tropical dry forests. Journal of Ecology, 00, 1–12. DOI: 10.1111/1365-2745.13031

Ricetti, J., & Bonaldo, A. B. 2008. Diversidade e estimativas de riqueza de aranhas em quatro fitofisionomias na Serra do Cachimbo, Pará, Brasil. Iheringia, Série Zoologia, 98(1), 88–99. DOI: 10.1590/S0073-47212008000100013

Rodrigues, E. N. L. 2005. Fauna araneológica (Arachnida: Araneae) arborícola de duas áreas em uma mata de restinga no sul do Brasil. Acta Biologia Leopoldensia, 27(1), 73–92.

Rodrigues, E. N. L. 2011. Composição e estrutura da fauna araneológica (Arachnida; Araneae) associado ao estrato arbóreo arbustivo de matas ciliares e seus microambientes no Rio Grande do Sul, Brasil. Instituto de Biociências da Universidade Federal do Rio Grande do Sul. p. 246.

Rodrigues, E. N. L., Rodrigues, P. E. S., & Mendonça

Jr, M. S. 2016. Spider species composition in the tree-shrub strata of riparian forests and its microhabitats in southern Brazil. Zoologia, 33(3), e20150102. DOI: 10.1590/S1984-4689zool-20150102

Romero, G. Q., & Vasconcellos-Neto, J. 2003. Natural history of *Misumenops argenteus* (Thomisidae): seasonality and diet on *Trichogoniopsis adenantha* (Asteraceae). Journal of Arachnology, 31, 297–304. DOI: 10.1636/02-19

Scharff, N., Coddington, J. A., Griswold, C. E., Hormiga, G., & Bjorn, P. P. 2003. When to quit? Estimating spider species richness in a northern European deciduos forest. Journal of Arachnology, 31, 246–273.

Spiller, D., & Schoener, T. 1988. An ex-perimental study of lizards on web-spiders communities. Ecological Monographs, 58(2), 57–77. DOI: 10.2307/1942461

Uetz, G. W. 1991. Habitat structure and spider foraging. In: Bell, S. S., McCoy, E. D. & Mushinsky, H. R. (Eds.), Habitat structure: the physical arrangement of objects in space. pp. 325–348. London: Chapman and Hall Press. DOI: 10.1007/978-94-011-3076–9

Villanueva-Bonilla, G. A., & Vasconcellos-Neto, J. 2016. Population dynamics and phenology of the wall crab spider *Selenops cocheleti* Simon, 1880 (Araneae: Selenopidae) in Southeastern Brazil. Studies on Neotropical Fauna and Environment, 51(3), 215–230. DOI: 10.1080/01650521.2016.1234848

Villanueva-Bonilla, G. A., Safuan-Naide, S., & Vasconcellos-Neto, J. 2018. Population dynamics and phenology of two congeneric and sympatric lynx spiders *Peucetia rubrolineata* Keyserling, 1877 and *Peucetia flava* Keyserling, 1877 (Oxyopidae). Journal of Natural History, 52(5–6), 361–376. DOI: 10.1080/00222933.2018.1433339

Wise, D. H. 1993. Spiders in Ecological Webs. New York: Cambridge University Press. DOI: 10.1017/CBO9780511623431.001

Submitted: 17 January 2018
Accepted: 07 September 2018
Published online: 07 September 2018
Associate Editor: Ana C. Delciellos

Appendix S1. Subset of all generalized linear mixed models based on the relationshiops between community attributes (abundance and richness of adult spiders, and abundance of immature spiders) and monthly mean temperature and monthly rainfall. Sampling method and transect as random effects, and models were fitted using a Poisson error distribution. When models were equally supported (AIC ≤ 2), we selected the most parsimonious model (with lowest number of predictors). β = standardized coefficient; AICc = corrected Akaike Information Criterion, df = degrees of freedon, ΔAICc = diference between the AICc of a given model and that of the best model, Wt = Akaike weights.

Attributes	**GLMM**							
	Intercept	β Rainfall	β Mean Temperature	AICc	R^2	df	ΔAICc	Wt
Adults abundance	2.797	-	0.434	523.1	0.58	4	0.00	0.706
	2.796	-0.026	0.453	524.8	0.58	5	1.75	0.294
	2.855	0.233	-	657.6	0.22	4	134.58	0.000
	2.888	-	-	724.9	-	3	201.81	0.000
Adults richness	2.129	-	0.302	358.0	0.41	4	0.00	0.760
	2.129	0.008	0.297	360.3	0.41	5	2.30	0.240
	2.157	0.177		389.8	0.15	4	31.79	0.000
	2.174	-	-	407.6		3	49.58	0.000
Immature abundance	3.893	-0.050	-0.159	982.4	0.22	5	0.00	0.794
	3.894	-	-0.182	985.1	0.22	4	2.70	0.206
	3.902	-0.136	-	1040.5	0.12	4	58.13	0.000
	3.907	-	-	1092.4	-	3	110.05	0.000